TROPICAL RESOURCES

The Bulletin of the Yale Tropical Resources Institute

Contents

About TRI

Mission

The Mission of the Tropical Resources Institute is to support interdisciplinary, problem oriented, and applied research on the most complex challenges confronting the management of tropical resources worldwide. Lasting solutions will be achieved through the integration of social and economic needs with ecological realities, the strengthening of local institutions in collaborative relationships with international networks, the transfer of knowledge and skills among local, national, and international actors, and the training and education of a cadre of future environmental leaders.

The problems surrounding the management of tropical resources are rapidly increasing in complexity, while demands on those resources are expanding exponentially. Emerging structures of global environmental governance and local conflicts over land use require new strategies and leaders who are able to function across a diversity of disciplines and sectors and at multiple scales. The Tropical Resources Institute seeks to train students to be leaders in this new era, leveraging resources, knowledge, and expertise among governments, scientists, NGOs, and communities to provide the information and tools this new generation will require to equitably address the challenges ahead.

News

New TRI website!

We are excited to announce the new TRI website and web address (tri.yale.edu). We will gradually populate this new site with previous fellows and other background information.

Publications

We are building a database of all publications resulting from TRI support. If you are a previous TRI Fellow, and published *anything* resulting from your fellowship research (journal article, book, popular press article, webpage, report, …), please let us know at tri@yale.edu.

The Bulletin

Please access the 2016 Bulletin at http://tri.yale.edu/tropical-resources-bulletin in order to view maps, graphs, photographs, and figures in color.
All figures used in these articles are the authors' own unless otherwise indicated.

A Word from the Director

In this volume (Vol. 35) of *Tropical Resources*, we continue our period of reflection with a review of the previous publications in the Bulletin. Devon Parish (TRI Program Coordinator) finds that patterns of publication have shifted over the last three decades. Studies of humans in rural and mixed ecosystems have increased and studies of plants in forested ecosystems have decreased, reflecting similar changes in the make-up of F&ES. The balance of studies from tropical continents has become more equitable, with more studies from Africa.

Following this reflection, we present the research of five TRI Fellows who conducted fieldwork in 2015. As usual, fieldwork was conducted in a wide range of environments in all tropical continents, ranging from tree surveys in Sri Lanka to understanding the effects of soybean agriculture in Brazil.

First, Rafael Roca (MESc/MBA 2016) discusses the effects of small-scale artisanal gold-mining on the species diversity of forests in Rwanda's Nyungwe National Park. The impacts of local mining on the health of people and forests is becoming a topic of increasing concern, and several TRI Fellows have investigated this issue in the Americas and Africa. Rafael finds that, in Nyungwe at least, there are signs that the forest may begin to recover if left long enough.

Second, one of TRI's first undergraduate Fellows, Elizabeth Tokarz (BS 2017, Yale College), presents her investigation into the fundamental biological question of how high numbers of species can coexist in small areas. Working in a hyper-diverse tropical rain forest in Ecuador, she made a detailed census of individuals of the common and colorful genus *Heliconia* and found distinct patterns of habitat associations that may go some way to explain how seven superficially similar species can coexist within a few hectares.

Third, Vinh Lang (MF 2015) presents his attempt to link field measurements and remote sensing images as a way to rapidly identify forest structure and physiognomy and levels of disturbance. If successful, this and similar techniques could be used to monitor forest health and human impact far from the site of the disturbance. Vinh's study highlights the difficulty of working with remote sensing data (if you thought that fieldwork was hard!), as well as the issue of taking comparable measurements from real and digital trees.

Fourth, Ruth Metzel (MF/MBA 2016) describes her evaluation of several community projects of the United Nations Development Program's Global Environmental Fund's Small Grants Program in Cuba. She was able to identify several key elements that led to the success of these programs, not least being the interactions between project leaders, members, and their community.

Finally, Mariana Vedoveto (MEM 2016) presents her analysis of the efforts to use soybean agriculture to decrease deforestation rates in the Brazilian Amazon. Her research highlights the importance of addressing a complex problem from a variety of angles, including policy, law, consumer pressure, and monitoring.

In all these studies, the importance of networks and interactions is key. Understanding the local, regional, and global pressures that drive socio-economic and ecological phenomena are important for making advances, both in practical terms, such as explaining why a farmer's decision to plant more soy subsequently leads to more deforestation, as well as documenting what drives variation in forest distribution and structure in the first place. Documenting the flow of carbon through a forest or political power through a nation will help us strive toward a more sustainable future. The work of TRI Fellows in this effort remains of utmost importance.

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TRI Fellows research sites represented in this issue

Brazil:	Mariana Vedoveto
Ecuador:	Elizabeth Tokarz
Rwanda:	Rafael Roca
Sri Lanka:	Vinh Lang
Cuba:	Ruth Metzel

Thirty Years of *Tropical Resources: The Bulletin of TRI*

Devon Parish, TRI Program Coordinator[*]
Simon A. Queenborough, TRI Director

Abstract

It is thirty years since the first article resulting from work of Fellows of the Yale Tropical Resources Institute was published. Since then, Fellows have written over 300 articles for the *Bulletin*. As a complement to our review of the current careers of TRI Fellows (Beasley et al. 2015), here we present a review and analysis of the research articles published in the *Bulletin*.

Introduction and a Brief History of the TRI Bulletin

The mission of TRI is to support interdisciplinary, problem-oriented student research on the most complex challenges confronting the conservation and management of tropical environments and natural resources worldwide. How its publication, *Tropical Resources: The Bulletin of the Yale Tropical Resources Institute*, reflects this mission is of key interest as TRI reflects on 30 years of tropical research.

The TRI *Bulletin* has undergone an evolution quite as thorough as that of the Tropical Resources Institute itself. Initially called *TRI News*, the publication once served as a combination newsletter, research catalogue, and networking tool for collaborating partners. That first issue, edited by Katherine A. Snyder, assistant to TRI's founding director, Professor William R. Burch, Jr., contained research articles from one faculty and one student contributor. The issue provided reference data for fifteen other working papers as well as literature from the broader community of tropical research. It consisted of sixteen typewritten pages. This latest issue, on the other hand, was written on numerous personal computers, formatted in Markdown, and easily converted using open-source software to HTML and professional-quality PDF documents for electronic and hard copy printing and distribution.

Thirty years, thirty-seven issues, two titles, and eight different cover designs later, the TRI *Bulletin*'s primary purpose is to highlight the research conducted by recipients of the TRI Fellowship, all Yale School of Forestry master's and doctoral students. Manuscripts are published in full and cover a broad range of topics in the natural and social sciences, many of which expand beyond TRI's stated focus areas in 1986 of secondary forest management, wildland protection management, and bioenergy systems. By 2015, *Tropical Resources* was 109 pages long and contained eleven research articles written by TRI Fellows.

It is clear that much has changed in the look and format of the TRI *Bulletin* over thirty years—but what about its content? How has the research itself evolved? To answer that question, we re-

[*]Devon Parish joined TRI as the Program Coordinator in November of 2015. She brings to Yale over six years of experience in nonprofit administration and development across a variety of sectors. She worked on the fundraising team for the Conservation Law Foundation in Boston and is passionate about issues of environmental justice, sustainable development, and climate change mitigation. She has a B.A. in Religion and Environmental Studies from Middlebury College and an M.A. in International Development from Eastern University.

viewed every available article of *TRI News* and *Tropical Resources* from 1986 to 2015, examining patterns ranging from author gender to research ecosystem, as well as the broader global issues that the author sought to address. Some trends we discovered were predictable and others less so, but viewed as a whole, the *Bulletin*'s many pages served to illuminate TRI's rich institutional history.

Methods

Digital copies of all volumes of the TRI *Bulletin* are available on the TRI website (environment.yale.edu/tri)[1] in various formats (older articles are scanned as images, newer articles are generated PDF files; we are in the process of converting all articles to text-based HTML to allow more refined searching and archiving). Together, volumes from 1986 to 2015 total 37 separate issues spanning a period of 29 years. Within these issues, 299 articles could be classified as research. Conference summaries, project updates, and biographical pieces were excluded from further analyses. Articles did not need to be authored by students to qualify; however, only 14 (4.7%) were authored by non-students.

For each article, we scored it for the following categories: author gender, status, and degree/s, region and country of study site, scientific field (natural science, social science, or interdisciplinary), discipline within field (e.g., ecology, anthropology, management), organism (animals, plants, or humans), location type (natural, rural, urban, or mixed), ecosystem (e.g., forest, freshwater), and global issues referenced (e.g., climate change, economic justice).

For degrees, ecosystems, disciplines, and global issues, we recorded up to two responses per article. We categorized study site ecosystems into six groups: agricultural, desert/arid, savanna, forest, freshwater, and marine. Some studies took place in multiple ecosystems (up to two were noted), and others had to be grouped according to their closest relative (i.e., high altitude tundra was included in desert/arid). We recognized 11 field disciplines: anthropology/human behavior, agriculture/agroforestry, climate, ecology (including silviculture), economics, energy, environmental education, environmental management/planning, health, industrial ecology, and religion/ethics, reflecting the main areas of study in F&ES.

For global issues, two of nine potential areas were noted if they were referenced in the article: civil rights and equality, climate change, deforestation and habitat destruction, development and globalization, economic justice, hunger, invasive species, over-hunting and fishing, and pollution.

To allow comparison across time, we either tabulated articles and their categories by year or by decade. We used chi-squared tests to examine if the proportion of studies in each sub-category had changed across the three decades (1986–1995, 1996–2005, and 2006–2015).

Results and Discussion

A total of 299 research articles were published in the *Bulletin* between 1986 and 2015. The mean number of research articles per year was 9.7 (range = 2–16). However, this mean number obscures the low number of articles over the first five years (mean = 4.6, range = 2–7). From 1991, the yearly output has been higher although still with considerable variation (mean = 10.75 articles, range = 7–16; Fig. 1), in some cases driven by the presence of a double-issue (e.g., volume 32/33 was published in 2014 with papers from 2013 and 2014).

The number of articles published in each of the three decades was similar, with 87, 95, and 98 articles, respectively.

Authors

Of all the articles studied, only 23 had more than one author, ten of which were mixed-gender teams. For single-authored articles, from the first decade of the *Bulletin* to its third, the number of male au-

[1] We were unable to locate copies of issues 14.2,and 15.2 (falls of 1995 and 1996 respectively), if indeed they were published.

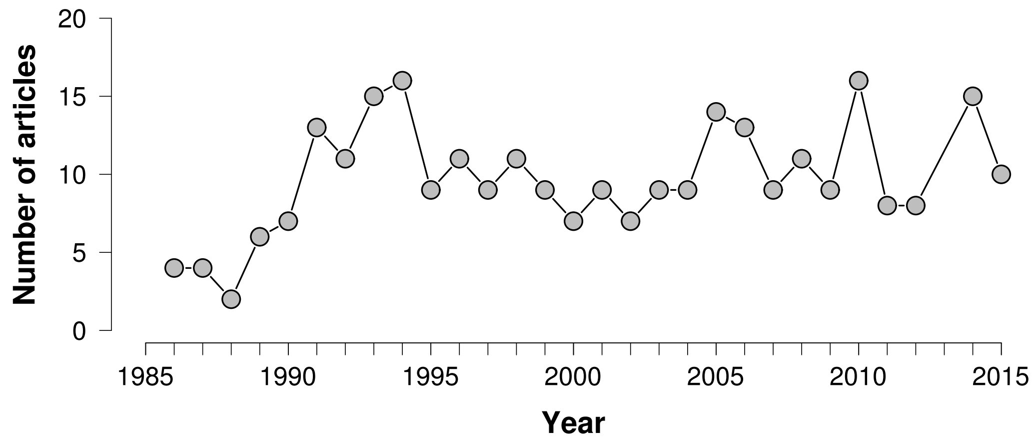

Fig. 1. Number of research articles in the TRI *Bulletin* per year.

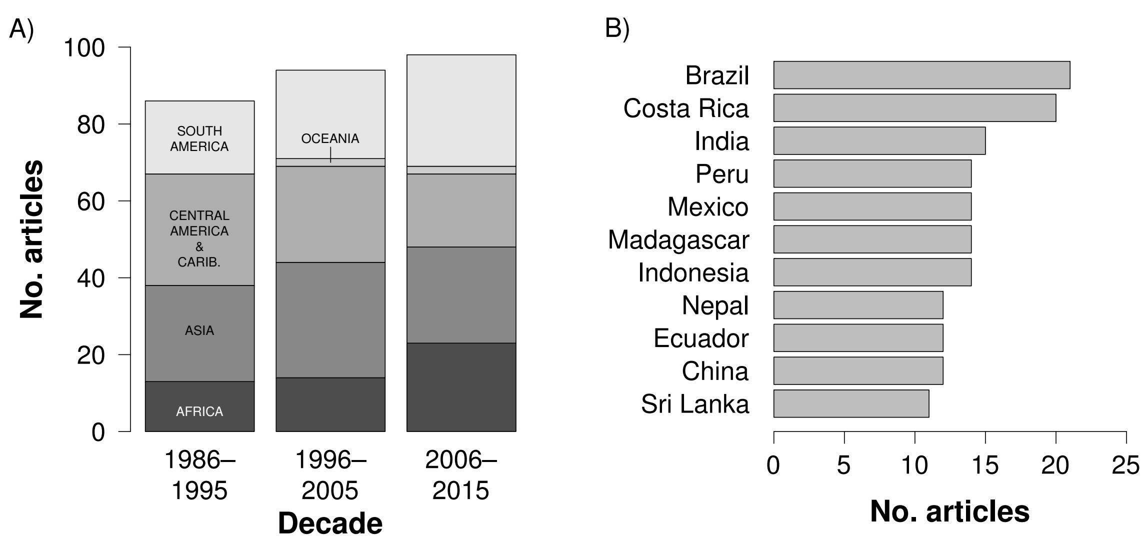

Fig. 2. Number of TRI *Bulletin* articles focused on (A) each global region by decade and (B) the eleven most popular countries.

thors halved, the number of female authors more than doubled, and the proportion of females grew by 80% (χ^2 = 10.9, df = 2, p < 0.001, Fig. 2F). This change parallels a growth in female representation both at the Yale School of Forestry and Environmental Studies and in graduate programs overall during that time.

The vast majority of researchers were students (95.3%), with the remainder being Yale faculty or non-Yale affiliates. Degree tracks were difficult to measure over time as the school's offerings changed (MES was dropped and MEM added in 1998), but it was clear that over its tenure, the *Bulletin*'s contributors have been primarily master's students. Master of Environmental Studies and Master of Environmental Science were the highest contributing degrees (n = 122), followed by Master of Forestry and Forest Science (n = 73), Master of Environmental Management (n = 47) and doctoral students (n = 31). Thus, the TRI *Bulletin* continues to occupy the unique niche of providing a publication opportunity for master's level environmental researchers in the tropics.

Study site

Studies were conducted in all tropical continental regions. The number of studies conducted in Africa and South America were greater in the most recent decade compared to the first decade (Africa had 13 in 1986–1996 versus 23 in 2006–2015, South America had 19 versus 29), maybe driven by a growing population of F&ES students who are from those continents and choose to do research in their home countries or native languages. Conversely, the number of studies focused on Central America-Caribbean decreased (29 versus 19), and Asia remained constant (25–30). Despite this apparent change in balance among regions, there was no significant change in the proportion of studies from each global region across the three decades of publication, both when we included the four studies from Oceania (χ^2 = 9.7, df = 8, p = 0.29) or excluded them (χ^2 = 7.6, df = 6, p = 0.25; Fig. 3A).

Over the course of the TRI *Bulletin*'s history, research has been featured from 61 countries. Of these countries, about half (n = 29) were featured in only a single study (e.g., Comoros, Haiti, Liberia, Paraguay, and Vietnam). Thirty-two countries were highlighted by two or more articles over the three decades (e.g., five studies in Bolivia, three in Ghana, and two in Thailand). Eleven countries had ten or more studies since 1986 (Fig. 3B), split evenly between the Americas (n = 5) and Asia (n = 5), plus Madagascar. As we might expect, countries with large areas of tropical forest featured prominently in this list (e.g., Brazil, Peru) as well as those with a strong tradition of sending students abroad for graduate study (e.g., Brazil, India, Mexico). Further, some countries have organizations with strong partnerships with TRI and F&ES, such as those examining silviculture in Costa Rica and Sri Lanka.

Study characteristics

In line with the increasingly broad focus of the School of Forestry, reflected in the addition of 'Environmental Studies' to its name in 1972, there was a significant shift from studies focused on plants (n = 37 in 1986–1996 to n = 22 in 2006–2015) to studies focused on people (n = 40 to 69), which now outnumber plant studies 3:1 (χ^2 = 11.09, df = 4, p = 0.026, Fig. 2A). Studies of animals concerned only a mean of 9 studies per decade (range = 8–10).

Likely tied to this trend was a change in the types of location and ecosystem that were studied. In its first decade, the *Bulletin* contained comparable numbers of studies based in rural (n = 37) and natural (n = 31) areas, and only two studies had an urban focus. By 2006–2015, however, natural area studies were far less popular (n = 7), while rural (n = 62) and urban (n = 5) research had both increased significantly (χ^2 = 34.2, df = 6, p < 0.001, Fig. 2B). This change aligns with the move from plant to human-focused research, but notably, rural and mixed location studies still far outnumber those conducted solely in urban areas.

Similar to location type, study ecosystem varied significantly over time (χ^2 = 29.7, df = 10, p = 0.003, Fig. 2C). The two most common ecosystems saw dramatic change: fewer studies were conducted in forests (58 studies to 38) and more studies were conducted in agricultural land (12 studies to 28). Further, the number of studies in fresh water doubled from 4 to 11. Studies in deserts, savannas, and marine ecosystems showed little variation and even combined accounted for only about 10 studies per decade. This shift in ecosystem likely reflects the increasingly applied nature of the work of TRI Fellows, broadening from the management of forests to the management and study of the environment and its inhabitants as a whole.

Fields of enquiry

The Tropical Resources Institute, and the School of Forestry and Environmental Studies more widely, aim to be interdisciplinary institutions. In agreemement with this goal, there was a significant increase in social science and explicitly interdisciplinary studies from the first decade to the third, concurrent with a decline in natural science studies (χ^2 = 20.5, df = 4, p = 0.0004, Fig. 2D). Interdisciplinary studies, while consistently the smallest category, included intriguing topics such as the future of yerba mate farmers in Argentina, use of Himalayan 'viagra' in Bhutan, dynamics of mangroves and the fishing industry in Madagascar, and the role of sacred pools in forest conservation in Benin.

In addition to the broad fields of natural and social science, we sorted the *Bulletin* articles according to discipline. A predictable scenario was observed. Between 1986 and 2015, studies in ecology decreased while studies in anthropology, health, and environmental management increased (χ^2 = 33.1, df = 18, p = 0.016, Fig. 2E). Despite active and engaged faculty in F&ES, economics and energy articles represented only a small and stable fraction of studies, and climate and industrial ecology only appear as disciplines in the second decade, reflecting recent understanding of these important issues.

Global Issues

TRI Fellowships are aimed at addressing some of the most complex challenges in the conservation and management of tropical environments. This aim is reflected in the broader global issues that motivate studies published in the *Bulletin*, with most authors placing their study in to this larger context. Deforestation and habitat destruction was by far the most common issue addressed (n = 152), referenced in more than half of all articles. Including all unsustainable extraction of plant material, this category showed no decline in its significance over time. Other global issues did show substantial variation among decades, but not significantly so, when we looked at all issues together (χ^2 = 29.6, df = 18, p = 0.042).

The issue of development and globalization, second to habitat destruction, increased from 24 to 32 studies from the first to the third decade. Maybe unsurprisingly, references to climate change and global warming were absent from the first ten years of the *Bulletin*, but are increasingly common, whereas the issue of hunger and famine decreased in prevalence.

Conclusion

The patterns of publications in the TRI *Bulletin* reflect the interests as well as changes occurring within F&ES as well as society at large. Some elements of *TRI News* and *Tropical Resources* have been maintained throughout all three decades of publication. These include a commitment to student-directed, primarily master's level research; representing a diverse array of regions and countries across the global tropics; and addressing ongoing threats to tropical environments such as deforestation, habitat destruction, and development.

Other aspects of the *Bulletin* have shifted. More research is being conducted by women. More projects are focused on social science, humans, and the environments that humans inhabit. Pure

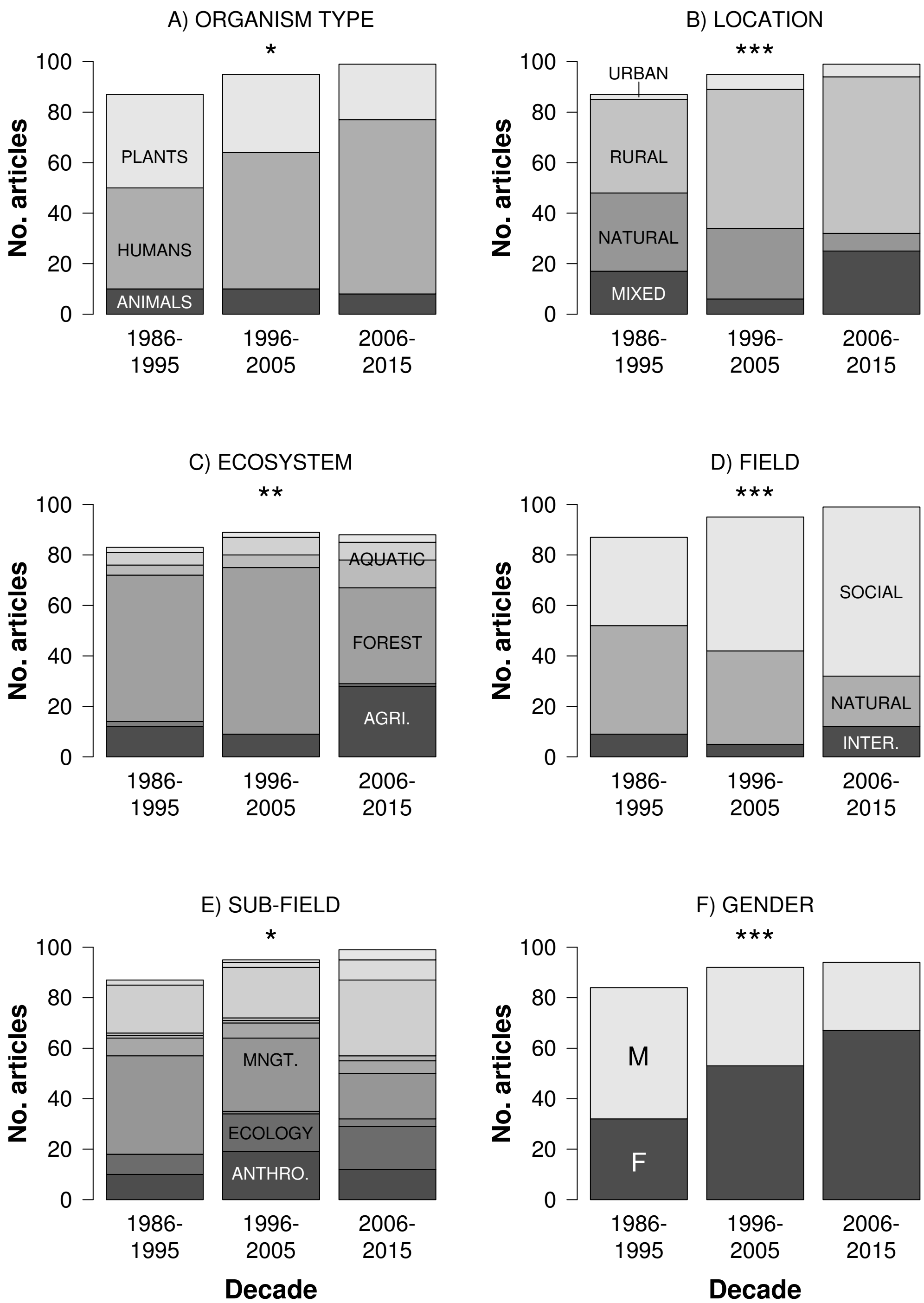

Fig. 3. TRI *Bulletin* article traits by decade: (A) primary organism studied; (B) primary location of research; (C) primary ecosystem studied; (D) general field of research; (E) sub-discipline; and (F) author gender. Stars indicate degree of statistical significance: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

ecological studies are less common than studies of environmental management, planning, politics, and land use. Fewer studies are forest-focused. Crossover and interdisciplinary research is growing.

We might glean from these trends that the direction of tropical research itself has changed, and is changing. The demographics and definition of the field are expanding and diversifying. The inextricable fates of the natural environment and human communities—especially those in less-developed countries—are more broadly understood and the urgency of conservation-oriented research only grows.

As the TRI *Bulletin* enters its fourth decade, we expect many of these trends to continue. To remain relevant, TRI Fellows' research must strike a balance between asking meaningful cutting-edge questions and upholding the legacy and diversity of fields, regions, and ecosystems that the Tropical Resources Institute seeks to recognize and conserve. Student interest alone is not the only factor shaping the themes of TRI research, however. Degree and course offerings, funding levels, in-country partnership opportunities, and faculty interests all play a role in ensuring that future student research achieves this desired balance. We hope this retrospective analysis will be a helpful tool as strategies and procedures are put into place that will shape the next thirty years of TRI research.

Acknowledgements

We thank previous TRI staff Dana Graef, Dana Baker, Sarah Tolbert, and Emily Zink for collating all the previous issues of the *Bulletin*, and Bart DiFiore and Allyza Lustig for assisting with scoring articles according to categories.

References

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Roca & Zúñiga. 2016. Floristic inventory of tropical forest in Rwanda 20 years after artisanal gold-mining.
Tropical Resources **35**, 8–17.

Floristic inventory of tropical forest in Rwanda 20 years after artisanal gold-mining

Rafael Roca, MESc/MBA 2016[*]
Claudia Zúñiga Carrillo[†]

Abstract

Floristic inventories of tropical forest after 20 years of artisanal gold mining practices in Nyungwe National Park, Rwanda, were undertaken to understand the effect of this mining on forest composition and diversity. All selected sites had suffered severe mining impacts by 1993. Three plots of 0.05 ha were surveyed in each of four locations (Karamba, Rugazi, Akabaguri, and Mugote), and all trees >10 cm DBH were censused. We found a total of 215 individual trees of 23 species and 18 families. The most common and dominant species was *Hagenia abyssinica* (Rosaceae), while the most frequent was *Dichaetanthera corymbosa* (Melastomataceae). In order of importance, *Dichaetanthera corymbosa*, *Anthocleista grandiflora*, *Maesa lanceolata*, *Chionanthus africanus* and *Afrocrania volkensii* were the indicator species in Karamba; *Dichaetanthera corymbosa*, *Syzygium guineense*, *Hagenia abyssinica*, and *Anthocleista grandiflora* were the indicator species in Rugazi; and *Hagenia abyssinica* was the indicator species in Akabaguri and the sole species found in Mugote (fire recovery site). The mixing ratio of the mining recovery sites range from 0.19 to 0.21, suggesting the regeneration of heterogeneous ecosystems.

Introduction

Mining is a well-known destructive practice within many forests around the world (Dudka & Adriano 1995). Trees are cleared, topsoils and organic litter removed, and water streams are modified (Cooke & Johnson 2002). Such disturbances have an impact on nutrient cycling processes and forest regrowth (Congdon et al. 1993). Legal mines are obliged to comply with environmental commitments, and often set up a plan to achieve a desired and approved state of restoration. The ultimate long-term objective is that mined sites return to the state of pre-mined forest, with the presence of all plant species at the same frequency and density as before (Koch 2007). However, attempted restoration of mined sites in Brazil and Australia have shown contrary results in returning these sites' ecosystems back to a pre-mining state. Some studies indicate successful forest regeneration already advanced through secondary succession (Rodrigues et. al 2004), while others show that rehabilitated sites are not becoming more similar to the unmined forest over time (Norman et al. 2006). Understanding the factors that aid or inhibit successful restoration is a key question in determining the long-term effects of mining and other destructive impacts on forests.

In 2014, Rwanda was considered the 19th most densely populated country in the world, averaging 460 inhabitants per km² (World Bank, 2016). This is no exception in Nyungwe National Park, where family farms located within or near the National Park's buffer zone average less than 1 hectare in size, and over 90% of the population engage

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in subsistence farming (Mazosera et al. 2006). To supplement this livelihood, local communities historically have used the forest to generate additional income through gold mining, wood cutting, hunting, and honey collection. Even though Nyungwe has had some form of protection since it was established as a forest reserve in 1933, accumulated deforestation between 1958 and 1979 was estimated at 15% (Weber 1989). Further, in 1993 an estimated 2,528 artisanal miners were living and working within 16,000 ha of Nyungwe (Fimbel & Kristensen, 1994). To mediate this threat to the National Park's continued conservation, Fimbel & Kristensen (1994) proposed establishing policies that would permit miners to continue their operations within already impacted areas but limit their spread into highly biodiverse zones. Since then, strong enforcement after the genocide, the establishment of Nyungwe as a National Park in 2004, and constant efforts by conservation organizations (such as the Wildlife Conservation Society and the Rwanda Development Board) have led to implement controls that support the complete ban on mining, hunting, and extraction of other forest products within the Park. Enforcement registers indicate that from 2006 to 2010 there were at least 227 poachers arrested (Mulindahabi et al. 2011).

Tourism has co-evolved with conservation, alleviating some of the impact generated by illegal activities within Nyungwe. From 2001 to 2014, the number of tourist visits increased from 5,965 to 67,871, an average of 18% per year (Rudasingwa 2014). However, despite the associated increase in income from tourists (in 2014, Nyungwe's tourism revenues increased by 37%), this revenue source amounts to only 2% of the estimated $16.8 million of total revenue generated by Rwanda's National Parks system. Most revenue comes from gorilla trekking in Volcanoes National Park, accounting for 94% in 2014. Revenue streams in Nyungwe include trail walks (27%), primates visits (29%), and canopy walks (38%) (Rudasingwa 2014). A system of revenue sharing among all Parks has been set up, where 5% of all revenues are directed to community projects bordering the parks. These revenues are apportioned 40% to communities located near Volcanoes National Park and 30% each to Akagera and Nyungwe National Parks. Despite this effort, illegal activities still occur within Nyungwe National Park and nearby communities still rely on forest resources or extractive mining to sustain their livelihoods.

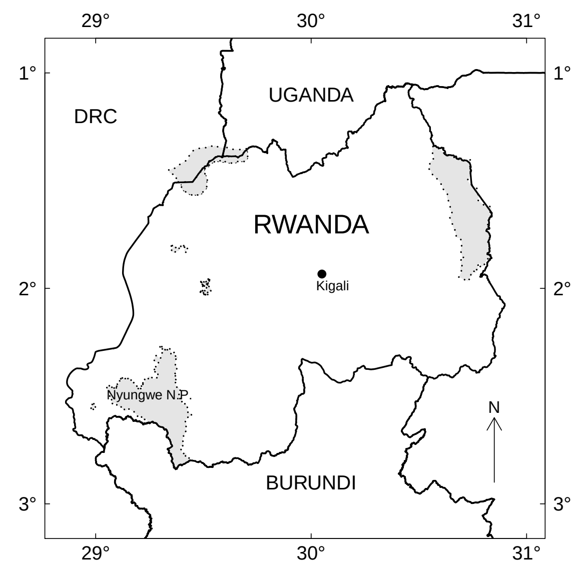

Fig. 1. Map of Rwanda, showing Nyungwe National Park.

Artisanal gold mining continues, but the limited area generates poor returns and it is viable only for subsistence purposes. Mining began in 1935, with records reporting as many as 12,000 miners between 1972 and 1985 (Fimbel & Kristensen 1994). Miners use alluvial techniques, deforesting sites close to watersheds, burning them to later extract the sediments from the soil. Sifting is common to separate the gold and is considered a safer and less environmentally harmful technique than using mercury, a practice still common in the Peruvian Amazon (Ashe 2012). However, negative correlations between signs of gold mining and ungulate populations (Plumptre et al. 2002) suggest that miner's intensive hunting practices have been highly detrimental for the forest (Weber 1989). At present, illegal miners tend to work fast and move to new remote areas, instead of setting up camps in previously established sites.

Mined forest in Nyungwe, Rwanda, has been left undisturbed for the past 20 years, and no restoration activities other than non-human natural interactions have taken place. To date, no study has documented the ecological recovery of mined areas within Nyungwe and there is little understanding of the environmental impacts of this activity and how the forest responds to such stress. This paper examines the regeneration of areas mined in 1994 to determine the speed and trajectory of forest recovery and asks whether mined forest is likely to return to its previous state.

Methods

Study Site

Nyungwe National Park is Rwanda's largest standing forest at 970 km². It is located in the southwest (latitude 2°15' and 2°55'S, longitude 29°00' and 29°30'E) and extends along mountainous areas that range from 1600 to 2950 meters above sea level (Weber 1989, Masozera et al. 2006, Fig. 1). Data from 1988–1993 suggests average annual rainfall of 1,744 mm, fluctuating considerably between July–August (dry season) and other seasons. Temperatures are typical for a tropical region, with daily variation greater than annual variation (average minimum temperature = 10.9°C, and average maximum temperature = 19.6°C; Sun et al. 1996). Nyungwe National Park is highly biodiverse, with 86 recorded species of mammals, 280 birds, 43 reptiles, 33 amphibians, 1105 plants (ferns, herbs, climbers and shrubs) and 230 trees; both represent 137 out of 551 endemic species found in the Albertine Rift (Plumptre et al. 2007). Thirteen species of primates have been recorded within Nyungwe, including chimpanzees, owl-faced guenons and Angolan black and white colobus monkeys in groups of 300+ individuals (Fimbel et al. 2001, Plumptre et al. 2002)

The selection of study sites was based on sites classified as suffering severe mining impacts by 1993, and accessibility to the areas. Information on the sites was based on the mining census elaborated by Fimbel and Kristensen (1994). Specific locations (Appendix A) within the sites were randomly determined once the affected areas were clearly identified. Local park rangers validated the fact that these areas have not been mined in approximately 20 years.

Floristic Inventory

The vegetation and floristics of the previously mined forest sites were assessed with a series of 20 x 25 m (0.05 ha) tree plots within which all trees >10 cm diameter at breast height (DBH, 1.3m) were recorded and identified (Synnot 1979). Each tree was measured for DBH, height (electronic altimeter), and projected canopy area. All trees were identified to species. Plots were established at three sites: Karamba (4 plots, 0.2 ha total), Rugazi (4 plots, 0.2 ha total), and Akabaguri (3 plots, 0.15 ha total) (Appendix A). Plots were randomly located within each mined site if the shape allowed.

In addition, we measured one plot (0.05 ha) near Mugote, an area burned by an uncontrolled fire in the 1990s, with the purpose of comparing the ecological recovery of mining and fire sites. Finally, a new recently found illegal mining site was visited near Bweyeye, found by local park rangers around May 15th 2015. They claimed that miners must have been there about two weeks before. The objective of this visit was to visualize the direct immediate effects of mining on the land, with the purpose of having a better understanding of the areas studied almost 20 years after.

Data analysis

For each plot, we calculated the Importance Value Index (IVI, Equation 1) for each species. This statistic is a summation index that encompasses relative density plus relative frequency plus relative dominance for each species, with a value of 300 as the total for all species within a site (Curtis and McIntosh 1951). This index allows the comparison of the ecological weight of each species within its ecosystem. Similar IVI's for indicator species in different plots suggest similar forest composition, structure, and dynamics (Lamprecht 1990). Indicator species are those that form the top 150 IVI.

$$IVI = RA + RF + RD \quad (1)$$

where RA = relative abundance, RF = relative frequency, and RD = relative dominance.

For each species, we calculated relative abundance:

$$RA = (n_i/N) * 100 \quad (2)$$

where ni = number of trees of species i and N = total number of trees of all species;

relative frequency:

$$RF = (F_i/F_t) * 100 \quad (3)$$

where F_i = absolute frequency of species i and F_t = the total number of absolute frequencies;

and relative dominance:

$$RD = (G_i/G_t) * 100 \quad (4)$$

where G_i = total basal area of all the trees of species i and G_t = total basal area of all the trees of all species.

Finally, we calculated the mixing ratio, an indicator that measures the degree of homogeneity or heterogeneity within the forest (Lamprecht 1990, CM):

$$CM = S/N \quad (5)$$

where S = the total number of species within the sample and N = the total number of trees within the sample.

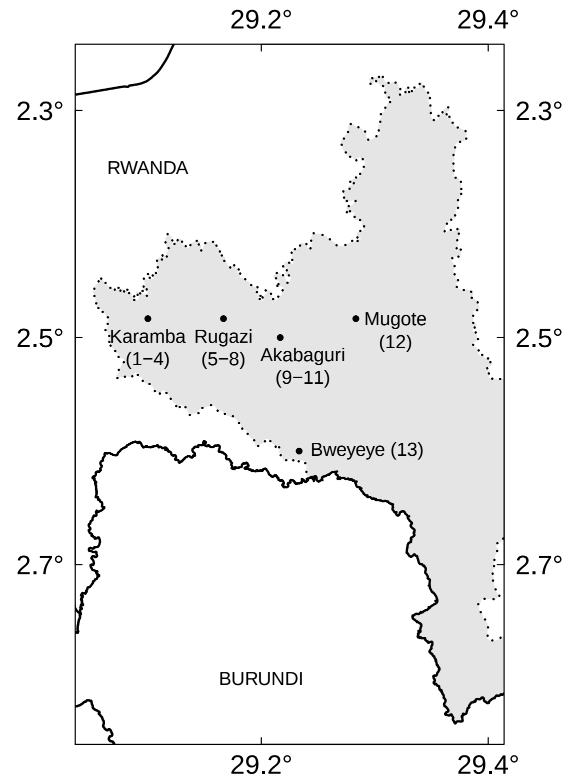

Fig. 2. The location of sites in Nyungwe National Park, Rwanda.

Results

Within the twelve 0.05 ha plots, we found a total of 215 individual trees >10 cm DBH in 23 species and 18 families. Density in each plot ranged from 7 to 24 trees (mean = 18, SD = 6). DBH ranged from 10 to 65 cm (mean over all trees = 17.1, SD = 8.5; mean per plot = 17.5 cm, SD = 3.4).

The species richness of each site varied considerably. Karamba was the richest with 16 species, followed by Rugazi (14 species), Akabaguri (9) and Mugote (1). Karamba and Rugazi had the same tree density (75) over the same number of plots. The most common species over all individuals on the three mining sites was *Hagenia abyssinica* with 42 trees, despite its absence in Karamba. The next most common was *Dichaetanthera corymbosa* with 32 trees. Eighteen species had less than 10 individuals and six species were present as single individu-

Table 1. Indicator species for each site (those summing to at least an IVI of 150. Full details of each site are given in the Appendix.

Species	Abund.	Rel. Abund.	Freq.	Rel. Freq.	Dom.	Rel. Dom.	IVI
Karamba							
Dichaetanthera corymbosa	16	21.33	4	11.76	0.4747	24.51	57.61
Anthocleista grandiflora	7	9.33	4	11.76	0.2116	10.92	32.02
Maesa lanceolata	9	12	3	8.82	0.0892	4.61	25.43
Chionanthus africanus	8	10.67	3	8.82	0.1092	5.64	25.13
Afrocrania volkensii	5	6.67	3	8.82	0.1723	8.9	24.39
Rugazi							
Dichaetanthera corymbosa	15	20	4	12.12	0.4255	21.11	53.24
Syzygium guineense	5	6.67	3	9.09	0.6376	31.64	47.4
Hagenia abyssinica	11	14.67	4	12.12	0.2333	11.58	38.36
Anthocleista grandiflora	14	18.67	2	6.06	0.1693	8.4	33.13
Akabaguri							
Hagenia abyssinica	31	68.89	3	23.08	1.4743	77.63	169.59

als.

The species frequency was best represented by *Dichaetanthera corymbosa* and *Anthocleista grandiflora* in Karamba, *Dichaetanthera corymbosa*, *Macaranga kilimandscharica* and *Hagenia abyssinica* in Rugazi, and *Polyscias fulva* and *Hagenia abyssinica* in Akabaguri. The most frequent species on these sites was *Dichaetanthera corymbosa*, present on 82% of the mined plots. The next most frequent was *Polyscias fulva* with 73% presence. Seven species were found in only one plot.

Overall dominance was greatest for *Hagenia abyssinica* with 29% of relative dominance among the mining plots. The next most dominant species was *Dichaetanthera corymbosa* with 16%. The species dominance was best represented by *Dichaetanthera corymbosa* in Karamba, *Syzygium guineense* and *Dichaetanthera corymbosa* in Rugazi, and *Hagenia abyssinica* in Akabaguri.

In order of importance, *Dichaetanthera corymbosa*, *Anthocleista grandiflora*, *Maesa lanceolata*, *Chionanthus africanus* and *Afrocrania volkensii* were the indicator species in Karamba, *Dichaetanthera corymbosa*, *Syzygium guineense*, *Hagenia abyssinica* and *Anthocleista grandiflora* were the indicator species in Rugazi, and *Hagenia abyssinica* is the indicator species in Akabaguri (Table 1).

All the sites are fairly similar when discussing the mixing ratio, ranging from 0.19 to 0.21 (Table 2).

Discussion

In eleven 0.05 ha tree plots in previously mined forest sites in tropical forest in Nyungwe National Park, Rwanda, we documented 195 trees >10 cm DBH in 23 species. Two species were dominant in terms of abundance (*Hagenia abyssinica* and *Dichaetanthera corymbosa*), two were dominant in terms of frequency (*Dichaetanthera corymbosa* and *Polyscias fulva*), and two in terms of basal area (*Hagenia abyssinica* and *Dichaetanthera corymbosa*). These data presents some of the first information on forest regeneration following gold-mining in tropical Africa.

Species diversity of 20-year old mined forest

There are over 100 species of large trees (>30 cm DBH) in Nyungwe National Park (Plumptre et al.

2002). However, more than half of the individual trees come from only five species: *Syzygium guineense*, *Macaranga kilimandscharica*, *Carapa grandiflora*, *Strombosia scheffleri*, and *Hagenia abyssinica* (Fashing et al. 2007). Of these, only *Strombosia scheffleri* was absent from our census. Out of the top 20 species of large trees, 10 were also registered in this study (Plumptre et al. 2002).

Tropical forests tend to have a high number of species per area, usually showing a mixing ratio of at least 0.2 (Malleux 1987). This claim suggests that these sites are recovering in a way that promotes a heterogeneous ecosystem.

Table 2. Mixing ratio (number of species / number of individuals) of each site.

Site	Mixing Ratio
Karamba	0.21
Rugazi	0.19
Akabaguri	0.20

Important and indicator species in mined forest

Indicator species (those in the top 150 IVI) were similar across the sites, with *Dichaetanthera corymbosa* and *Anthocleista grandiflora* present at both Karamba and Rugazi. Both sites had similar species richness (16 and 14 species) and stem density (75 trees >10 cm DBH). In contrast, Akabaguri had one indicator species, *Hagenia abyssinica*. This species was also an indicator species for Rugazi and was the sole species found within the Mugote plot, in the fire-recovered area close to the Congo Nile Trail (Appendix B). Other studies have suggested that it is a fire-tolerant pioneer species (Finch and Marchant 2011, Lange et al. 1997, Greenway 1973; White 1983; Lovett et al. 2006). This native species also has the ability to produce leaf litter that decomposes quickly, adding nutrients to disturbed soils (Assefa and Glatzel 2010). Despite these properties, its use as a construction material, firewood, medicine and livestock fodder in other parts of Africa, such as Ethiopia, has led to decreasing populations (Tegegne and Mekonnen 2007; Assefa and Glatzel 2010).

Dichaetanthera corymbosa, *Anthocleista glandiflora* and *Maesa lanceolata* have been identified respectively in Congo, Equatorial Guinea and Nyungwe as signs of secondary succession after periods of human disturbance in the form of shifting and semi-permanent cultivation, i.e., cacao (Yamada 1999; Zafra Calvo 2008; Graham, Moermond et al. 1995).

Conclusion

The ecological recovery of these mining sites shows promising results for the future. Natural regeneration is taking place with native species that are able to adapt to extreme conditions after being mined. This is a slow process, but the indicators suggest that diverse pioneer species have already established themselves, and will allow the forest to eventually recover through its natural dynamic process. To understand this better, further long-term studies should be undertaken, including a re-assessment of these sites in the future, and their comparison to young and mature forest within Nyungwe using larger sample areas. If left undisturbed by human activity, these forest sites may well return to forest similar to the natural old-growth forest.

The objective of this preliminary study has been to pursue an initial understanding of the state of abandoned artisanal gold mining sites in Nyungwe. With these results, showing slow but diverse natural recovery by pioneer species, we point out that strongly positive outcomes have resulted from the conservation efforts of Rwandan authorities and local actors. Further forest succession would be expected with continued law enforcement and development of alternative sources of livelihoods to reduce pressure to the forest.

Artisanal gold mining remains a threat, especially in more remote areas. The site observed near Bweyeye (Appendix A) suggested a short-term stay with intense labor, and the possibility that mining and miners move readily between Rwanda and Burundi. Given the nature of subsistence of this activity, it is vital to understand the new sources of revenues of past miners, and promote economic development in a way that makes it more profitable for them to pursue legal alternative activities. This will have a significant contribution to the conservation of Nyungwe National Park. It is therefore imperative to complement the current efforts successfully undertaken through tourism to continue reducing pressure towards the forest.

Acknowledgements

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Table 3. Importance Value Index calculations for all three sites.

Species	Abund.	Rel. Abund.	Freq.	Rel. Freq.	Dom.	Rel. Dom.	IVI
Karamba							
Dichaetanthera corymbosa	16	21.33	4	11.76	0.4747	24.51	57.61
Anthocleista grandiflora	7	9.33	4	11.76	0.2116	10.92	32.02
Maesa lanceolata	9	12	3	8.82	0.0892	4.61	25.43
Chionanthus africanus	8	10.67	3	8.82	0.1092	5.64	25.13
Afrocrania volkensii	5	6.67	3	8.82	0.1723	8.9	24.39
Sapium ellipticum	7	9.33	3	8.82	0.0812	4.19	22.35
Polyscias fulva	2	2.67	2	5.88	0.2169	11.2	19.75
Syzygium guineense	3	4	2	5.88	0.1807	9.33	19.21
Bridelia brideliifolia	5	6.67	2	5.88	0.0816	4.21	16.76
Ilex mitis	3	4	2	5.88	0.0701	3.62	13.5
Harungana montana	3	4	1	2.94	0.1213	6.26	13.2
Cleistanthus polystachyus	3	4	1	2.94	0.0784	4.05	10.99
Macaranga kilimandscharica	1	1.33	1	2.94	0.0227	1.17	5.45
Casearia runssorica	1	1.33	1	2.94	0.0113	0.58	4.86
Carapa grandiflora	1	1.33	1	2.94	0.0079	0.41	4.68
Hymenodictyon floribundum	1	1.33	1	2.94	0.0079	0.41	4.68
TOTAL	75	100	34	100	1.937	100	300
Rugazi							
Dichaetanthera corymbosa	15	20	4	12.12	0.4255	21.11	53.24
Syzygium guineense	5	6.67	3	9.09	0.6376	31.64	47.4
Hagenia abyssinica	11	14.67	4	12.12	0.2333	11.58	38.36
Anthocleista grandiflora	14	18.67	2	6.06	0.1693	8.4	33.13
Harungana montana	8	10.67	3	9.09	0.1272	6.31	26.07
Maesa lanceolata	6	8	3	9.09	0.0693	3.44	20.53
Macaranga kilimandscharica	5	6.67	4	12.12	0.0655	3.25	22.04
Polyscias fulva	3	4	3	9.09	0.0579	2.87	15.96
Tabernaemontana stapfiana	2	2.67	2	6.06	0.0906	4.5	13.22
Bridelia brideliifolia	2	2.67	1	3.03	0.0661	3.28	8.98
Ficalhoa laurifolia	1	1.33	1	3.03	0.0434	2.15	6.52
Sapium ellipticum	1	1.33	1	3.03	0.0113	0.56	4.92
Carapa grandiflora	1	1.33	1	3.03	0.0095	0.47	4.84
Cassipourea gummiflua	1	1.33	1	3.03	0.0087	0.43	4.8
TOTAL	75	100	33	100	2.0152	100	300
Akabaguri							
Hagenia abyssinica	31	68.89	3	23.08	1.4743	77.63	169.59
Polyscias fulva	3	6.67	3	23.08	0.0559	2.94	32.69
Albizia gummifera	4	8.89	1	7.69	0.1104	5.81	22.39
Harungana montana	1	2.22	1	7.69	0.1195	6.29	16.21
Bridelia brideliifolia	2	4.44	1	7.69	0.0267	1.41	13.54
Dichaetanthera corymbosa	1	2.22	1	7.69	0.0573	3.02	12.93
Mitragyna stipulosa	1	2.22	1	7.69	0.0314	1.65	11.57
Ilex mitis	1	2.22	1	7.69	0.0133	0.7	10.61
Neoboutonia macrocalyx	1	2.22	1	7.69	0.0104	0.55	10.46
TOTAL	45	100	13	100	1.8992	100	300

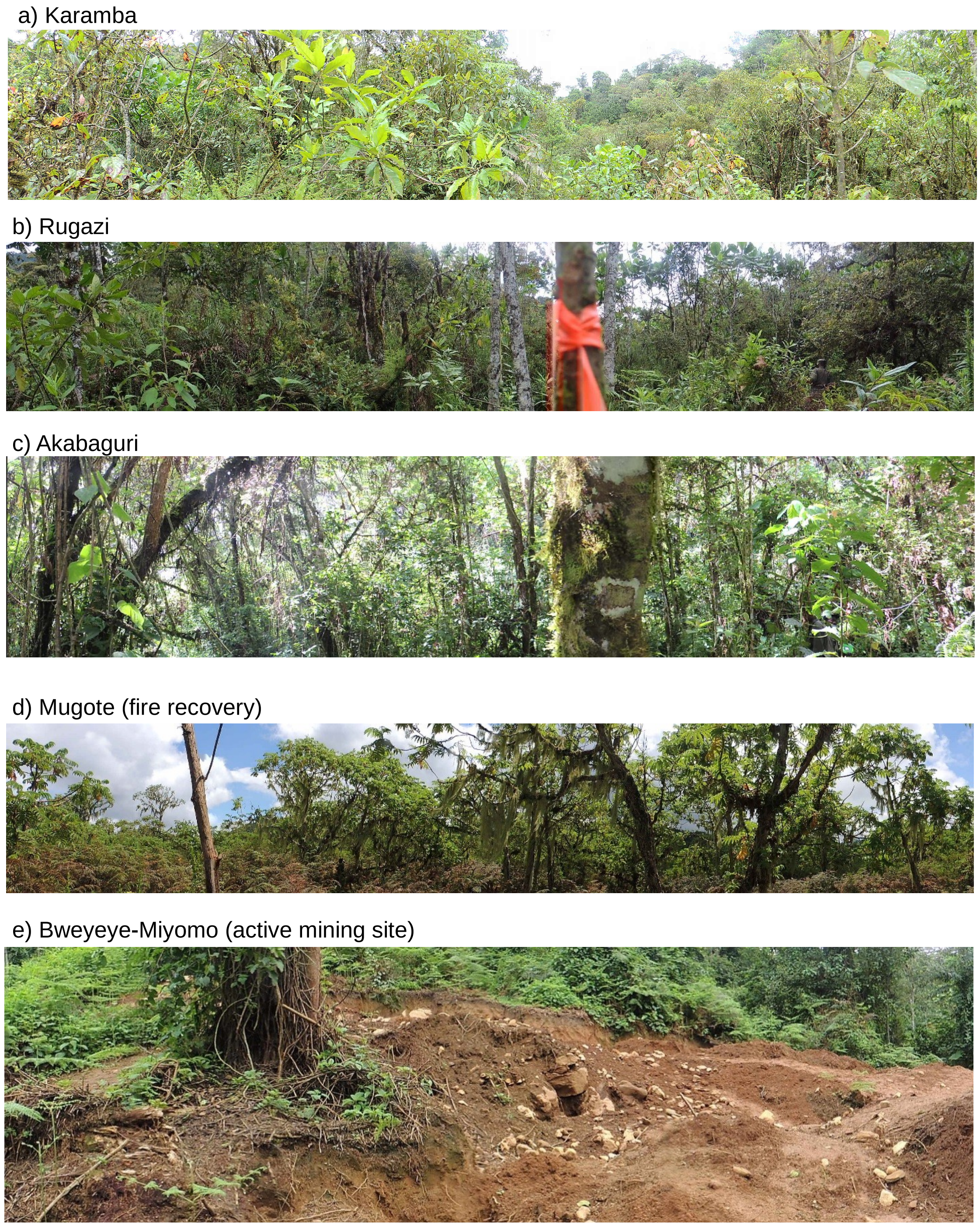

Fig. 3. Photos showing typical forest from each inventory site.

Tokarz. 2016. Habitat associations of herbaceous plants in Yasuní National Park, Amazonian Ecuador: A study of *Heliconia*. *Tropical Resources* **35**, 18–29.

Habitat associations of herbaceous plants in Yasuní National Park, Amazonian Ecuador: A study of *Heliconia*

*Elizabeth L. Tokarz, BS 2017 Yale College**

Abstract

The abundance, diversity, and distribution of herbaceous plants within tropical forests are often neglected in favor of woody tree and liana species, even though the herbaceous understory layer of these forests plays a major role in nutrient cycling and frequently encompasses a greater species diversity than trees. In a 50-ha permanent lowland Amazonian rain forest plot in Yasuní National Park, Ecuador, a census of six species of *Heliconia* (Heliconiaceae) was carried out in a stratified random manner across three topographic habitat types: valley, slope and ridge. Distribution patterns consistent with habitat niche partitioning were observed for the two most abundant species on the plot: *Heliconia stricta* was found predominantly in valley habitat and *H. velutina* in ridge habitat. Further, *H. velutina* was the only species to be present at high abundance and frequency in ridge habitat, suggesting that it can succeed in the drier ridge conditions and may even have better drought tolerance than the five other *Heliconia* species. Such habitat associations consistent with niche partitioning have been found in tree species within the plot, and likely contribute to the coexistence of these six closely related herbaceous species in this forest.

Introduction

Many censuses of plant diversity neglect to account for herbaceous species, particularly in forest ecosystems. Herbs offer special problems to census-taking scientists because they can be small, short-lived, rhizomatous, and difficult to enumerate and tag. Because of these difficulties, many botanical species diversity studies exclude herbs from their tallies, and previous censuses in tropical forests are no exception (Gentry and Dodson 1987). For example, despite an extensive network of tree plots throughout the world's forests, very little is known about the herb flora and dynamics of many of these sites (Bass et al. 2010, Valencia et al. 2004, Feeley et al. 2011, Toriola et al. 1998, Guo-Yu et al. 2008). Still, in tropical forests, most individual plants are non-trees and terrestrial herbs account for about 13% of total plant composition (Gentry and Dodson 1987), suggesting important roles in ecosystem processes and services.

Herbs contribute to the forest ecosystem differently than their woody counterparts. For example, the herbaceous layer plays a crucial role in influencing the cycling of essential plant nutrients; herbaceous leaf litter decomposes more than twice as fast as tree litter (Gilliam 2007). Herbs also respond to disturbances such as tree-falls differently than trees do, so herbs may associate with such habitats differently than trees (Murphy et al. 2016).

Herbaceous plant composition and dynamics have been investigated more frequently in temperate climates than in tropical ones. Most forests in temperate North America are approaching a climax state of succession and experience annual variability with seasons (Gilliam 2014), whereas tropical forests have more recently been involved in a cycle of clearing and settling, and experience less drastic

*Elizabeth (BS 2017) has researched tropical plants in Panama, Ecuador, and Missouri Botanical Garden. She plans to pursue a career in botanical conservation changes in temperature. These different contexts make it harder to directly compare the dynamics of herbaceous plants between the two biomes. It seems that in temperate forests, seasonal and regional patterns in herbs are better explained by soil conditions than by climate (Gilliam 2014), though climate may play a role in driving soil conditions. Even if the rest of the forest is approaching the climax stage, the understory is a more dynamic habitat and is not usually in equilibrium because of its dependence on the dynamic canopy of trees (Gilliam 2014, Brewer 1980, Gilliam 2007). As a result, the herbaceous layer tends to increase in diversity and quantity in a forest approaching climax (Davison and Forman 1982).

Research has suggested that high diversity in woody species in tropical forests is driven in part by variation in soil resources varying in response to topography and geology (Valencia et al. 2004, John et al. 2007, Pitman et al. 2008). The catena topography gradient, ranging from the high ridgetop to the low valley, often covers a wide range of soil variation over a small area. Soil minerals are essential nutrients for plants, and can be a key axis of niche partitioning, allowing the coexistence of multiple species. For example, in some temperate studies, forb species richness has been found to strongly correlate with nitrogen mineralization rate in fertile ground (Hutchinson 1999). Interactions between the abiotic environment, such as climate and topography, affect different plant growth forms, including lianas and trees, differently, so herbs require specific study (Dalling et al. 2012).

In other Amazonian tree censuses, when compared with distance-dependent relationships, habitat associations were found to be stronger: 77% of tree species in Peruvian forests exhibited a significant habitat association (Phillips et al. 2003). More importantly, it was suggested that habitat associations were made possible due to "substrate-mediated local processes", like soil content, which is consistent with the findings in the temperate zone (Gilliam 2014). However, habitat associations tend to vary locally – some habitat associations may be partially or fully caused by interactions with other species (Harms et al. 2001). Other underlying factors that differ between microhabitats in certain areas may explain the instances where species display habitat associations. The semi-deciduous forest of Barro Colorado Island (BCI) in Panama is one such site of several habitat association studies where most woody species did not seem to associate with any certain type of topography (Harms et al. 2001), although topographic variation here is much less than at other forest sites.

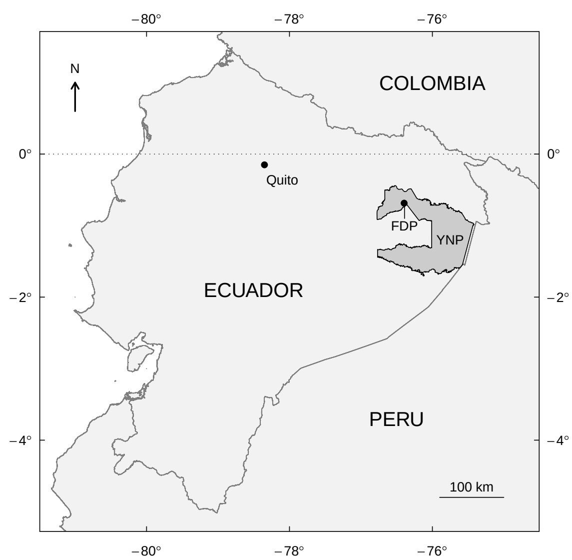

Fig. 1. Location of Yasuní National Park in Ecuador.

In the lowland rain forest of Amazonian Ecuador, habitat associations have been shown, dividing about a quarter of the tree community into species that occur predominantly on ridge-tops versus those that occur in valleys, and another quarter that occurs regularly in each (Valencia et al. 2004). Similar patterns have also been demonstrated among specific taxa, such as palms (Svenning et al. 1999) and the Myristicaceae (Queenborough et al. 2007). Dispersal limitation and other habitat- and topography-related factors also influence the distribution of species (Valencia et al. 2004, Dalling et al. 2012, Phillips et al. 2003, Moeslund et al. 2013). However, very little is known about how these factors influence the distribution and potential coexistence of herbaceous plants. In this study, I examined patterns of diversity, distribution, and abundance in *Heliconia*, a genus of easily-recognizable, large, herbaceous plants, within a large 50-ha forest dynamics plot in Yasuní National Park, a lowland aseasonal rain forest in the Amazon region of eastern Ecuador.

Questions

1. Do *Heliconia* species differ in abundance, composition and diversity according to habitat?

2. Do *Heliconia* species exhibit habitat preferences according to topography?

3. Do *Heliconia* species exhibit preferential co-occurrence?

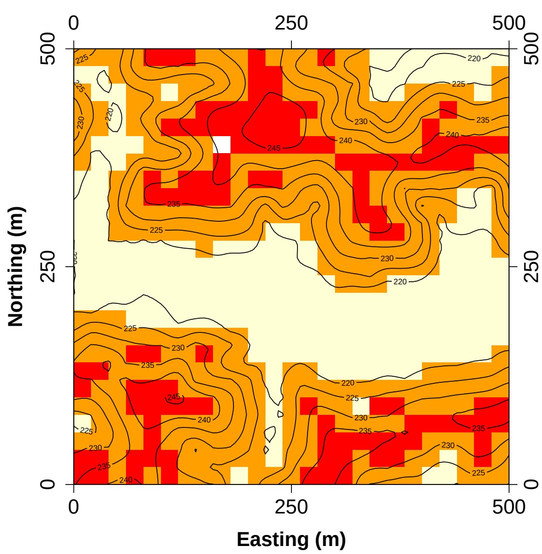

Fig. 2. Topographic map of the 25-ha plot in Yasuní National Park, showing valley (yellow), slope (orange), and ridge (red) categorized habitats. Sample quadrats were randomly selected within each habitat.

Methods

Study Site

The combined Yasuní National Park and Biosphere Reserve make up the largest protected area in the Ecuadorian Amazon at 1.6 million ha (Fig. 1). Disturbances within the forest occur from natural and anthropogenic causes, with the indigenous Waorani living in several recently-founded communities (Valencia et al. 2004).

Yasuní has an aseasonal climate, with a mean monthly temperature of 25°C and an average annual precipitation of c.3,000 mm, with lower levels of precipitation in June-August, when this study was conducted (Pérez et al. 2014, Valencia et al. 2004). This continuous evergreen lowland wet forest is recognized worldwide for having extremely high biological diversity and maintains sizable populations of vertebrate fauna (Bass et al. 2010, Valencia et al. 2004).

A 50-ha permanent Forest Dynamics Plot (FDP, 230 meters above sea level, with 33.5 m of elevation change within it) was established in the park at 0°41' S latitude, 76°24' W longitude in 1994, about a km from the research station (Valencia et al. 2004, Pérez et al. 2014, Fig. 2). Since 1995, tree censuses have been carried out roughly every five years. All trees >1 cm DBH are mapped, tagged and identified. A total of 1,104 species are so far recognized on the plot (Valencia et al. 2004).

Study Species

Heliconia L. (Heliconiaceae) is a genus of large herbs, growing up to 4 m, often with distinctive washboard-like leaves. The genus is the only genus in Heliconiaceae, with 225 species, growing primarily in the Neotropics. The inflorescences and bracts of *Heliconia* are visually striking, with an arrangement and pattern unique to each species (Fig. 3). Each ovary can produce up to three seeds, dispersed via mature purple berry (Costa et al. 2011).

Heliconia are ubiquitous in the understory of the Yasuní forest and they are sensitive to forest succession. Not only are *Heliconia* highly abundant in Yasuní's state of secondary growth, but they are also highly specific and adapted to the habitats in which they thrive (Stiles 1975).

Sampling and Data Analysis

In the plot there are two main ridges dominated in composition by red clay, centered around a valley region characterized by brown or gray alluvium soils, and a swamp containing standing water at times (Valencia et al. 2004, Fig. 2). The Yasuní 50-ha plot is subdivided into a total of 625 20x20m quadrants. Habitat type (valley, slope, or ridge) of each quadrant was assigned based on topography according to mean elevation, slope and convexity (Harms et al. 2001, Valencia et al. 2004). Using a stratified-random sampling approach, 68 of the 20x20m quadrants were randomly selected from each habitat type (total n = 203). Within each quadrant, all *Heliconia* individuals present were recorded and identified to species.

In each sample quadrant, I counted the total number of individuals of each species present, from small, single-leaved individuals of *H. stricta* to towering *H. vellerigera*. To test for differences in relative abundance of each species, I used a proportion test. To test for differences in the probability of a species present in a habitat, I used logistic regression. All analyses were carried out in R version 3.2.2 (R Core Team 2014).

Results

A total of 2,347 *Heliconia* individuals were recorded from the 203 quadrants sampled, distributed among six species (Figs. 3 and 4). All individuals were identified to species. When inflorescences were not present on the plant, leaf color and form, petiole pattern and placement on the stem were useful indicators of species.

Heliconia *communities differ in species abundance, composition, and diversity according to habitat*

In order of abundance, species documented were: *Heliconia stricta* Huber (n = 1135 plants), *Heliconia velutina* L. Andersson (n = 903), *Heliconia spathocircinata* Aristeg. (n = 239), *Heliconia ortotricha* L. Andersson (n = 36), *Heliconia vellerigera* Poepp. (n = 20) and *Heliconia schumanniana* Loes. (n = 14).

Fig. 3. *Heliconia* species found in the Yasuní forest dynamics plot, in order of abundance, from top left to bottom right: *Heliconia stricta* Huber, *Heliconia velutina* L. Andersson, *Heliconia spathocircinata* Aristeg., *Heliconia ortotricha* L. Andersson, *Heliconia vellerigera* Poepp. and *Heliconia schumanniana* Loes.

More *Heliconia* individuals were found in the valley (979, 41%) than on the slope (847, 35%) or on the ridge (571, 24%).

As well as differences in total abundance, these six species also differed in their abundance by habitat (Fig. 5). *Heliconia stricta* was the most common species in valley habitat (n = 656), with about 5–6 times more individuals than either *H. velutina* (n = 136) or *H. spathocircinata* (n = 120). *Heliconia stricta* was the most common species on the slope (n = 407) and in the valley, though many *H. velutina* (n = 292) and *H. spathocircinata* (n = 107) individuals lived on the slope as well. *Heliconia velutina* was

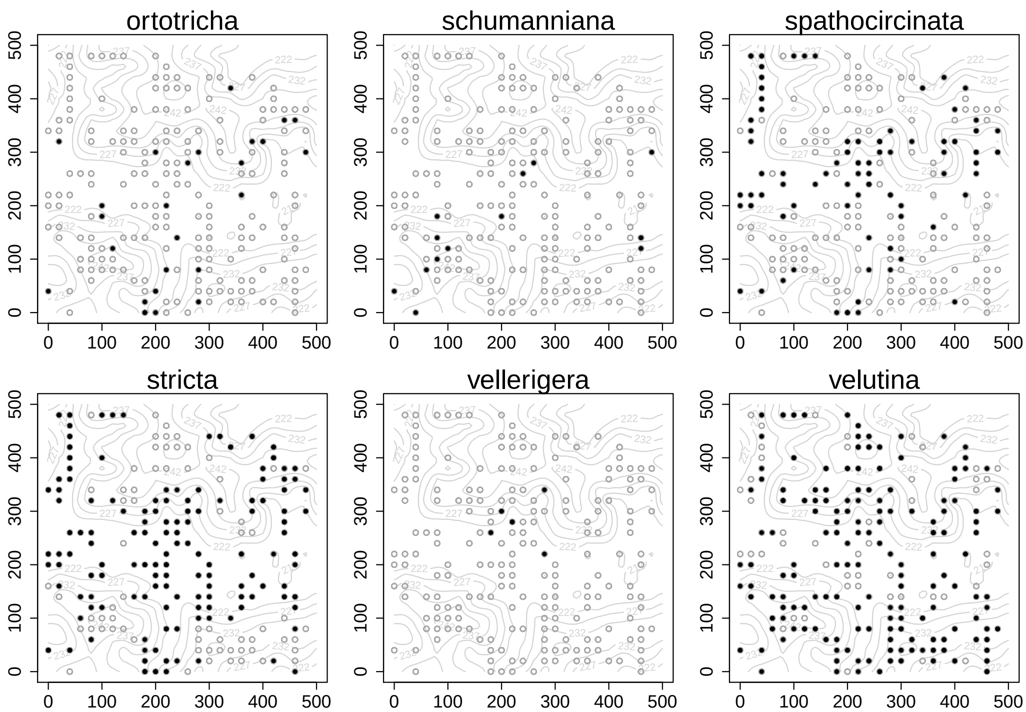

Fig. 4. Distribution of six species of *Heliconia* in the Yasuní forest plot. Circles indicate 20x20m sample quadrants; filled circles indicate the presence of that species.

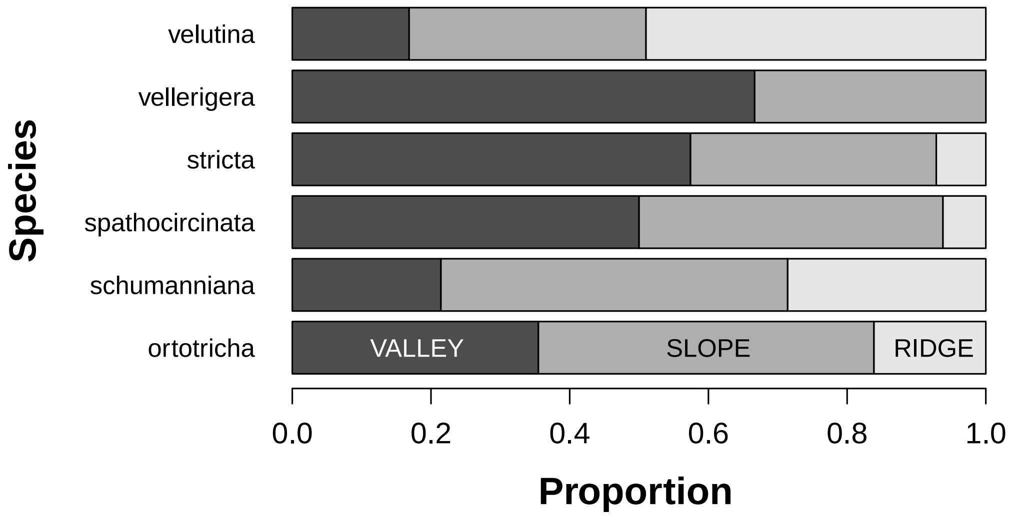

Fig. 5. *Heliconia* species proportions by habitat. Because the *Heliconia* species differ greatly in total frequency, the proportion plot offers a more direct comparison for which habitat the species exhibits a preference. Valley = dark-grey, slope = mid-grey, pale-grey = ridge. Most *Heliconia* species were found in the valley. *H. velutina* was the only species that preferred the ridge.

the species most likely to be on a ridge ($n = 475$), with 6 times more *H. velutina* individuals than the second most common species, *H. stricta* ($n = 72$). No *H. vellerigera* individuals were found on a ridge.

Most of the correlations between species presence in a particular habitat were consistent and statistically significant (logistic regression of presence as a function of habitat). *Heliconia stricta* ($t_{ridge} = 6.739$, $t_{slope} = 6.695$, $t_{valley} = 10.665$, all $p < 0.01$) and *H. spathocircinata* ($t_{ridge} = 2.660$, $t_{slope} = 3.261$, $t_{valley} = 5.643$, all $p < 0.01$) were likely to be present in slope and valley but absent in ridge quadrants. *Heliconia ortotricha* ($t_{ridge} = 1.843$, $p = 0.068$; $t_{slope} = 2.259$, $p = 0.0249$; $t_{valley} = 0.521$, $p = 0.6027$) was likely to be present in slope quadrants, but not on the ridge. *Heliconia velutina* ($t_{ridge} = 16.801$, $p < 0.01$; $t_{slope} = 0.720$, $p = 0.472$; $t_{valley} = -3.126$, $p < 0.01$) was likely to be present in ridge quadrants and absent in the valley. *Heliconia vellerigera* and *H. schumanniana* had small sample sizes.

There was a significant difference in the number of species per quadrat by habitat (generalized linear model with Poisson counts, $p < 0.01$, Fig. 6). Valley habitat averaged 2.4 ± 0.111 species present per quadrant, and slope 2.3 ± 0.128 species. Ridge habitat was less diverse, with 1.4 ± 0.112 species.

Heliconia *species exhibit habitat preference with respect to topography*

Most *Heliconia* species exhibited significant variation in their relative abundance across the three habitats, according to a proportion test of the total quantity of each species, with only *H. schumanniana* showing no significant difference from an even distribution of 1/3 of individuals in each habitat (Fig. 7 and 8) (test of equal proportions: *H. stricta* $p < 2.2e-16$, *H. velutina* $p < 2.2e-16$, *H. ortotricha* $p = 0.004631$, *H. spathocircinata* $p < 2.2e-16$, *H. vellerigera* $p = 1.995e-6$, *H. schumanniana* $p = 0.2484$).

Heliconia stricta and *H. ortotricha* were significantly more abundant in valley and slope habitats, *H. vellerigera* was significantly more abundant in valley habitat, *Heliconia velutina* was significantly more abundant in ridge habitat, and *H. schumanniana* in slope habitat.

Some Heliconia *species exhibit preferential co-occurrence*

Most of the *Heliconia* species pairings appear to be random in the Yasuní sample (Table 1). However, *H. stricta* and *H. velutina* exhibited a negative correlation, indicating that each grew in quadrants absent of other species more often than would be expected to occur randomly by chance. In contrast, *Heliconia stricta*, *H. ortotricha* and *H. spathocircinata* tended to display an opposite preference because they tended to coincide grow in quadrants where each with one other was also present more often than would be expected by chance.

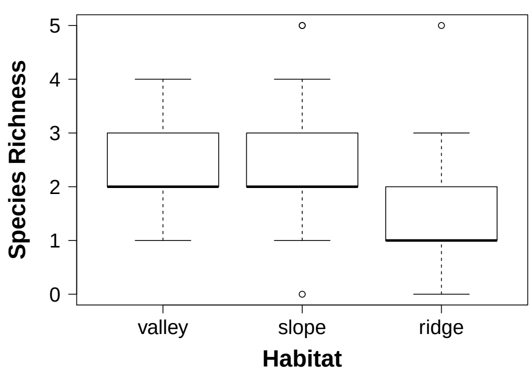

Fig. 6. Mean *Heliconia* species richness per quadrat by habitat. Ridge habitat had lower richness than valley and slope.

Table 1. Co-occurrence of *Heliconia* species in Yasuní National Park. Species pairs exhibited positive (+), negative (-), or random (o) co-occurrance patterns.

	spath.	ortho.	stric.	vel.
spathocircinata		+	+	o
ortotricha	+		+	o
stricta	+	+		-
velutina	o	o	-	

Discussion

The distributions of many woody tree species vary significantly according to topographic variation (Valencia et al. 2004). Similarly, this study found that species of *Heliconia* also had distinct distributions across the three habitats in the Yasuní plot. There are likely several drivers of this variation.

The most striking distribution was, when considering all the *Heliconia* individuals, most were found in the valley habitat (40%), with fewer on slopes (35%) and even fewer on ridges (25%). Major differences in water and light availability are easily seen between were the valley and the ridge quadrants (Tokarz 2015, personal observation), as in previous studies (Queenborough et al. 2007, Davison and Forman 1982, Harms et al. 2001). For example, the valley often contained water running through streams or standing in swampy regions, which the ridge did not have. This correlation of species distributions with resource gradients is common. Treefalls and lower canopies were more characteristic of the valley. Increasing canopy gaps is believed to increase light and moisture conditions (Davison and Forman 1982).

In temperate zones, herb diversity and distribution fluctuates with variation in resources influenced by topiography, such as soil nutrients and light availability (McEwan et al. 2011). The few studies conducted in the tropics have shown similar patterns (Tuomisto et al. 2003) The factors may overlap in influence and may not act independently. Past studies have shown that species-topography associations may be underlain by the amount of water that soil retains in each habitat type over small spatial scales such as those in the Yasuní plot (Comita and Engelbrecht 2009), as well as over much larger scales. Drought resistance has been shown to be a strong driver of the distribution

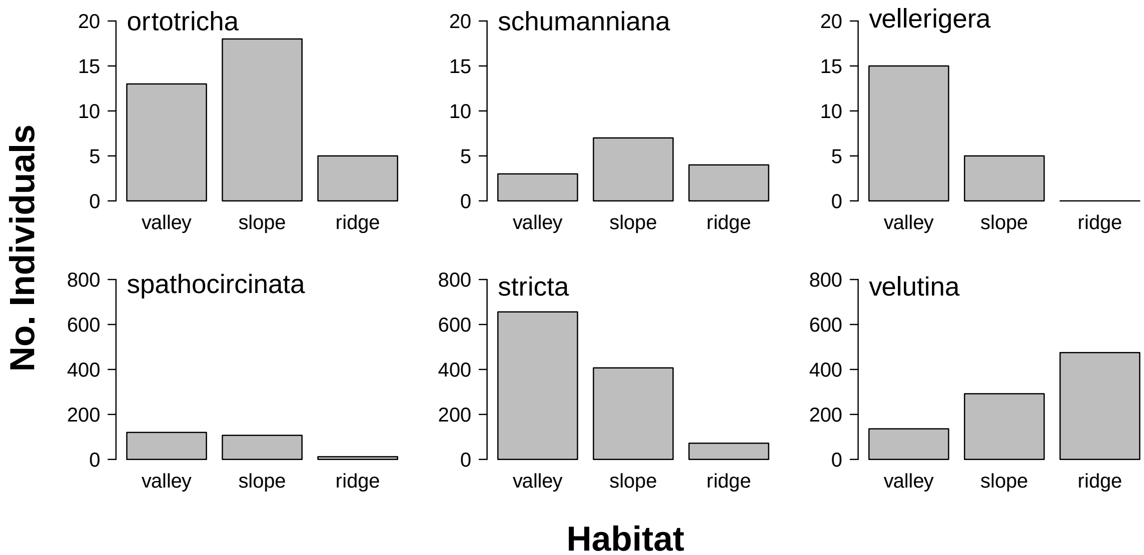

Fig. 7. Number of individuals of each *Heliconia* species found in each of three habitat types in Yasuní plot. *Heliconia stricta* tended to grow in lower elevation habitats and *H. velutina* tended to grow at higher elevation habitats.

and performance of tropical tree seedlings. Though habitat associations are greatly pronounced with the changing elevation and temperature gradient along a mountainside, differences in hydrology probably lead to the strongest habitat associations between species (Moeslund et al. 2013).

This pattern is exemplified by *Heliconia vellerigera*. Only found in only 2% of the quadrants surveyed, it displayed the strongest habitat association, with 75% of individuals in the valley, 25% on the slope, and none in ridge quadrants. Moreover, individuals in the valley were much larger (up to 4 m) than the individuals on the slope (1 m) (Tokarz 2015, personal observation), which suggests that *H. vellerigera* had access to better or more resources in the valley and that the species has a strong positive association with the valley.

Heliconia ortotricha was found in 12% of the quadrants surveyed, but was spotted frequently along the roadside en route to the plot and a large individual was situated along a trail inside the plot. If they are successful on a sunny roadside plot, *H. ortotricha* presence may be indicative of a recent disturbance and greater amounts of light. *Heliconia ortotricha* were certainly least common in the ridge, and were slightly more prevalent in slope quadrants than in valley quadrants. This may show that the slope also has greater amounts of light available than the ridge, and possibly more than the valley. *Heliconia* species, in general, tend to grow in disturbed areas, though *H. ortotricha* may be more prone than the other species in this survey. Although treefalls and natural disturbances are common and expected in a tropical forest, *Heliconia* species may play a bigger role in freshly cleared areas where plenty of light is available.

Heliconia stricta and *H. velutina* were the most abundant *Heliconia* species found in the plot. *Heliconia stricta* was found in 67% of the quadrants surveyed. Not only is *H. stricta* the most abundant species in the plot, but it far outnumbers any other species in the valley, with six times as many individuals as the second most abundant valley *Heliconia*. *Heliconia velutina* was found in 76% of the quadrants surveyed. *H. velutina* was by far the most abundant species on the ridges, with six times as many individuals as the second most abundant ridge *Heliconia*. Due to their overall greater abundance, both *H. stricta* and *H. velutina* were also the most abundant *Heliconia* on the slope, but only about 30% of the individuals of each species were on the slope for both species. 50% of each species was in the preferred habitat and about 10% of each species was in the habitat furthest removed from the one preferred. This created a distribution of about 50-35-15 for each of the most common *Heliconia* species spread across their most preferred to least preferred habitat.

Heliconia velutina was the species with the highest proportion of individuals on the ridge with about half of the individuals of *H. velutina* found in a ridge quadrant. The next highest proportion was that a quarter of *H. schumanniana* individuals were found in ridge quadrants, but the sample size of *H. schumanniana* is about a hundredth that of *H.* velutina. In short, *H. velutina* grew much better on the ridge than any other *Heliconia* and composed over 80% of all the *Heliconia* found on the ridge. *Heliconia velutina* also grew successfully in other habitats, so this does not necessarily mean that *H. velutina* is a dry habitat specialist, but it does suggest that *H. velutina* has a higher drought-tolerance than other *Heliconia* species, so they are able to dominate an otherwise *Heliconia*-poor habitat. Considering diversity, valley quadrants were the most diverse for *Heliconia* species with about 2.4 species found in each quadrant (compared to 2.3 species in slope quadrants), and ridge quadrants were the least diverse with about 1.4 *Heliconia* species found per quadrant. The observation that there is greater *Heliconia* diversity in the valley and the slope suggests that *Heliconia* species prefer valley and slope conditions to those of the ridge, in general.

While *H. stricta* often grew alongside other species in its preferred valley habitat, *H. velutina* was more often by itself in the ridge quadrants. Once again, this general absence of *Heliconia* species from ridge quadrants is also an absence of *Heliconia* competition, which allows *H. velutina* to dominate the resources.

The difference in the distributions of *H. stricta* and *H. velutina* presence are not inverse, as the distributions of individual counts are (Figs. 9 and 10). *Heliconia stricta* and *H. spathocircinata* do have similar distribution shapes, present in more quadrants in the valley than in the slope or the ridge. On the other hand, *H. velutina* is present in nearly as many slope quadrants as ridge quadrants, despite having a much higher individual count on the ridges. The number of valley quadrants in which *H. velutina* is present is also rather large, especially when we see that *H. stricta* is present in half as many quadrants of its least common habitat, the ridge. The distribution of *H.* velutina, in terms of how many quadrants of each habitat in which it is present, is the most even of the six species. Gravity may play a role. Because *H. velutina* appears to consistently find success in ridge quadrants, *H. velutina* on the ridge are likely to produce seeds in larger amounts than *H. velutina* in other habitats. Ridgetop *H. velutina* individuals do not even have to compete for pollinators with other *Heliconia* species because the ridge is a less diverse place for *Heliconia*. Seeds produced by *H. velutina* on the ridge can also roll along the topography and land in either slope or valley quadrants. Because valley quadrants are more devoid of *H. velutina* than the slopes, it seems that it is easier for seeds to reach the slope because slopes are closer to the ridgetop. Even if most of the *H. velutina* that grows in non-ridge habitats are not successful enough to sustain a new population surrounding them, the seeds from the ridge will continue to tumble and create a steady supply of *H. velutina* seeds in every habitat. On the other hand, it would be more difficult for *H. stricta* seeds to ascend to different habitats. It is not impossible, but the transport of *H. stricta* seeds up to slopes or ridges may have to be facilitated in smaller increments by an animal. This upward process is slower and less trustworthy than the forces of gravity, so it may explain why *H. stricta* and *H. spathocircinata* are not found as often on the ridge as in the valley.

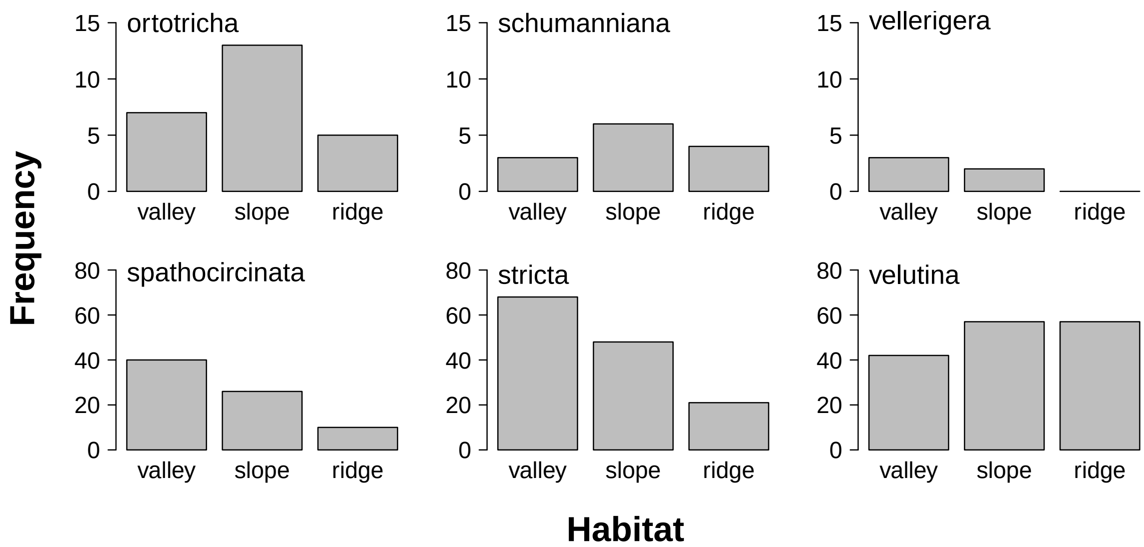

Fig. 8. Frequency of occurrance of each *Heliconia* species found in each of three habitat types in Yasuní plot. The maximum amount of quadrants a species could be found in is 68 per habitat. *Heliconia stricta* was found in almost every valley quadrant surveyed. *Heliconia vellerigera* was not found in any ridge quadrant surveyed.

Specific details about the physiological functions and traits of the *Heliconia* species in the study highlight their functional differences from trees. First, *Heliconia* are rhizomatous and clonal, meaning that one *Heliconia*'s root system can expand to support additional plant structures. This strategy gives the appearance of many *Heliconia* when all the stems actually share the same root system. Although counted *Heliconia* were counted as separate when they were more than about a meter apart from each other, the exact quantities tallied may be an overestimate of the amount of individuals.

Second, a *Heliconia*'s, inflorescence lasts for a few days before the plant is pollinated and no longer in need of attracting pollinators, but the florescence makes plant recognition and species identification easier. Without florescence, a *Heliconia* may be confused with a member of Marantaceae or simply easier to overlook. Especially with such a small team, the census is probably not an exact representation, but I confidently say that it is similar.

On a larger scale, it is uncertain how broadly these findings generalize to other herbs. Only six species of a specific genera were counted for this survey, but the herbaceous layer in species-rich forests has historically been under-sampled (Gilliam 2014). More detailed studies and complete inventories of herbaceous plants would better reveal the mechanisms that drive variation in the abundance, distribution, and diversity of this important component of forest ecosystems.

Conclusion

A census of six species of *Heliconia* revealed distinct variation in abundance and diversity by habitat. The two most abundant species, *H. stricta* was dominant in the valley and *H. velutina* was dominant on the ridge. Species diversity was greater in the valley and most species were more abundant in valley quadrats, probably due to local increased availability of light and water. The success of *H. velutina* on the ridge suggests an increased drought resistance in comparison to other *Heliconia*. These results suggest that habitat niche-partitioning is a strong driver of the coexistence of herbaceous plants in tropical forests.

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I wish to thank everyone who has helped me with this project; those who introduced me to my first *Heliconia* specimens at the Herbarium at Chicago's Field Museum of Natural History, those who scoured the forest for *Heliconia* while precariously maintaining their balance, those who offered software expertise and those who supported me financially and morally. You all have contributed immensely to this study.

Simon Queenborough is the mentor to whom I owe the greatest appreciation. Dr. Queenborough guided me throughout the process in helping develop the project, connecting me to Yasuní and revising my final drafts.

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Detection and characterization of Sri Lankan mixed dipterocarp forest structure across physiographic gradients and its effects from logging

Vinh Lang, MF 2015[*]

Abstract

The ability to document change in forest structure from remote sensing images would greatly assist in monitoring and conservation efforts. This study compared the spatial distribution of individuals across physiographic gradients in an attempt to characterize differences in stand structure resulting from past disturbance regimes, using field and remote sensing data. Past selective logging has led to major impacts on mixed dipterocarp forests of Sri Lanka, one of the most biologically diverse regions in the world. Using crown width measurements taken directly from Google Earth®, stand structure was characterized for different site types through comparison and analysis of biophysical measurements obtained from field sampling. In the study area, a high correlation was found between remote crown spread measurements and physiographic position. Additionally, remote crown spread measurements were found to correlate with field measured DBH and height measurements. It was concluded that accurate predictions among disturbed and undisturbed sites could not be obtained through crown spread measurements alone.

Introduction

Understanding the nature of forest canopy structure and its ability to recover in relation to past disturbance is a critical attribute for development and implementation of conservation strategies. In the past, a major impact on the mixed dipterocarp forest of Southeast Asia has been selective logging. A better understanding of the effects of selective logging on forest dynamics could greatly benefit efforts for future land management in planning, conservation, and restoration. Moreover, while many studies have utilized remote sensing and Geographic Information Systems (GIS) for land classification worldwide, few have focused on Sri Lanka (Rebelo et al., 2000; Dahbouh-Guebas et al., 2002; Miura, 2006; Lindström, et al., 2012; Perera, 2013), and fewer have addressed anthropogenic disturbance in Sri Lanka (Perera, 2001; Madurapperuma and Kuruppuarachchi, 2014). With increased public availability of aerial data through Google Earth and GIS, development of cheap and robust methodologies would greatly empower conservationists of the region and aid in restoration strategies.

There exist numerous examples where GIS and remote sensing have been used to build time-lapsed chronologies of disturbance regimes, including mountain bark beetle (Masek, et al., 2008), human disturbance of buffer zones (Lindstr:om, et al., 2012; Madurapperuma, 2014), clear-cut logging and wildfires in North America (Cohen et al., 2002; 2010), and landslides, volcanoes, flooding, and coastal inundation in various regions (Tralli

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et al., 2005; De LaVille et al., 2002). While many of these studies focused on effects at the landscape level, none have integrated remote sensing, GIS, and aerial photography to observe the effects of forest canopy disturbance at a local scale. This study attempted to use remote sensing, GIS, and Google Earth® for characterization of the forest canopy across physiographic gradients to reveal the effects of selective logging.

Sri Lanka is a tropical island located off the southeastern coast of India. Vegetation types differ across the country depending on climatic variability; both tropical wet forests and tropical dry forests occur on the island. The island contains several areas recognized as the most biologically diverse and important regions of the world. One of which is the Sinharaja Forest Reserve, the last extensive vestige of primary wet forest and home to over 830 endemic species (UNESCO, 2015). Changes in land use since colonial times have increasingly pressured these natural ecosystems resulting in increased conversion and degradation of native forest. Of the total 65,610 km² of land in Sri Lanka, the total forested area decreased from 23,350 km² to 19,330 km² between 1990 and 2005 (FAO, 2006).

Since 1900, the population density of Sri Lanka has increased more than five-fold from 54 persons km^{-2} to 269 persons km^{-2}, while forest cover has decreased from 4.5 million ha to 1.6 million ha (IUCN, 2010). Further, the Forestry Sector Master Plan has estimated that by 2020 closed canopy forest will decline to 17% of the country's land area down from 70% of the land area at the turn of the 20th century (IUCN, 2010). As of 2001, only 15% of the remaining mixed dipterocarp forest in the southwest of the island remains (Ashton, et al., 2001), an important forest type, which is home to the majority of endemic flora and fauna in Sri Lanka.

According to Ashton et al., (2001), disturbance regimes vary in type and severity in the mixed dipterocarp forest and result in tree species having different topographic affinities (Gunatilleke et al., 2006). Canopy crown size, degree of homogeneity and compactness can be observed to change across topographic gradients presumably in response to underlying drivers in soils, hydrology and mesoscale exposure to differences in wind, radiation and temperature (Ediriweera et al., 2008). Research is now needed to quantitatively link field measurements of crown and tree structure to changes in crown size and structure of mixed dipterocarp forest through remote sensing, GIS, or Google Earth®.

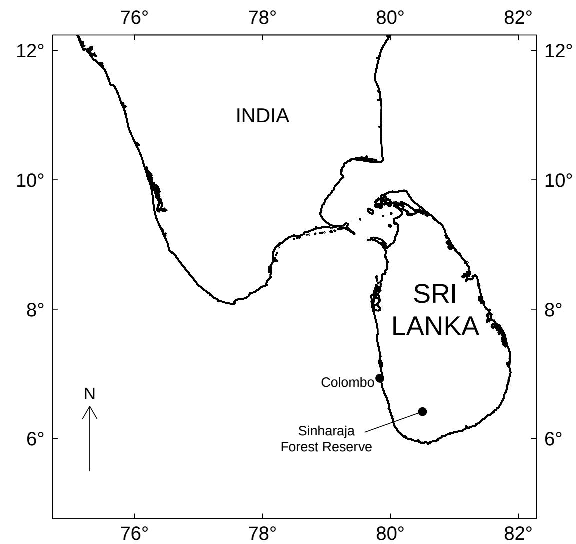

Fig. 1. Location of Sinharaja Forest Reserve within Sri Lanka.

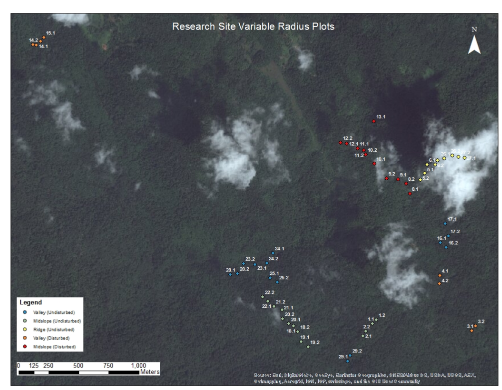

Fig. 2. Sampling locations within Sinharaja. *Note:* Projection is different to Google Earth; clouds did not hinder measurements.

Measuring forest stand structure responses to selective logging across a physiographic gradient and matching this to remotely sensed data could potentially advance our ability to interpret impacts through mapping. This study seeks to develop a localized methodology that could be used as guidance for forest planning, restoration, and conservation strategies. More specifically, this study seeks to answer the following questions:

1. Does Google Earth® provide sufficient data alone to characterize changes in forest structure across physiographic gradients?
2. Can mixed dipterocarp forests be evaluated using aerial imagery alone to characterize the effects of selective logging?

The study has widespread potential relevance to a forest type that is the richest timber type, in terms of biodiversity, within Southeast Asia and the most severely impacted from logging.

Methods

Study Site

The chosen field site for the study is located at the northwestern boundary of the Sinharaja Forest Reserve, adjacent to the small village of Pitakele, Sri Lanka (6°24'56.8", 80°25'28.3", Fig. 1). This area contains an important array of land uses including managed mixed dipterocarp forest, home gardens, tea plantations, spice cultivation, rice paddy, second-growth forest, and some of the last contiguous protected primary forest. The location is exceptional in the sense that logged forest is adjacent to unlogged forest, providing an ideal site for comparison. Logging operations were conducted in 1975 and in 1990 in two separate managed areas, both adjacent to undisturbed forest. The topography of the research site is undulating ridge-valley (600-1000 m), the monsoonal rains average 5000 mm yr^{-1}, and the mean annual temperature is 27°C (Ashton et al., 1997; Blackenburg et al., 2004). The soils are deep well-drained (valley) to thin-skeletal (ridge) podsols or ultisols of khondalitic gneiss origin, (Moorman & Panabokke, 1961; Cooray, 1967; USDA, Soil Conservation Service 1975; Ashton et al., 1997; Ediriweera et al., 2008).

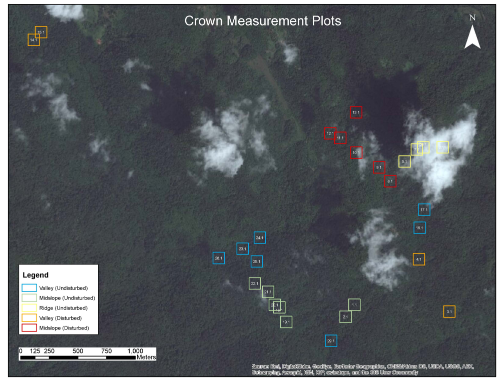

Fig. 3. Sampling locations of crown spread measurements across the research site. The center of the square plots is precisely the same as the center of the variable radius plots measured in the field.

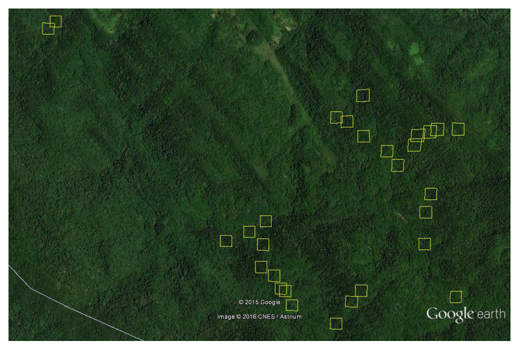

Fig. 4. Example of the actual imagery used to measure crown spread on Google Earth®. *Note:* Measurements were taken at a much finer resolution.

Sampling Design

During June and July of 2015, a forest inventory was carried out to provide ground-truthed data for comparison with data derived from Google Earth® imagery. Twenty-nine randomly selected sites (Fig. 2) were chosen along transects of different topographic positions to capture natural variation resulting from distinctive physiographic inputs. Within each site two variable radius plots

(VRP) were sampled. Sites were classified by disturbance history and elevation to capture variation resulting from inorganic disturbance, resulting in five possible categories: disturbed valley, disturbed midslope, undisturbed valley, undisturbed midslope, and undisturbed ridge. Disturbed ridge sites are unaccounted for because it is assumed there is a lack of this forest type because of operational limitations, difficult terrain, and a lack of incentive to harvest in such areas.

At each plot, a Garmin GPSMAP 64s handheld GPS unit (Garmin International Inc., 1200 E. 151st St. Olathe, KS 66062-3426) was used to record the location of the plot center. Waypoint averaging was used to more precisely record the location for use with ArcGIS and Google Earth®. From the plot center, the researchers thumb "approximately a BAF 2.296 angle gauge" was used to obtain 'in' trees to obtain an estimate of basal area; since distance to each tree was recorded from plot center, limiting distances could be computed to ensure accuracy. The bearing to each tree within the VRP with a diameter at breast height (dbh) above 30cm was recorded using a Silva® Ranger® compass, and the distance from plot center was measured using a meter tape. The crown spread of "in" trees was measured in four cardinal directions (0, 90, 180, and 270), respective of plot center, with a meter tape and clinometer to find the canopy drip line of each specimen. Heights for individuals were calculated using the clinometer where possible. Using the collected field data, basal area, crown area, and stem density could be derived for trees ≥30cm dbh.

Data Analysis

For each plot, canopy width for emergent trees was measured and averaged using a fixed area of 10,000 square meters (1 ha) with the recorded GPS plot center serving as the centroid (Fig. 3). Using this shapefile as a reference, these plots were projected in Google Earth® (Fig. 4). Within each square plot, nine subplots were divided evenly within the square and the most prevalent tree chosen as a sample totaling nine samples per plot. Each sample was measured twice at perpendicular angles capturing the longest crown spread and the longest crown cross-spread following similar procedures to the "axis method" suggested by the American Forests Tree Measuring Guidelines, (American Forests, 2016). These samples were replicated across elevation gradients as well as in forest areas that were logged (1978 and 1990) and unlogged. Finally, the measurements were averaged for comparison with ground-truthed data, and to compare measurements across topographic positions and disturbance histories.

Results

A total of 517 trees ≥30cm were recorded across 58 variable radius plots. Of the 517 trees, 508 were retained for analysis. Snags (n = 76) were retained possible explanation and correlation for potential observed gaps in aerial imagery. The number of trees per plot ranged from 5 to 15 (mean = 9, sd = 2.4). Tree DBH ranged from 30 cm (minimum size included in the plots) to 223 cm (mean = 61.6, sd = 28.7). Tree height ranged from 2 m (a snag) to 70 m (mean = 23.8, sd = 8.6). The 76 snags had a crown spread of 0. Crown spread of non-snags ranged from 1 m to 21.9 m (mean = 11.6, sd = 3.3).

The aerial imagery analysis resulted in 29 1-hectare plots. A total of 252 trees were measured for analysis of crown spread. Crown spread ranged from 7.3 m to 39.0 m (mean = 20.5, sd = 5.2).

Field data

DBH.—Within undisturbed forest, tree DBH differed significantly between physiographic positions (ANOVA, $F_{2,318} = 6.289$, $p = 0.0021$, Fig. 5 A). Trees in ridge habitat were significantly smaller than trees in valley or midslope (linear regression, $t = -2.852$, $p = 0.00463$), although habitat explained little variation in tree DBH ($R^2 = 0.038$). Within selectively harvested forest, there was no significant difference between midslope and valley habitat (ANOVA, $F_{1,179} = 0.108$, $p = 0.74$). Over all physio-

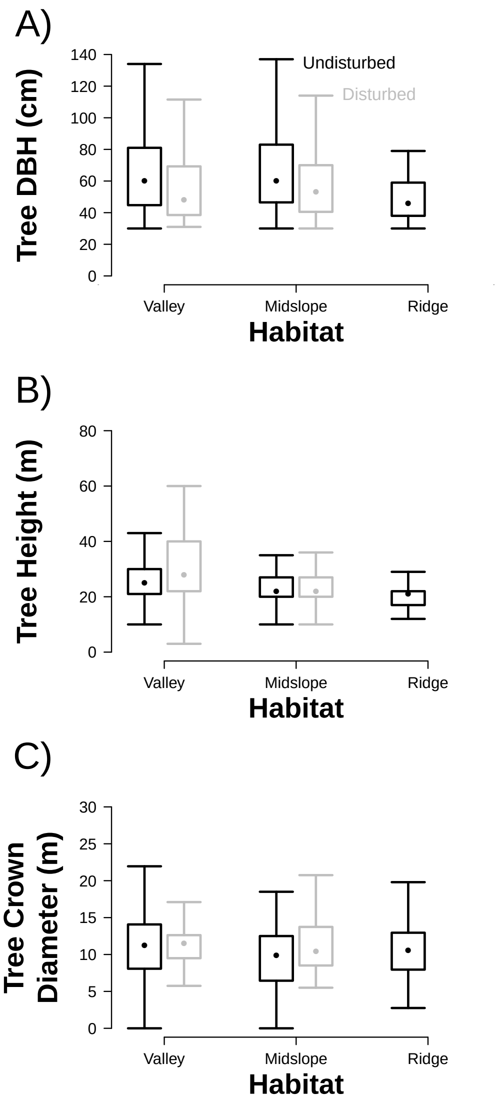

Fig. 5. Field measurements of tree structure from selectively harvested and undisturbed sites in Sinharaja Forest Reserve adjacent to Pitakele, taken from 29 sites. A) Tree diamater at breast height (DBH). B) Tree height, and C) Tree crown diameter. Black boxes indicate undisturbed sites, grey boxes indicate harvested/disturbed sites.

graphic positions, undisturbed forest trees had significantly greater DBH than selectively harvested forest, on average 10 cm greater (ANOVA, $F_{1,498}$ = 12.834, $p < 0.001$).

Height.—Within undisturbed forest, tree height differed significantly between physiographic positions (ANOVA, $F_{2,318}$= 14.1, $p < 0.0001$, Fig. 5 B). Trees in ridge habitat were significantly shorter than trees in midslope (linear regression, t = -2.862, p = 0.0045); trees in valley habitat were significantly taller than trees in midslope (linear regression, t = 2.948, p = 0.0034). Within selectively harvested forest, trees in valley were significantly taller than trees in midslope (ANOVA, $F_{1,179}$ = 33.1, $p < 0.0001$). Over all physiographic positions, trees in undisturbed forest were on average 1.8 m shorter than trees in selectively logged forest (ANOVA, $F_{1,498}$ = 5.061, p = 0.0249).

Crown spread.—Within undisturbed forest, tree height differed significantly between physiographic positions (ANOVA, $F_{2,260}$ = 3.44, $p < 0.0154$, Fig. 5 C). Trees in valley habitat (12.5 + 0.4) had significantly greater mean crown spread than trees in midslope (11.3 + 0.3) (linear regression, t = 2.438, p = 0.015). Within selectively harvested forest, there was no significant difference between midslope and valley habitat (ANOVA, $F_{1,161}$ = 0.062, p = 0.80). Over all physiographic positions, trees in undisturbed forest had on average 1 m smaller crown spread than trees in selectively logged forest (ANOVA, $F_{3,498}$ = 2.388, p = 0.0387).

GIS/Google Earth® Analysis

Within the 29 plots located on Google Earth, 504 crown measurements were made (Fig. 6). Crown spread ranged from 7.3 m to 39.0 m (mean = 20.5, sd = 5.2). Within undisturbed sites, there was a significant difference in crown spread depending on position (ANOVA, $F_{1,159}$ = 8.877, $p < 0.001$). Valley sites had the greatest crown diameter (22.2 + 4.9 m), midslope was intermediate (21.6 + 6.80 m) and ridges contained the smallest mean crown diameter (17.5 + 3.7 m). Within selectively harvested sites, there were also significant differences in crown size (ANOVA, $F_{1,88}$ = 6.491, p = 0.013). Crown spread was greatest on midslope sites (20.5 + 0.5 m). Over all physiographic positions, trees in undisturbed forest had on average 2 m smaller crown diameter than trees in selectively logged forest (ANOVA, $F_{1,498} = 4.295$, $p = 0.0387$).

Discussion

Data from the field and from remote sensing images found significant differences in tree structure and form between different physiographic habitats. Trees higher up on ridges or midslopes were shorter with smaller crowns than trees in valleys, in both undisturbed and selectively harvested forests. Trees in undisturbed forests, however, tended to be shorter, have smaller crowns, but larger trunks than trees in selectively logged forest.

Field sampling observations showed that both dbh, height, and crown spread were significant variables for characterizing forest at different topographic positions, especially in undisturbed forest. However, the differences were small (<2 m) for height and crown spread, limiting their usefulness for discerning forest history.

Comparisons of selectively harvested and undisturbed sites in terms of dbh and height showed that undisturbed sites had stronger trends than selectively harvested sites. Crown spread was sporadic in both site types. The low correlation among site and response variables is likely the result of selective harvesting. Undisturbed sites follow a more pure stratification based on resource gradients whereas selectively harvested sites are stratified according to resource gradients in addition to responses arising from disturbance regimes. These different stratification processes are discussed thoroughly by Ashton and Peters (1999).

Google Earth measurements showed high correlation of crown spread according to topographic position. These measurements followed similar trends as the response variables dbh and height for both disturbed and undisturbed sites. Selectively harvested sites and undisturbed sites could not be detected using this measurement alone.

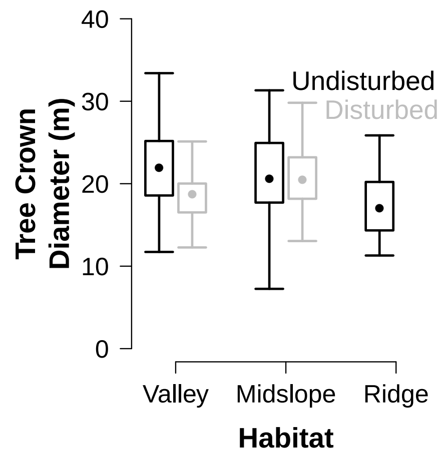

Fig. 6. Measurements of tree structure from selectively harvested and undisturbed sites in Sinharaja Forest Reserve adjacent to Pitakele, taken from Google Earth images.

Preliminary analysis of remotely sensed images using Landsat 8 found that imagery and data derived from remote sensing was difficult to obtain at the time of research and at a resolution too coarse for local characterization. Results of the analysis are in line with observations by Perera (2013) for MODIS imagery. No images were found (for the Sinharaja region) that were unobscured by atmospheric interference. Application of a tasseled-cap transformation, using coefficients by Baig et al., (2014), helped to distinguish different land classes. However pixel sizes of imagery were still too coarse to reveal the nature of tree crowns.

While accurate predictions of the complete stand structure cannot be achieved due to limitations in visibility from aerial imagery (smaller specimens are difficult to distinguish), much can be derived from the information for the assessed individuals above 30 cm dbh. Since these are often the canopy dominants, much of the basal area, density, and structure of the overall stand can be determined by these resource pools of which occupy the most biomass (Ploton et al., 2012). Much of the available resources are effectively locked up in these emergent trees, which may have implications for resource use in lower strata.

The trend of species stratification across physiographic gradients makes sense when taking into account resource gradients and individual's abilities to capture growing space following disturbance and based on their site restrictions (Ashton, 1995; Ashton et al, 1995; Gunatilleke et al, 1998; Gunatilleke et al., 2006; Poorter et al., 2006). Trees on undisturbed sites tend to decrease in size as one moves up slope. In this study, this phenomenon proved true for observed field parameters dbh and height but not average crown spread.

Interestingly, the trend of the measured crown spread as obtained from Google Earth® measurements followed the expected trends with respect to topographic position (undisturbed). However, the measured spreads were an order of magnitude greater than the field observations. This may be the result of field sampling error, or the fact that Google Earth® measurements were biased towards emergent trees. Field measuring protocol assigned measurements regardless of strata and were reliant on research technician's ability to be seen via angle gauge. The aerial reconnaissance derived from Google Earth® relied dominantly on the user's ability to discern the predominant canopy (emergent). This implies that some non-emergent 'in'trees within the variable radius plots were not detected by the satellite imagery. Additionally, the Google Earth® protocol encompassed a much greater area (1 ha) of which more emergent individuals could be included.

Since the trend of the Google Earth® measurements parallel field observations of dbh and height with respect to topographic position. Further study should investigate possible correlations among other response variables. Biomass and carbon could possibly be related to remote measurements from Google Earth® since they are often correlated to dbh and height. Depending on results, indices and further characterization could be developed which would greatly benefit forest planning and management, restoration, and conservation efforts.

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Understanding the factors of scalable success: Broader adoption of community projects in Cuba

Ruth Metzel, MF/MBA 2016[*]

Abstract

Many government and non-government organizations and institutions fund and support a wide range of conservation and development projects all over the world. Many of them fail, many succeed within their own specific goals, and some achieve widespread success and are highlighted as model projects to be replicated. However, the political, economic, and social processes, and environmental conditions that influence the broader adoption and replication of community projects are poorly understood. In this study, I examined the United Nations Development Program's Global Environmental Fund's Small Grants Program's community initiatives in Cuba to determine the key conditions that lead to broader adoption of projects and their practices through six transformational processes: Mainstreaming, sustainability, upscaling, replication, market factors, and diffusion of ideas.

I identified five key elements and preconditions that enabled broader adoption to occur. (1) Integrating diverse actors into community project planning and financing processes from the very beginning through the encouragement of co-financing, multi-scale networks, and institutional allotment of time and resources; (2) An interactive project approval process that facilitates the identification of urgent and important issues as well as formal and informal leaders. If conducted before the project is approved, this process develops the organizational and human resources that will enable broader adoption at later stages; (3) The presence of visible components, diverse benefits, and "open door" gatherings that allow for the informal diffusion of ideas at the local level; (4) Highlighting key early adopters can increase the project's chance of economic success and promote innovation to develop new value-added products, leading to increased demand for sustainable practices that incentivize wider participation from other community members and surrounding communities; and (5) Resource allocation is determined by a participatory group process, forcing project groups to address issues of equity and reciprocity within the project, instilling a sense of responsibility among direct beneficiaries.

Muchas organizaciones e instituciones gubernamentales y no-gubernamentales apoyan una gran variedad de proyectos de conservación y desarrollo alrededor del mundo. Muchos de estos proyectos fracasan, otros son exitosos dentro de sus propias metas específicas, y algunos logran un gran éxito y se enfatizan como modelos que se debe replicar a futuro. Sin embargo, muchas veces no se entiende los procesos políticos, económicos y sociales, y las condiciones ambientales que influyen en la adopción y replicación de proyectos comunitarios. En este estudio, yo

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investigué las iniciativas comunitarias del Programa de Pequeñas Donaciones del Programa de las Naciones Unidas para el Desarrollo (PNUD) y el Fondo para el Medio Ambiente Mundial (FMAM) en Cuba para determinar las condiciones claves que promueven la adopción amplia de proyectos y prácticas mediante seis procesos transformativos: la creación de normas, la sostenibilidad, la ampliación a escala, la replicación, los factores del mercado, y la difusión de ideas.

Identifiqué cinco elementos y precondiciones que promueven la adopción amplia: 1) La integración de actores diversos en los procesos de planificación y financiamiento de proyectos comunitarios desde el inicio a través de la promoción de co-financiamiento, redes multi-escala, y distribución de tiempo y recursos institucionales; 2) Un proceso interactivo de evaluación de proyectos que facilita la identificación de temas importantes y urgentes además de líderes formales e informales. Si se conduce antes del inicio del proyecto, este proceso desarrolla los recursos humanos y organizacionales que fomentarán adopción amplia en etapas futuras; 3) La presencia de componentes visibles, beneficios diversos y reuniones a "puerta abierta" que permiten la difusión informal de ideas a nivel local; 4) La identificación de actores modelos claves en etapas iniciales puede incrementar el chance de que un proyecto tenga éxito económico y promover la innovación para desarrollar nuevos productos de valor-agregado, lo cual promueve una demanda incrementada por prácticas sostenibles que incentivan participación más amplia de otros miembros de las comunidades cercanas; y 5) La distribución de recursos se determina por un proceso participativo y grupal, asegurando que grupos que implementan proyectos tratan temas de equidad y reciprocidad dentro del proyecto, y creando un sentido de responsabilidad al grupo entre beneficiarios directos.

Introduction

A shift in the focus of the international development community in the 1990s to "community-based" initiatives highlighted "model" communities deemed successful and worthy of further study (Brosius and Tsing 1996). However, the mechanisms through which successful practices are adopted more widely remains poorly understood. Many studies have analyzed how community characteristics (size, composition, norms, and resource dependence) and context (land tenure, cultural beliefs, and institutions) affect the success of individual community projects. However, less research has been conducted on how individual community projects affect their larger context to create change on a broader scale (Agrawal 1999, Brooks 2012). In this study, I address this gap by analyzing which processes and characteristics of community-based projects impact their ability to influence other communities and institutions within the context of Cuba. I seek to answer the question: *What are the political, economic, and social processes and environmental conditions that influence the broader adoption and replication of community projects?* Because of recent liberalization of exchange and diplomatic relations between Cuba and the United States, this research is a timely glimpse into the nature of community-based conservation in the country.

The United Nations Development Program (UNDP)-implemented Global Environment Facility's Small Grants Programme (UNDP/GEF-SGP) is an organization explicitly charged to "think globally, act locally" by delivering grants of up to $50,000 USD directly to local communities around the world (Huq and Faulkner 2013). Since 1992, the program has supported over 14,500 community projects in over 125 countries (UNDP/GEF-SGP 2015). However, the SGP's philosophy of disbursing small grants directly to local and indigenous communities is different from that of the other Global Environment Facility (GEF) sectors dedicated to much larger projects (GEF manages an estimated total of $15.2 billion of environmental funding). The relative impact of these two approaches is unknown, emphasizing the need to understand the linkages between different scales of development (Berkes 2006). The UNDP/GEF-SGP provides a unique case study to examine the linkages and characteristics that determine how an initial small project can ultimately create a landscape-level impact (GEF 2015).

By identifying the key elements and preconditions that enable the broader adoption of successful practices, such practices can be explicitly integrated into the design of future UNDP/GEF-SGP projects and evaluative frameworks to increase the impact and utility of these small direct grants. The six key processes within the framework used to examine the broader adoption of community initiatives are defined as follows:

1. *Mainstreaming* affects the official functioning of civil society organizations, governmental agencies and for-profit businesses, normalizing the principles of a project using advocacy, lobbying, advising, training, and knowledge creation, among others.

2. *Sustaining* maintains a functioning project over time.

3. *Up-Scaling* expands the impact of a successful activity by adapting and applying it at a larger scale (geographic, financial, operational, etc.)

4. *Replication* copies and applies a successful activity in a different location.

5. *Market change* affects the supply or demand of a product or service by expanding the number of consumers who know about it and use it.

6. *Diffusion of ideas* describes the informal communication of information about the project to a larger public, from one-on-one conversations to interactions on social media.

National Context and Policy Framework

The Cuban case has many lessons to offer up to the international sphere in terms of the institutionality of broader adoption and how an extensive state apparatus can facilitate the spread of ideas and the broader adoption of community initiatives. Within Cuba, the application of community-based approaches varies widely (Spiegel 2001). For example, although the government has long advocated the community-based approach in the area of human health, conservation and development are still heavily vertically integrated. Local communities are involved in the implementation stage, but most projects are initiated at higher levels and then communities are educated and recruited (Toledo et al. 2007). The approval of the 311 Cuban Lineamientos (Guidelines) for Economic and Social Policy in May 2011 bolstered the small farming and business sectors by allowing individuals to claim usufruct rights to small plots of land and supporting local development and small businesses (Lineamiento 259/300).

In each community where research was conducted for this study, at least 15 government entities were named as having a presence (individual or group) within the community itself, with numerous other representatives of municipal or regional institutions visiting communities on a regular basis. An estimated half of SGP projects occur within or around national protected areas. Research participants described the SGP approach as unique among other funding agencies and international programs because of its participatory process with local communities and governments, comparatively rapid results, agility in experimentation, simple methodology, transparency, voluntary Directive Committee, and accessibility to smaller countries that might have difficulties accessing larger development funds.

Project Profiles

Within Cuba, four main project case studies were selected for further research (Fig. 1). Final research field sites were determined by the SGP National Coordinator's perceptions of successful projects and community leaders' willingness to participate in the project. Other factors that contributed to field site selection were travel logistics from the capital city, operational phase of the project (last operational phase or project completion preferred), notable success or failure of the project, and maintenance of diversity in the regions and work themes represented.

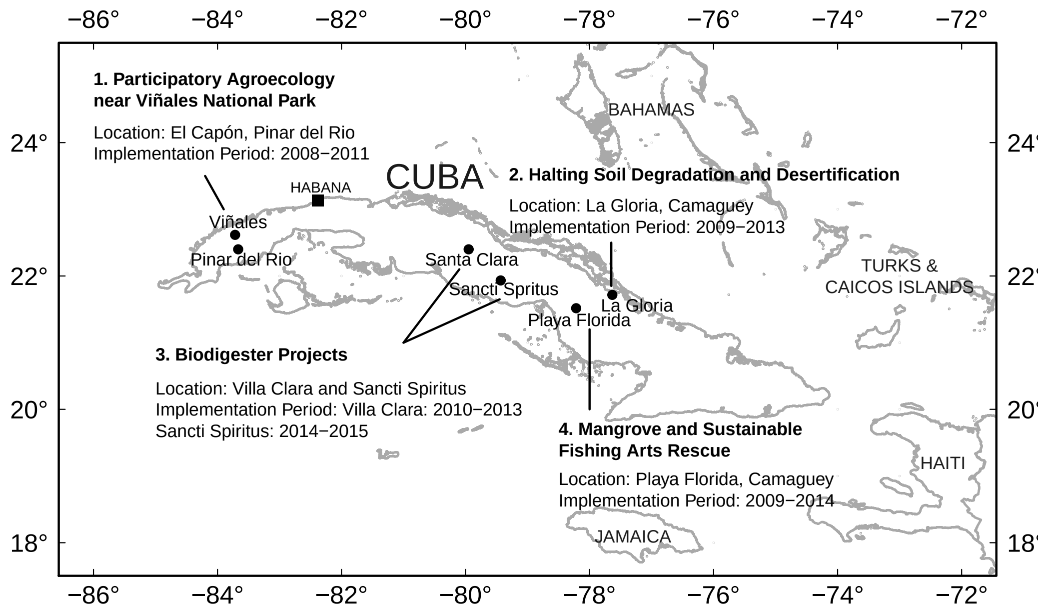

Fig. 1. Locations of research sites and projects within Cuba.

1. Participatory agroecology near Viñales National Park

SGP Project Objectives: *Improve soil quality, reforest and restore forest areas, improve quality of life through renewable energy and energy efficiency, train local actors in sustainable agricultural development*

Viñales National Park lies within the Viñales Valley World Heritage Site.[1] There has been an increasing interest in promoting sustainable livelihoods in the buffer zones around the National Park. Before the SGP project began, the park had 5 tourism hikes but only one of these involved local farmers. In 2008, the SGP began to work with communities and the Park to create seven agroecological farms, bring electricity to 45 homes, and to expand the number of tourism hikes that pass by local farms and actively involve local residents. Today, at least three of the park's ecotourism hikes pass by multiple local farms. In 2010, three of the agroecological farms in the project obtained the new official status of "eco-tourism agroecological farm" from the local government. The project has been awarded prizes at the provincial level and at the national level from the Ministry of Science, Technology and Environment (CITMA) and Ministry of Agriculture (MINAGRI). In 2015, the project participated in a South-South information exchange between farmers' organizations in Cuba, Fiji, and the Solomon Islands.

2. Halting soil degradation and desertification in La Gloria, Camaguey

SGP Project Objectives: *Improve soil quality, reforest, train community members in sustainable natural resource management*

La Gloria town is located in the Sierra de Cubitas area of northern Camagüey province. La Gloria, or "La Gloria City," emerged in 1900 as a destination for 200 U.S. men and women who bought plots of land in Cuba with the Cuba Land

[1]Viñales Valley. http://whc.unesco.org/en/list/840
[2]Grant, W. La Gloria: An American corner in Cuba. BBC News. http://www.bbc.com/news/world-latin-america-33330432

and Steamship Company of New York.[2] Initially misled by false conceptualizations of what awaited them in Cuba and disappointed by the subsequent lack of infrastructure, many of the settlers returned home shortly after arrival. The current residents of La Gloria derive their income from livestock ranching and growing citrus and fruit trees. Before the SGP project was approved in 2009, the larger UNDP-GEF Sabana-Camaguey project[3] was active in the surrounding area and many environmental problems in La Gloria were identified through the community's participation in a FAO diagnostic process but had remained unaddressed. From 2009-2013, the community conducted a SGP project to reforest 72 hectares, restore 140 hectares of degraded land, use livestock to control an invasive species, and install greenhouses. In addition to the environmental benefits, the removal of the invasive tree marabú (Dichrostachys cinerea, Fabaceae) and incorporation of sustainable land use practices has led to large increases in the productive capacity of the farms involved in the project.

3. Biodigester projects in Villa Clara and Sancti Spiritus

SGP Project Objectives: *Reduce atmospheric methane emissions through biodigesters, improve soil fertility, train beneficiaries in new technologies and sustainable natural resource management*

From 2010–2013, agricultural cooperatives from the Caibarién, Camajuaní, and Remedios communities of Villa Clara developed a cluster of nine biodigester technology transfer projects to reduce greenhouse gas emissions, installing 34 biodigesters on smallholder pig farms at a cost of $36,000. These projects produced a cohort of trained agriculturalist biogas experts and were later replicated in different regions prioritized by Cuba's Environmental Strategy, supported by the Ministries of Agriculture, Economy, and the National Commission on Renewable Energy. The second wave of biodigester installation, from 2014-2015, occurred mainly in Sancti Spiritus province, where 44 of the total 130 biodigesters were installed. A third wave of biodigester projects launched in 2015 in collaboration with government ministries and community cooperatives with the goal of installing 432 biodigesters in 5 provinces, making the Villa Clara and Sancti Spiritus projects the epicenter of a growing renewable energy movement in Cuba.

4. Conservation of mangrove and sustainable fishing arts in Playa Florida, Camaguey

SGP Project Objectives: *Recuperate mangroves, improve sustainability of fishing practices, implement a community biodiversity monitoring program, train community members in ecologically sustainable practices*

Playa Florida is one of the Cuban coastal communities most vulnerable to climate change and most isolated from its neighbors, being separated from the mainland by a large swathe of mangrove. The town is now linked to the mainland by a 4 km elevated road, the construction of which divided and caused the death of parts of the mangrove inland from the road. Of all the towns in the Southern Camagüey municipality, Playa Florida is the town that most frequently evacuates during storm events and the entire community was evacuated twice in 2008 during storms Ike and Paloma. Cuba's Environmental Agency (CITMA) predicts that the town will need to relocate further inland by the end of this century.

The largest employer in the town is the fishing Entrepreneurial Grassroots Unit (Unidad Empresarial de Base, UEB) – Playa Florida, that employs 137 of the estimated 500 community members. When the SGP project started, there were only 17 fishermen approved to sell to the UEB, giving them higher percentage of profits, greater in-

[3]Mainstreaming and Sustaining Biodiversity Conservation in three Productive Sectors of the Sabana Camaguey Ecosystem. http://www.thegef.org/gef/sites/thegef.org/files/gef_prj_docs/GEFProjectDocuments/Biodiversity/Cuba%20-%20Mainstreaming%20and%20Sustaining%20Biodiversity%20Conservation-Sabana%20Camaguey/11-11-04%203254%20Revised%20Concept%20Sabana%20Camaguey%20for%20Pipeline%2018.doc.doc

come stability, and access to resources and protection. By 2015 there were 25 approved UEB members. At the same time, the project encouraged improved environmental practices such as not cutting mangrove for firewood, using wider-holed fishing nets to reduce bycatch, respecting fishing bans, and organizing and following monthly fishing plans. The project partnered with government agencies to construct sea passes under the road, allowing salt water to flow again to the eastern inland mangrove, and more than 50 community members have since been involved in monitoring mangrove regrowth following this intervention.

Results: Evidence of broader adoption

In this section I highlight some of the key factors that influenced how the six transformational processes manifested themselves within the case study projects visited. Examples of all six transformational processes were present to different degrees among the projects.

Mainstreaming

One of the key ways that community projects were mainstreamed was through the early integration of diverse institutional actors that produced a **prolonged dedication of resources and institutional time to SGP projects and the priorities they address**. For example, in the biodigester case, residual management requirements had existed for a long time before the establishment of the SGP project, but the sector had never been enthusiastic or organized enough to reconcile policy with the implementation priorities of government agencies. Through involving diverse agencies (Ministry of Science, Technology and Environment (CITMA), the Pork Production Industry (Empresa Porcina), and the Public Works Division (Dirección de Planificación Física), among others) the SGP biodigester project helped to elevate and integrate the role of control and auditing organizations so that there was a greater general enforcement of environmental waste management standards at the provincial and national levels, including the enforcement of stricter requirements for managing of porcine waste. In large part due to this early integration of diverse institutional actors, successful SGP projects are frequently asked to appear as models on regional or national tours or displays. All case studies had been showcased by local or national actors during and after the implementation of the projects.

Community projects also commonly achieved mainstreaming through **precedent establishment**. For example, the Viñales project facilitated the creation of "eco-tourist agroecological farms" and the recognition of three new farms in the project under this classification, increasing the number of eco-tourist trails that included local farms. During and after the implementation of the SGP project, both Camajuaní and La Gloria were invited to host the annual Earth Day Celebrations in their provinces, recognizing that they obtained the best annual regional indicators out of all municipalities in their province. Since working on the SGP project, Playa Florida has been an active participant in the co-management planning process for two nearby protected areas. One participant noted that differences between the ground planning processes for the GEF "Sabana Camaguey" Project in the 1990s and the current GEF "BASAL" and OP-15 projects may reveal an influence of the Small Grants Programme approach on the planning of larger regional projects. Further, by establishing these precedents, SGP projects were able to institutionalize their mission within government institutions and organizations, thereby contributing to sustained action on the priorities of the original project.

A big driver for SGP projects to integrate diverse actors early in project planning is the fact that the SGP cannot fund international travel or certain types of infrastructure. This restriction often leads to an early broad coalition of funders to support these other activities. This restriction creates an incentive for SGP and communities to collaborate with other funders to fill these gaps. SGP's reliance on government co-funding in the construction of Playa Florida's water passes was suggested as one of the factors in changing the way the municipality does its budgeting, increasing its flexibility in funding community projects. Similarly, components of the La Gloria project that involved electricity and water provision involved extensive collaboration with government agencies to provide the infrastructure needed to implement the project.

Fig. 2. Biodigester with round excrement tank innovation.

Sustaining

Evidence of sustainability of community projects can be found in the **high comparative durability of materials given to community members in successful projects** over other alternative arrangements. For example, individual smallholder farmers in La Gloria who had been given greenhouses by their cooperatives have been more effective at maintaining them and more efficient at mounting them than large State-owned enterprises. Biodigester owners have made a series of modifications to biodigester design in order to increase effectiveness or adapt the biodigester to their farm. Adaptations to biodigester valves are one example where farmers have adapted, modified and repaired technology to make it more resilient. In one particular case, a recipient repaired a damaged biodigester and went on to become part of the biodigester training team. Another biodigester recipient modified the excrement storage container for easier processing (Fig. 2), a design that later became standardized in future biodigesters. Throughout each successive implementation stage of biodigester SGP projects, trainers have incorporated innovations in past projects as standard suggestions to farmers in the next round of implementation.

The scarcity of direct benefits combined with group decision-making for allocation of resources created a **sense of responsibility to both the group and the wider community among those who receive direct benefits** from community projects. In La Gloria and the biodigester projects, for example, cooperatives had to decide as a group which individuals would receive the direct benefit of a greenhouse or biodigester from the project. In Playa Florida, communities decided to provide tools for repairing boats instead of new boats, to allow for a more equitable distribution of benefits.

Although the economic benefit that each individual derived from these decisions were often unclear at the outset, direct beneficiaries felt responsible to others in their social group to implement and maintain the project, and if the project was successful, to share further benefits with the group and the larger community. For example, some biodigester recipients with few pigs relative to the capacity of their biodigester allowed neighbors with pigs to also use the biodigester and all shared the resulting gas benefits. Many beneficiaries train others (five out of six biodigester trainers on the current regional training team were early adopters) or go on to distribute further benefits more widely (La Gloria and Viñales agricultural producers donated produce to different community organizations). The small nature of the grants combined with the fact that they are given to a group within the community forces communities to consider innovative ways to incorporate equity and reciprocity into project budgets.

The **selection of proven informal and formal leaders** in each community also facilitated success. Successful SGP projects often take the route of supporting leaders and innovators in struggling communities, so that they, in turn, provide the social recognition and resources needed for projects to be implemented by secondary adopters on a larger scale. One of the first biodigester installation pioneers in Villa Clara was the retired Director of the regional Forest Agency (Empresa Forestal). In La Gloria, the first person to implement management of the invasive marabú tree with goats was one of the cooperative's leading producers, who then went on to involve several of his neighbors in the project. To a certain extent, this producer leveraged his participation in the SGP project as a guarantee to acquire the credit needed to implement and expand upon the initial project. Two of the members of the Playa Florida project board were key people in organizing their community in their comparatively frequent storm evacuations to the mainland. In seeking biodigester early adopters, SGP's collaborating organization, National Association of Small Producers (Asociación Nacional de Agricultores Pequeños, ANAP), sought out leaders in Farmer-to-Farmer (Campesino a Campesino) training practices developed through involvement on past international projects. In a similar way, the positionality of the Cooperative or Association that implements a project is important. The cooperatives that pioneered the tubular biodigester technologies were some of the largest and most productive cooperatives at the regional and national level. Thus, the selection of "winners" or community leaders and groups, be they informal or formal, is critical to broader adoption.

When compared to other funding agencies, SGP's interactive application process allows them to uniquely seek out informal leaders as well as formal ones. For example, one of the key members of Playa Florida's project board was the person who mobilizes the community on her block to come to local meetings, and has since been given a formal position on the SGP project board. In La Gloria, another strong informal leader has since become the accountant and turbine-supervisor for the group. All groups included individuals who were innovating not just within the context of SGP projects but also in other dimensions (art, historical preservation, literature, gender relations, technological innovation, and business entrepreneurship are a few examples). Through the SGP project implementation process, some of these informal leaders were recognized and given formal leadership roles like those above, but many of them also bring their prestige and knowledge from past experiences to enhance the implementation of the SGP project.

Up-Scaling

Cuba's rigorous national SGP approval process ensures a **close alignment of project themes with national priorities**. This nation-wide organization of international and civil society funding facilitates the expansion of accomplishments and goals by other actors or programs. In Viñales, the SGP sought alliances with other programs that were able to double the number of rural homes electrified. The biodigester movement provided an implementation mechanism for an existing regional priority that had long gone unaddressed. Biodigester projects also aligned closely with the priorities of the collaborating implementing organization, ANAP, that organizes the "Movimiento por las 100 Toneladas" (Movement for 100 Tons), an agricultural initiative to increase national production capacity. In order to increase productivity while maintaining its focus on sustainability in farming, ANAP sought ways to better manage waste from its farms.

In the successful scaling-up of SGP projects, community members embark upon **extensive multi-scale network formation through a required budget allotment and the initiative of SGP staff and collaborating institutions**. This network formation is closely linked to the institutional communication mentioned below that allows for the diffusion of ideas. SGP staff and collaborating institutions play a key role in connecting community groups to each other and to other larger funding institutions that implement the project more broadly. One agroecological farm and restaurant in Viñales has hosted ambassadors, the Minister of Tourism, and a donor for the World Food Program, among others.

Approval of a second project with increased non-SGP co-financing often occurs in successful cases. After the implementation of the SGP project in Playa Florida, a project by S.O.S. Pesca was able to provide continuity with the original project goals by greatly increasing funding, providing around six times the original SGP amount. Many of the same project board members who served on SGP's board now serve on the board of the S.O.S. Pesca project, and research participants observed that many of the organizational processes developed through working on the SGP project provided the foundations for the S.O.S. Pesca collaboration.

Replication

The **interactive SGP project approval process facilitates the identification of urgent and important community issues**. The paper application is merely a representation of a larger process in which the SGP national coordinator visits the communities to talk with community leaders and understand the situation on the ground. In this way, there is a significant amount of project development and organizational mentoring that occurs before the project is ever approved. SGP's success in La Gloria is due in part to the fact that the project was initiated in one of the town's most critical periods of drought (urgent) and could identify the strategies forward to combat long-term degradation (important).

Because SGP projects often demonstrate that it is possible to address these urgent and important issues, formal and informal replications of SGP concepts are common. For example, in La Gloria, greenhouse technicians and owners often give informal lessons to fellow community members on responsible farming practices. Many producers are now demanding biodigesters to comply with increasing enforcement of environmental legislation. The interactive SGP process allows identification of key priorities, and key risks, of projects on the ground with communities and collaborators.

Distribution of projects within organizational governance regions allows information sharing between similar communities and allows officials whose jurisdiction spans those governance zones to easily apply successful models to nearby communities. Thus you see the proliferation of other SGP projects on similar themes in multiple communities within the same governance region. For example, leaders of Cooperatives with biodigesters reported their success to other leaders in provincial meetings of Cooperative presidents, who then sought biodigesters of their own. Since 2010, the number of biodigesters in Cuba has expanded from 40 biodigesters to the recent approval of a project to install 432 biodigesters in multiple provinces in 2015. Similarly, in Playa Florida, the town delegate and President of the SGP project board, regularly mentions the success of the project at meetings throughout the town and at the municipal assembly. In this way, neighboring fishing communities have also become interested in implementing Playa Florida's improved fishing practices.

Market Change

Economic success inspires interest among secondary adopters. Interviewed project participants frequently quoted the saying that la vista hace fe (seeing is believing), and that at the beginning, fellow community members thought that they were wasting their time participating in the project. It was only once the economic benefit of the new practice was demonstrated that other community members became interested. For example, cooperative leaders in Villa Clara describe how initially it was very difficult to find takers for the initial 34 biodigesters, and now they estimate they have a waiting list of over 1000 interested farmers in the province. In Viñales, there has been a proliferation of unofficial "agroecological" farms that may not adhere to environmental standards but nonetheless represent a clear indication of interest in the economic opportunities offered by the newly approved agroecological tourism farm modality.

Community projects create a **further demand for labor and products through the creation of community mini-industries**. Examples include La Gloria's fruit processing mini-industry that in the future could demand increased planting of fruit trees from other producers in the region, and the El Paraíso agroecological restaurant in Viñales that since 2011 has grown from 1 to 10 employees and now serves 250-300 tourists daily. This community restaurant also sources organic, agroecological produce from neighboring farms. Creating added value products at the community level promotes further demand for products and services that allows other community members to benefit. This phenomenon depends heavily on the success of first adopters, so the **strategy of choosing proven leaders within communities** to implement models of success further contributes to this process.

Another way that community projects can increase broader adoption through markets is through the **education of consumers and industry through the product itself**. Particularly in Cuba, technology transfer through importation of key technological advances facilitates information exchange. For example, when Viñales' agroecological farms take tourists around to see sustainable agricultural practices or serve restaurant guests their products, they are directly educating them through their products. In La Gloria, SGP provided the fruit-processing mini-industry with state-of-the-art machinery, a huge incentive for government and other institutions to collaborate in order to gain exposure to and information on these technological innovations. Thus, innovations in the production process facilitate information spread. The biodigester projects have developed familiarity with the tubular biodigester technology such that national agencies are working with SGP to develop a mini-industry to produce tubular biodigesters in-country to meet demand. Thus, an innovative product can itself create opportunity for broader adoption through market factors.

Diffusion of Ideas

Much of the diffusion of ideas happens through **institutional communication**, i.e., formal meetings or informal exchanges between work colleagues. Cuba's case is particularly illustrative of how institutional communication can lead to broader adoption of community projects because of its high degree of institutionalization and the powerful role of government down to the community level. Involving a diverse collection of institutions in SGP projects allows communities access to the network of government institutions, academia, and international agencies. When community actors meet the local technician or project official in an early field visit, this interaction can lead to further phone calls and requests for support. Participants from collaborating organizations are key actors in organizing formal exchanges between groups and information sharing within their jurisdictions. Frequent visits by institutional representatives or international visitors can create an accountability that, in turn, contributes to the sustainability of the SGP project.

The **presence of the project in the media** is critical for massive informal diffusion of ideas. Cuba is unique in this respect, in that because it has limited internet accessibility (as of 2015) and only six centralized TV stations, any material shown on national TV has a wide viewership. SGP projects have been featured in full-length documentaries, music videos, and promotional tourism videos. Academic theses were written about two of the SGP projects

Fig. 3. The visible changes associated with SGP Projects create fodder for informal discussions on community environmental issues and a hook for others to get engaged. In this picture you can see the difference between a field in an SGP project and the invasive marabú species in the background.

visited, allowing for project integration into the academic communications space. Further, social media discussion, news articles and features in multiple languages, and online agroecological restaurant ratings are all examples of diffusion practices that reach larger international audiences.

Informal conversations are some of the most difficult elements of the diffusion of ideas to document, but have perhaps the greatest impact on the broader adoption of the project locally. In Playa Florida, the use of new fishing equipment led to conversations with other fishermen at sea. Members of agricultural cooperatives in La Gloria and Viñales frequently exchanged seeds and planting tips. After official initial visits and exchanges, SGP projects often continue communication with each other. Further, cultural events are often the most common places for informal conversations to occur. For example, after a formal exchange supported by the national SGP office and the provincial CITMA office, Playa Florida and La Gloria organized a sporting competition between the two communities, providing a further space for communication on project practices.

The **presence of a visible component in the original model project** facilitates informal conversation. In Playa Florida, roadside mangrove recuperation and the associated return of wildlife occurred on the popular beach route that is the only entry and exit to the town, drawing comments and photographs from passersby. In La Gloria, the noticeable absence of marabú, the aggressive invasive tree species, provoked comments from other community members (Fig. 3). Greenhouses and biodigesters are two other visible components in the projects studied that serve as conversation starters.

SGP's strategy of model establishment combined with a **policy of "open door" training sessions** facilitates informal idea spread within communities. In Viñales, the SGP project fed into the National Park's larger processes of environmental education, allowing a greater number of communities to become exposed to the project and benefit indirectly from the seven agroecological farms established.

The different levels and ways for community members to benefit directly and indirectly contributed to the informal diffusion of ideas. In particular, the **presence of diverse benefits** facilitated collaboration by a broad coalition of stakeholders. In La Gloria, some community members received connections to the water supply while others received greenhouses. This diversity of benefits allowed the project to draw in community members interested in water and in agriculture, as well as the government agencies that would need to collaborate on installation and technical assistance. In projects, like Playa Florida, where one component of the project is very conservation-focused or has intangible, long-term benefits (like mangrove conservation), tangible individual benefits like fishing supplies provided the “hook” that allows the space for the larger long-term environmental conversation.

Conclusions and Insights

Each of the four case studies mentioned occupies a unique national significance in Cuba that allowed it to expand its priorities to achieve broader adoption beyond its individual site. La Gloria developed successful strategies for combating an invasive species of agricultural land at the same time as the Cuban government emphasized a national priority to increase food production. Playa Florida is acutely vulnerable to climate change and so provides a model for how to increase resilience to rising sea levels. In Viñales, a new approach to sustainable tourism was developed that also integrated community and government priorities in one of Cuba’s most cherished UNESCO World Heritage sites. Lastly, the experimental biodigester program has now developed into a nationwide movement, with nine of Cuba’s provinces enforcing legislation on environmental pollution standards and gaining the support of the Ministry of the Environment and the Ministry of Economy and Finances.

The following insights emerge as key points to consider from our research for those hoping to encourage broader adoption of community projects:

1. Integration of diverse actors into community project planning and financing processes from the very beginning of a project facilitates the mainstreaming, sustaining and upscaling of project priorities through encouraging co-financing, multi-scale networks, and institutional allotment of time and resources to the project.

2. An interactive project approval process uniquely facilitates the identification of urgent and important issues and informal and formal leaders. This project development process, which is conducted before the project is approved, develops the organizational processes and human resources that will enable broader adoption at later stages.

3. The presence of visible components, diverse benefits and “open door” gatherings allows for the informal diffusion of ideas at the local level.

4. Choosing key early adopters can ensure project economic success and innovation to develop new value-added products, which can then increase demand for sustainable practices that incentivize wider participation from other community members and surrounding communities.

5. When resource allocation is determined by a participatory group process, project groups are forced to address issues of equity and reciprocity, and so the limited nature of SGP funding instills a sense of responsibility among direct beneficiaries.

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Please note that all translations in this document, unless otherwise noted, are unofficial translations by the author. Appendix 1 contains unofficial English translations of organization names and acronyms in Spanish. All images, unless otherwise cited, were taken by the author in the course of performing field research.

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The potential of deforestation-free agreements to decrease deforestation and promote sustainable supply chains: The case of the Soy Moratorium in Brazil

*Mariana Vedoveto, MEM 2016**

Abstract

Deforestation trends in the Brazilian Amazon have been increasingly linked to globalized markets for beef, timber, soybean, and other commodities. In recent years there has been a remarkable proliferation of deforestation-free agreements to pressure corporations to adopt more environmentally responsible practices around the world. The Brazilian Soy Moratorium (SoyM), the first voluntary deforestation-free agreement carried out in the tropics, was implemented in 2006 and pressed major soybean traders to stop purchasing soy grown on deforested lands in the Amazon.

To better understand the uptake process of the SoyM, this research: i) explored the ways in which diverse forces (markets, international rules and norms, and direct access to domestic policies) influenced the agreement; ii) analyzed key concomitant events that took place throughout the agreement's implementation; and iii) developed recommendations to enforce deforestation-free agreements. Studies show that eight years after the establishment of the SoyM, soy expansion realized through deforestation in the Amazon has decreased considerably, yet the overall soy production continued to grow. Enforcement of laws, restrictions on access to credit, and expansion of protected areas appear to have contributed to this decline, as did a decline in the demand for new deforestation. This case study provides valuable lessons on the importance of a package of measures (public policies, monitoring systems, supply chain interventions) to slow the advance of a complex agricultural frontier.

Introduction

Deforestation trends in the Brazilian Amazon have been increasingly linked to globalized markets for beef, timber, soybean, biofuels, and other commodities (May et al. 2011). In early 2016, the pace of deforestation in the region almost doubled from rates of 2015 (IMAZON 2016), transforming native forests into agricultural and pasture lands (May et al. 2011), especially in Pará, Amazonas, Mato Grosso, and Rondônia States (IMAZON 2016). This conversion of forest areas has contributed approximately half of the country's total net CO_2 emissions (MCT 2010). Furthermore, deforestation results in severe social and environmental problems, such as the disruption of indigenous people's livelihoods, loss of biodiversity, and shifts in the precipitation regime.

The expansion of large-scale cattle ranching and agriculture at the forest frontier has become one of the major drivers of forest loss (Brown et al. 2005). Improvements in cultivation and productivity of adapted crop varieties have made Brazil a lead-

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ing producer of grains such as soy, and the agribusiness sector accounts for more than one third of Brazil's GDP (Carvalho 1999). Between 2001 and 2006, for example, soybean fields expanded by one million hectares in the Amazon biome.

The agricultural frontiers along the Brazilian Amazon have long been the world's most active hot spots for forest loss (FAO 2006; Santilli et al. 2005) and greenhouse gas (GHG) emissions (MCT 2010). Continued expansion of cropland production in the Amazon is likely for three reasons: i) extensive areas of the Amazon basin are thought to have suitable soils, climate, and topography for large-scale mechanized agriculture (Jasinski et al. 2005); ii) recent and planned development of critical infrastructure, such as roadways and ports, is intended to support farming operations by reducing the cost of transportation, and iii) there is a growing global market demand for agricultural commodities and high potential return on investment (Morton et al. 2006).

Deforestation-free agreements and the case of the Soy Moratorium

In recent years, non-governmental organizations (NGOs) have succeeded in pressuring corporations to adopt more environmentally responsible practices around the world. While critics of environmental campaigns claim that results are often ephemeral (Urs & Auld 2015), advocates emphasize the potential of market campaigns to influence corporate decision-making (Doh & Guay 2006), achieve positive environmental and social change in the absence of legislation (WWF 2008), or even inspire law enforcement and the creation of stricter environmental regulations.

In fact, in recent years there has been a remarkable proliferation of deforestation-free agreements[1] (alternatively, "no deforestation" or "zero-deforestation") among governments, the private sector, and NGOs, although the concept is still ambiguous. Deforestation-free or zero-gross-deforestation aims to end deforestation from supply chains and investments. The World Wildlife Fund (WWF) defines zero-deforestation as the elimination of deforestation from the production of timber and agricultural commodities, maintenance and enhancement of high conservation value (HCV) and high carbon stocks (HCS) areas, protection of peat lands, and prevention of primary forest from clearance (WWF 2008). Deforestation-free commitments do not consider offsetting gains in forest cover (TFD 2014). Nonetheless, zero-net-deforestation (ZND)[2] acknowledges that some forest loss could be offset by forest restoration, which is likely to collide with the ultimate goal of protecting biodiversity.

In 2010, the board of the Consumer Goods Forum (CGF)—a key international network of industry members including retailers, manufacturers, service providers, and associations—pledged to achieve ZND by 2020 through responsibly sourcing major agricultural commodities, including beef, soy, and timber (WEF 2012). To uphold this commitment, CGF joined with national governments, civil society groups, and other industry members to create the Tropical Forest Alliance (TFA), a public-private partnership that aims to address deforestation related to the sourcing of soy and other key commodities (TFA 2015). Individual companies, such as Mars, Marks and Spencer, Unilever, and Cargill, have made similar commitments.[3] Another important initiative is the New York Declaration on Forests, a non-binding international political declaration among governments, companies, and civil society to halve natural forest loss by 2020 and end it entirely by 2030 (United Nations Climate Summit 2014).

In Brazil, the private sector and NGOs are the predominant actors engaged with deforestation-

[1]This paper does not intend to present a comprehensive list of agreements. Some examples are mentioned to illustrate the different types of agreements and main actors involved.

[2]WWF calls for pledges of ZND by 2020.

[3]Personal communication with representative of the Rainforest Alliance, November 15th 2015.

free agreements; only a few subnational governments have signed these agreements, and the federal government's involvement has been relatively low. For example, the CGF pledge includes brands, traders, and retailers—such as Walmart, Cargill, and Carrefour—that commercialize commodities (beef, soy, and palm oil) produced in the Amazon region. In the case of the NY Declaration on Forests, Brazil did not sign the declaration as a country, but some subnational governments (e.g., the states of Acre, Amazonas, and Amapá), and national NGOs (e.g., IDESAM, IMAFLORA, and IPAM) are signatories to the pledge (United Nations Climate Summit 2014). The TFA 2020 includes two Brazilian NGOs (IMAFLORA and Amigos da Terra-Amazonia Brasileira), several international NGOs that develop projects in the Amazon region (The Nature Conservancy, World Wildlife Fund, Rainforest Alliance, Conservation International, etc.), and all of the CGF members (TFA 2015). Despite buy-in from NGOs and the private sector, commitments have been signed so rapidly that there has been little opportunity to reflect on the concepts, mechanisms, and targets of the commitments themselves (TFD 2014). Furthermore, these initiatives are voluntary and do not establish any binding targets or obligations of conduct.

The Brazilian Soy Moratorium (SoyM), the first voluntary deforestation-free agreement carried out in the tropics, was implemented in 2006 and pressed major soybean traders to cease purchasing soy grown on deforested lands in the Amazon. This historic agreement, initially between the Brazilian Vegetable Oil Industry Association (ABIOVE) and several national and international environmental NGOs, occurred as a response to increased pressures from retailers and NGOs driven by environmental stewardship. Gibbs et al. (2015) affirm that the SoyM agreement led to huge changes on the ground and dramatically decreased deforestation caused by soy crops. However, the long-term effectiveness of the SoyM is still unclear, as are its effects on the private sector practice, public policies, and deforestation leakage.

This research aimed to better understand the uptake process of the SoyM and the ways in which diverse forces (markets, international rules and norms, and direct access to domestic policies) influenced the agreement's implementation and results. Specifically, the research aimed to understand the role of the SoyM in reducing deforestation by exploring the following areas:

First, this work required a better understanding of the SoyM agreement, the stakeholders involved in the uptake of the SoyM, and their specific roles and motivations to adhere to the agreement. Questions explored in this phase include: what kind of causal pathways has the SoyM travelled through? What were the national and international forces that contributed to the SoyM implementation? To answer these questions, the pathways framework was used to identify the channels through which the SoyM may have influenced deforestation rates, domestic environmental regulation, and corporate responsibility in the soybean supply chain.

Second, concomitant and key events that occurred throughout the agreement's implementation were analyzed, as were the ways in which they have affected the SoyM performance. That is, what were the external constraints and drivers that impacted the SoyM? What interactions with market trends, environmental policies, and corporate citizenship have affected the SoyM implementation and outcomes?

Finally, the results and durability of the SoyM were explored, as was the potential for replication. Impacts of SoyM on deforestation rates and corporate sustainability were examined. Questions of best mechanisms available to enforce the agreement, maintain results, and ensure durability were also considered.

Methods

Fieldwork was conducted in the States of São Paulo, Pará (in Belém and Paragominas municipalities), Mato Grosso, and Brasília. Preliminary research to identify important interviewees was carried out to describe the story and impacts of the SoyM from different perspectives since its early beginnings in the 2000's.

Interviewees included corporate responsibility and sustainability directors of soy trading companies, federal and state associations of soy producers, the Brazilian Vegetable Oil Industry Association (ABIOVE), environmental NGOs and consultants, academic researchers and professors, representatives of the Ministry of the Environment, representatives of federal and state environmental agencies, and the Soy Working Group (GTS), among other important stakeholders. Data from secondary sources, such as scientific articles, reports, and news based on interviewees' recommendations, were also collected.

Understanding the Soy Moratorium

In 2004, Greenpeace began to investigate the soy industry and identified three giant soy traders (ADM, Bunge, and Cargill) engaged in the deforestation of the Brazilian Amazon rainforest. Soy plantations in the region expanded by approximately 1.2 million hectares that year. Meanwhile ADM, Bunge, and Cargill were deemed responsible for 60% of the total financing of soy production in Brazil. Together they controlled more than 75% of the soy crushing capacity in Europe, which supplied soy meal and oil to the animal feed market. At the same time, Cargill had buildt an illegal port facility in the state of Para. Environmentalists became concerned that this would enable easier exporting of soy, thereby feeding external soy demand, which could ultimately result in a surge in deforestation rates. (Greenpeace 2005). With the world's attention on this port facility, Cargill partnered with several environmental NGOs, including TNC, to ensure that the soy purchased by the corporation was sustainably grown by local farmers and respected local rights (Garrett 2011).

In response to the increasing deforestation rates, Greenpeace launched an international campaign, "Eating up the Amazon", that targeted the companies linked to soybean production in the region. The incisive campaign alerted European consumers of the links between the soy products they were purchasing and deforestation in the Brazilian Amazon (Greenpeace 2005). The campaign was very pertinent because there were no monitoring tools to investigate land use at the time; therefore there was very little information about land occupation and the drivers of deforestation at that moment. Greenpeace understood that, as major soy consumers, restaurant chains acting in Europe would have an important impact on the supply chain. As a result of the campaign, McDonald's was moved to pressure its entire soy supply chain, reaching even the biggest soy traders in Brazil including Cargill, ADM, and Bunge (Greenpeace 2005). Soy traders were targeted because of their broader influence on the upstream practices of the soybean supply chain.[4] Financiers were also pushed to divest from deforestation-related activities (Dieterich & Graeme 2015).

Finally, in July 2006, ABIOVE and ANEC (National Association of Cereals Exporters), together with their respective affiliates[5] and civil society,[6] announced a two-year commitment, the SoyM, to exclude from their supply chains soy produced in newly deforested areas as well as farmers using forced laborers in the Amazon. The agreement had been renewed on an annual basis since then, but was indefinitely renewed in 2016 (Estrada 2016a). The members created a multidisciplinary Working Group (GTS) to ensure the implementation of the SoyM. The GTS generally meets bimonthly and decides strategies, makes decisions, defines work plans, and coordinates sub-groups. There are three active sub-groups in the GTS: i) Mapping and Monitoring, which identifies deforestation since

[4] Personal communication with representative of Greenpeace, May 21st 2015.

[5] Amaggi Group, ADM, Baldo, Brejeiro, Bunge, Cargill, IMCOPA, Louis Dreyfus, Oleos Menu, and ABC Inco.

[6] Coordination Soy-Brazil, Conservation International, Greenpeace, IPAM, The Nature Conservancy, WWF Brazil, Imaflora, and Friends of the Earth – Brazilian Amazon.

the agreement's signature and tracks advances in soy planting (the SoyM monitors 76 municipalities that are responsible for almost all the soy produced in the Amazon) (Greenpeace 2016); ii) Environmental Rural Registry (CAR), which aims to accelerate the completion of the CAR among the soy producers and develop strategies to spread environmental law compliance; and iii) Best Practices, which enhances and promotes sustainable agricultural practices in the sector (ABIOVE 2008).

Despite this rich history of environmental activism and stakeholder engagement, there have been few attempts to understand how corporate commitments to improving social and environmental practices are put into practice (Estrada 2016a). The pathways framework (Bernstein and Cashore 2012) is used to analyze how each pathway has potentially influenced the adoption of the SoyM and promoted environmental stewardship in the Brazilian Amazon. The approach identifies four main pathways that may result in internationalization, that is the process by which domestic policies are influenced by international processes and actors: 1) market access, 2) international norms and discourse, 3) direct access to domestic policy-making processes, and 4) international rules.

In the case of the SoyM, some pathways are more promising than others as a means to affect change. Domestic policies influenced by internationalization may be more or less durable depending on the interactions amongst pathways, the effect on national sovereignty, and the influence of global markets. Usually, a policy that travels multiple pathways is more durable than policies that navigate one single pathway.

Market access pathway

This pathway is pursued via boycott campaigns or the adoption of market mechanisms, such as certification systems and green labels that attempt to regulate markets and influence behavior through firm recognition and price premiums. In the case of the former, NGOs or other actors can influence a government or companies to change their policies or behaviors through "naming and shaming" campaigns. Policies that result from this approach are likely to be durable if markets are reinforcing existing domestic rules and depend on exports.

Market pathways are the most common routes in the promotion of zero-deforestation agreements and commonly involve boycotting targeted companies (Bueno & Cashore 2013) that cause deforestation across their supply chains. Support for these agreements has been possible when commodities depend on sensitive foreign markets or when the actors involved perceive these agreements as a means to bolster their own interests (Cashore & Stone 2013), such as access to new markets, and/or continued access to existing ones.

The SoyM experience indicates that the markets pathway may be a promising avenue for international actors and forces looking to curb commodity-induced deforestation. The agreement came out of increased pressures from international retailers and nongovernmental organizations in support of deforestation reduction. An assessment of the soy supply chain identified the most strategic actors (soy traders) and stages to push for supply chains free from deforestation. After an incisive campaign, Greenpeace targeted McDonald's because of its important role in influencing the supply chain upstream. Although the SoyM is still a voluntary agreement, the pressure from one of the major consumers was crucial for enforcing a clear target (zero legal and illegal deforestation) amongst the biggest soy traders in Brazil. Other national NGOs acted as important players when they joined the GTS to operate as inspectors of the agreement's compliance.

However, with emerging markets constantly changing and demanding different product standards, the effectiveness of market pathways may happen only in the short-term, with no guarantee of a durable impact. Some soy producers,[7] for ex-

[7]Interview with soy producers and associations in the state of Para and Mato Grosso, June 2015.

ample, stated that China is now their most important consumer, and the previous standards set by Europe are no longer relevant for soy production and exports. Other producers that are not part of the SoyM are trading directly with China and have indicated that their practices have not changed after the enactment of the agreement. For this reason, using the markets pathway in combination with other pathways might result in more durable outputs.

International norms pathway

This pathway seeks to develop norms or establish protocols that will change or reinforce certain domestic policies or behaviors. International norms can influence what is considered appropriate within a domestic setting. The influence of international norms depends on the moral vulnerability of the target state or firm and on the resonance with domestic ideology and policy goals in a country (Berstein & Cashore 2012). Policies that result from this pathway are potentially durable.

The risk that corporations are associated with Amazon deforestation is already one of the major barriers preventing Brazilian products from accessing international markets (Nepstad et al. 2015). Many companies demand "zero-deforestation" and "zero illegality" from their commodity suppliers, as they seek to protect their own reputations. This perception may translate into support for zero-deforestation commitments. In fact, a widespread hope is that the need to protect the Amazon and the importance of a good reputation can induce more sustainable farming.

The Greenpeace "Eating up the Amazon" campaign brought considerable attention to the relationship between soy production and deforestation. Similar campaigns, such as the "Slaughtering the Amazon" initiative might gradually change Brazilian actors' perception of deforestation and commodity production in the Amazon. Continued campaigning from international NGOs and other actors is needed in order for the new norms to crystallize in the domestic setting. Partnerships with local NGOs and other domestic actors might be necessary to create durable effects and campaigns. Private and public interactions within transnational networks and in formal and informal events also seem to be relevant for the dissemination of norms (Berstein & Cashore 2012).

Direct access to domestic policy-making processes pathway

The direct access pathway can influence a country's domestic policy by building capacity, transferring technology, empowering disadvantaged groups, or directly funding particular projects. This pathway fosters independence, but depends on continued capacity building and funding from international organizations, NGOs, or states in order to be durable. This pathway may undermine national sovereignty, since external actors may pervade the domestic realm. However, some countries are likely to welcome external funding and technology transfers, in which case sovereignty would not be affected.

While markets are the primary pathway travelled by zero-deforestation agreements, the effectiveness of the commitment will require greater emphasis on domestic policies, monitoring, and verification capacity in order to ensure compliance with deforestation targets. The multi-stakeholder dialogue created by the GTS empowered domestic actors and engaged organizations in a push for deforestation reduction, while also encouraging compliance through the annual monitoring of deforestation caused by soy production in the Amazon. The establishment of a monitoring component pushed for the use and transfer of technology, capacity building, and third-party verification of the SoyM accomplishments to ensure a decrease in deforestation rates. Monitoring was particularly important in the case of the SoyM and seemed to contribute to reduced deforestation. Given these successes, SoyM represents a case in which a diverse collective of stakeholders successfully traversed the direct access pathway to contribute to a curb of deforestation in the Brazilian Amazon.

International rules pathway

The international rules pathway involves the use of international laws to influence domestic outcomes. Most international treaties require countries to enact legislation or policies that enable their compliance with the terms of the agreement. This pathway may undermine sovereignty if the international obligation challenges domestic policymaking processes; nevertheless, this pathway has the potential to produce durable policies if states actually implement and enforce the international agreements. There is a global movement to reduce deforestation, which has encouraged the private sector, NGOs, and governments to announce commitments to eliminate deforestation from their supply chains. Most of the agreements aim to influence domestic policies and count on domestic actors' participation. However, the vast majority of these commitments are still voluntary, rather than mandatory treaties.

As a promising international regulation, the Paris Agreement set the goal of achieving net-zero emissions in the second half of this century and finally enshrined Reducing Emissions from Deforestation and Forest Degradation (REDD+). As a result, tropical countries expect new and long-term investments from developed countries as well as from private sector actors through zero-deforestation policies and markets. Countries are also encouraged to measure forest conservation and establish incentives and regulations to support deforestation-free supply chains (Harris & Stolle 2016). The Agreement provided a political signal to mobilize action regarding forests and may result in an international binding commitment that promotes more durable outcomes in national settings (including that of Brazil).

External constraints and drivers that affected and affect the SoyM

In evaluating the impact of the SoyM, it is critical to understand the internal and external constraints and incentives surrounding the agreement and assess how it has interacted with other policies. Separate measures and conditions have also contributed to the decline of agricultural expansion into forestlands, such as public investments in law enforcement and the monitoring of deforestation, the creation of new protected areas, as well as changes in market conditions. The effectiveness of the SoyM alone is therefore unclear.

Corporate sustainability

The year 2014 was remarkable for the increase of corporate environmental responsibility. The following facts illustrate this trend: i) the green bonds market tripled in size (Urs 2014); ii) the New York Climate Summit established targets that build on corporate leadership and regional government initiatives (Urs 2014); and iii) the 400 members of Consumer Goods Forum announced zero-net-deforestation goals by 2020.

A rising sentiment of corporate citizenship, as well as recent technological advances in land use change analysis has encouraged the adoption of sustainable production and sourcing (SPS) practices (Urs 2014). The implementation of SPS has inspired a continuous dialog among the private sector, NGOs, and policy makers, and has stimulated the development of monitoring and verification systems (Urs 2014). SPS opportunities also include market differentiation, brand loyalty, and risk management (CDP 2014). However, while these commitments may leverage broader sustainability outcomes, their impact on the production of agricultural commodities is unclear.

International market trends

International trade and consumption have significantly driven deforestation and have notably contributed to global CO2 emissions. Approximately 30% of the carbon emissions associated with deforestation was exported from Brazil in the last decade, of which 29% was due to soybean production. The share exported to emerging markets is growing, especially to China. The Asian market now has a larger share of soybean emissions than the European market, and China alone is responsible for 22% of all emissions linked to soybeans in 2010 (up from 7% in 2000) (Karstensen et al. 2013).

Evidently, deforestation in Brazil is closely linked with the global chain of agricultural commodities. From the late 1990s through 2004, deforestation became more responsive to global influences as commodity markets and technological advances encouraged the expansion of soy and other mechanized monocultures into the Amazon (Nepstad et al. 2015).

Global consumers create demand for the production, international trade, and sustainability requirements of goods and services (Karstensen, Peters and Andrew 2013). As market dynamics shift with the growing influence of China, requirements for sustainability, which have been relatively strict across European markets, may change and affect the motivation to comply with the SoyM.

Environmental policies

Brazilian environmental policies have been very effective in curbing forest clearings. Simulations indicate that conservation policies collectively avoided 62,100 km² of deforestation from 2005 to 2009, around half of the forest area that would have been cleared had the policies not been passed (Assunção & Gandour 2013). Deforestation rates also vary with commodities pricing, but analyses that control for different sources of variations in prices showed that environmental policies were still responsible for avoiding considerable forest clearings in comparison with decreases in prices. (Assunção & Gandour 2013). In 2005, for example, soybean prices fell by more than 25%, but municipalities in the central agricultural zone of Mato Grosso (a state in mid-western Brazil and the largest soybean producer in the country) still maintained a similar rate of deforestation (Brown et al. 2005).

Preliminary analyses of the successful SoyM's impacts may have overestimated the actual results of the agreement, since policies have proved to play a fundamental role in decreasing deforestation. The victories of the SoyM may be an example of how the "claims of success of market mechanisms tend to be exaggerated, and based on partial data ..." (Balleti 2014). The effectiveness, challenges, and opportunities that deforestation-free agreements present require further assessment. However, it is a challenge to isolate different variables when determining drivers of deforestation and reasons for decreases in forest clearings. Furthermore, unless effective forest governance is in place, broader efforts to curb deforestation may achieve temporary success but will keep facing numerous challenges (Lawson 2014). Some of the policies that directly affected deforestation rates in the Amazon in the last decade are described below:

Action Plan for Prevention and Control of Deforestation in the Legal Amazon (PPCDAM).—The launch of the PPCDAM in 2004 introduced a new mechanism for combating deforestation in the Amazon. Conservation efforts, previously restricted to the Ministry of the Environment (MMA) and the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), were opened to integrated action and the participation of numerous ministries (IPAM 2009). Cooperation between different levels of government and the implementation of the Real Time System for Detection of Deforestation (DETER) provided support for the practice of stricter monitoring in the Legal Amazon. PPCDAM focused on three main areas: (i) territorial management and land use; (ii) law enforcement; and (iii) promotion of sustainable practices (Casa Civil 2004; May et al. 2011). PPCDAM regulated legal instruments for the punishment of environmental crimes, which increased the number of fines applied, embargoes, confiscation of goods, and prosecution (Assunção et al. 2013). Assunção et al. (2013) estimated that PPCDAM preserved more than 122,700 km² of forested area.

Resolution 3545/2008: Restrictions on rural credit in the Brazilian Amazon biome.—Introduced in 2008, this regulation redirected the rural credit system in the Brazilian Amazon and required borrowers to present proof of compliance with environmental regulation. Credit is an important source of financing for rural producers in Brazil, and this system led to a substantial reduction in rural credit borrowed throughout the region. Assunção and Gandour (2013) estimate that approximately USD 1.4 billion in rural credit was not contracted between 2008 and 2011 due to restrictions imposed by the Resolution, a decline that prevented over 2,700 km^2 of deforestation, or a 15% decrease in the typical deforestation rate over that time period.

Public list of illegally deforested areas.—A Decree in 2007 established the legal basis for distinguishing municipalities with very high deforestation rates. In January 2008, the Ministry of the Environment published a list ("black list") of thirty-six municipalities in need of action to combat illegal deforestation. The list was based on the following three criteria: (i) total deforested area; (ii) total deforested area in the past three years; and (iii) increase in the deforestation rate in at least three of the past five years (Assunção & Rocha 2011). After the publication, all illegally deforested areas on the list were embargoed, and landowners encountered tighter standards when trying to take out agricultural loans (Tollefson 2015). In response to this policy, 11 counties drastically reduced reforestation and the State of Pará launched the "Green Municipalities Program" to help blacklisted counties reduce their deforestation rates and reestablish access to rural credit (Nepstad et al. 2015).

Creation of protected areas.—Protected areas are effective instruments for safeguarding the integrity of ecosystems, biodiversity, and the associated environmental services (e.g., soil conservation, watershed protection, pollination, nutrient recycling, and climate regulation) (Veríssimo et al. 2011). Protected areas are also potentially important for protecting the rights of permanence and the culture of local traditional populations and indigenous peoples (Veríssimo et al. 2011). Some of the success in reducing deforestation in Brazil comes from the development of a network of indigenous lands and protected areas across the Amazon (Assunção & Rocha 2011). In addition to that, Barber et al. (2014) concluded that protected areas have a strong mitigating effect on the risk of deforestation due to the proximity to transportation networks. The establishment of protected areas gained momentum from 2003-2006, when approximately 500,000 km^2 of rainforest were set aside (Veríssimo et al. 2011). Significant progress was simultaneously made in the official recognition of indigenous lands (Assunção & Rocha 2011). The increase of the area officially protected in the Amazon may have potentially contributed to the drop in deforestation rates.

Brazilian Forest Code.—Global pressure on Brazilian agriculture to increase production (Nepstad et al. 2015) combined with recent changes to the Forest Code (Law n. 2651/2012) (Tollefson 2012) indicate that deforestation rates may be unlikely to decrease moving forward. The latest changes in the Forest Code concluded in 2012 have been controversial and added an extra layer of complexity to the issue of deforestation.

One of the most contentious changes was the suspension of federal administrative penalties imposed for illegal deforestation conducted before July 22nd, 2008, conditioned upon the adherence to an Environmental Regularization Program (Programa de Regularizacao Ambiental, PRA) (Malingreau et al. 2012). Furthermore, full compliance with the revised Forest Code can be achieved while still legally clearing 85 million hectares of forests (Nepstad et al. 2015). This means that the current rate of deforestation could double for four decades (Nepstad et al. 2015).

The incompatibility"between the SoyM, which aims for zero-deforestation, and the Forest Code sparked a debate around the renewal of the SoyM (which was ultimately renewed in May of 2016 until it is no longer necessary). Yet the Forest Code also established the Rural Environmental Registry (CAR), a public registry system in which landowners of rural properties declare their land boundaries and uses and must certify the intent to comply with environmental regulations. This system is supposed to improve law enforcement capacity at a property level and may inhibit deforestation when fully implemented. However, the deadline for the national completion of CAR has been extended to 2017 (after two previous extensions) so the effects of this policy will not be felt until that time.

The Climate Change Law and Support from Norway.—In 2009, Brazil enacted the Climate Change Law with the aim to reduce overall emissions by 36.1–38.9% relative to business-as-usual by the year 2020. In 2008, Norway promised to pay up to $1 billion for the Brazil's Amazon Fund on the condition of deforestation reductions. The fund "pays for performance", which means that the money will be invested only if the goal of reducing deforestation is met (Boucher 2014). In September of 2015, Norway made the final USD 100 million payment to Brazil to reward a slowdown in forest loss in the Amazon basin (Reuters 2015). However, with no more payments in the pipeline, there's no guarantee that the accomplishments will remain stable, although the Paris Agreement is expected to encourage international investments in tropical countries to reduce forest loss and GHG emissions. When aligned with financial incentives, domestic and international emissions reduction targets can considerably motivate agents to both reduce deforestation and monitor its major drivers.

The Soy Moratorium's effects on deforestation rates

In general, deforestation declined from 19,500 km² in 2005 to 5,843 km² in 2013, a 70% reduction (Nepstad et al. 2015). Two years before the establishment of the SoyM, nearly 30% of soy expansion was realized through deforestation (Gibbs et al. 2015). After the agreement in 2014, that number decreased dramatically to about 1% (Gibbs et al. 2015), yet the soy production continued to grow (Nepstad et al. 2015). Nevertheless, in the Cerrado biome, which is outside of the Amazon and thus beyond the jurisdiction of the SoyM, the annual rate of soy expansion into native vegetation remained substantial, varying from 11 to 23% during 2007–2013 (Gibbs et al. 2015). The eastern Cerrado region, Mapitoba, is the most recent hotspot for Brazilian agriculture and nearly 40% of total soy production (2007–2013) expanded into native vegetation (Gibbs et al. 2015).

There is a debate about whether the SoyM has encouraged deforestation in other biomes while limiting deforestation in the Amazon. It can be argued that lower rates in the Amazon, which receives more international attention than other national biomes, distracts attention from deforestation challenges in other regions. Thus, auxiliary studies are needed to assess the potential mal-effects of the SoyM in the Cerrado. As mentioned above, deforestation rates cannot be exclusively attributed to the SoyM; the annual expansion of soy in the Cerrado may have been inevitable, resulting from regional conditions and incentives rather than from implementation of the SoyM. Other factors such as fluctuations in soy prices and restrictions on rural credit have also impacted outcomes and should be taken into consideration when examining the hypothesis of "leakage" to the Cerrado.

Furthermore, it is imperative to recognize that the dynamic of deforestation in the Amazon is fairly complex (Barona et al. 2010). Recent analyses suggest that deforestation is mostly driven by the expansion of cattle ranching (Walker, Bramble, and Patel 2010). However, Barona et al. (2010) support the hypothesis that an increase of soy production in Mato Grosso has displaced pasture from the Cerrado and spurred deforestation in the Amazon. When soy eventually advances into the Amazon, it occupies areas previously opened by cattle ranching, which indicates that soy might not have been the first land use after clearing, but has indirectly caused deforestation in the region. Barona et al. (2010)'s findings suggest that potential causal links between soy, cattle ranching, and deforestation need further exploration to explain the results of the SoyM. The GTS monitoring methodology has so far been unable to identify this pattern.

Other results of the Soy Moratorium

Besides complementary contribution to the deforestation decrease in the last years, the SoyM also yielded other positive results. The SoyM: i) increased transparency and accountability in the soy industry; ii) revealed the influence of international markets in domestic environmental and social settings; iii) developed a monitoring and enforcement system to ensure compliance; iii) elucidated the dynamics of soy production and expansion in the Amazon; iv) increased the dialogue and exchange of knowledge among NGOs, soy traders and the government; v) encompasses more than 92% of the total soy produced in the Amazon (Greenpeace 2014); and vi) is the first agreement of its kind and now functions as a reference for lessons learned and for other related moratoria.[8]

Monitoring is crucial to track advances and ensure the commitment is upheld. In fact, monitoring and compliance mechanisms established by the SoyM offer a model for expanding supply-chain governance to other soy-sourcing regions and potentially to other commodities. ABIOVE hired a consulting firm to monitor deforestation and law compliance in in farms with which they have soy purchasing contracts. The results are annually published. Greenpeace executes another monitoring process, which included overflights in the first years, and compares both results (ABIOVE's and Greenpeace's) in order to guarantee accuracy and transparency in the process.[9] At the beginning of the agreement, NGOs were also critical in creating a protocol and a reporting framework to guide the monitoring process and establish meaningful indicators. However, Balleti (2014) argues that a satellite-imaging system capable of detecting deforestation on individual farms was only available six years ago. As such, claims of success by the GTS cannot be truly substantiated.

Farms that violate the SoyM are blocked from selling to SoyM signatories. This policy encourages compliance within the sector. The limited number of traders that exercise considerable control over the supply chain also facilitated the monitoring of the SoyM strategy. Participation in the collection, assessment, and interpretation of information increases stakeholders' credibility, salience, and legitimacy, and motivates engagement (Cash et al. 2012). Independent NGO monitoring increases transparency and avoids false allegations in general. Continued stakeholder engagement is also essential for ensuring compliance and tracking behavior change in the supply chain (Eyes on the Forest 2014).

Factors of success of the Soy Moratorium

The Soy Moratorium's results have been recognized (GCP 2016) and the commitment has become a case in how industry, governments, NGOs and consumers can drive and implement solutions to reduce deforestation linked to commodities (Greenpeace 2014). The following factors have led to the success of the SoyM:

- The limited number of traders that exercise considerable control over the supply chain has facilitated the implementation and traceability of the SoyM strategy.

- The synergy between private sector leadership, civil society know-how, and public sector policies can be crucial guaranteeing that goals are met and sustained over time. The collective action that resulted from this synergy in the SoyM case orchestrate different perspectives, roles and expertise that together generated collaboration and innova-

[8] Personal communication with Greenpeace in Sao Paulo/SP, May 20th 2015.
[9] Personal communication with IMAFLORA in through Skype, June 9th 2015.

tion, and built traction and credibility among the participants, and towards the enforcement of the agreement.

- Clear goals (zero deforestation and zero forced labor) and the establishment of a monitoring component were crucial to ensure adherence.
- Technology advances along with the implementation of the SoyM allowed for more accurate and refined analyses, amplified the geography under monitoring, reduced the monitoring costs, and eliminated the need for aerial surveys to identify soybean planting. The availability of satellite images also allowed for more transparency and pressure for compliance.
- A package of actions/conditions strengthened the SoyM: more governance and law enforcement in the region, loan programs tied to jurisdictional performance and compliance with environmental law, some favorable movements of commodities prices at ideal times, and a global effort led by responsible corporations pushing for supply chains free from deforestation.
- The availability of open and suitable land for soy expansion in the Amazon reduced the pressure on the forest and enabled the increase of soy production in already cleared areas without increasing deforestation rates directly linked to this monoculture.
- ABIOVE and ANEC control 92% of Brazilian soy production (Greenpeace 2014) and represent the most important soy traders operating in Brazil. The concentration of market power and the collaborative action among the ABIOVE members reduce the costs of the SoyM implementation, which became more cost-effective than any other type of certification or market-based mechanism that aims to verify sustainably produced crops.

The other side of the agreement: limitations and concerns

In spite of significant impacts, the SoyM reveals limitations in terms of deforestation reduction, behavior change in the soy industry and appropriateness of the agreement with the establishment of new policies and market trends. Some important points to reflect on and take into consideration while preconceiving strategies to strengthen and amplify the scope and impacts of the SoyM include the following:

- There are soy traders operating within the Amazon boundaries that are neither part of the ABIOVE nor part of the ANEC and therefore do not pursue zero-deforestation targets. Interviews with these producers showed that the SoyM did not impose any kind of pressure to change deforestation patterns, nor did it impact sales or revenues from the production of soy.
- China is currently the main destination of the soy produced in Brazil and plans to increase its imports by 50% by 2020 (GCP 2016). According to the Forest 500 rankings (GCP 2016), companies in China are performing poorly in terms of sustainable practices and have no commitments to ensure their soy is deforestation-free. If the Chinese standards do not improve and the Forest Code takes too long to be fully implemented, the market pressure for more soy may result in greater deforestation rates in the next years.
- The monitoring system has flaws. Although satellite images and deforestation analyses show a decrease in the soy expansion into forested areas, soy is often an indirect driver of forest clearing. The advance of soy is marked by the displacement of cattle ranches that previously cleared the forest. The increasing demand for soy plantations push cattle ranching deeper into the Amazon,

which is not captured by the current system that only monitors the first driver of deforestation in the year of clearing. The analysis does not scrutinize the deforestation dynamics and the linkage between soy and cattle ranching expansion. This approach also allows for 'on-property leakage' (Forest Trends 2016) when the same farm produces both cattle and soy. The monitoring system also does not recognize when soy is produced in an irregular property but is transported to a regular farm before the soy trader buys the production.[10]

- The soy quantity produced in the Amazon represents a relatively low percentage of the total produced in the Cerrado biome, where the production keeps growing. In fact, deforestation caused by soy production continues in other geographic areas.
- Although ABIOVE represents the Brazilian vegetable oil industry, the perception and endorsement of the SoyM varies among its members. There is a continuous debate about the zero-deforestation target. Some producers complain that the moratorium goes beyond the Forest Code and they believe that it constrains the growth of the sector since it could still clear areas according to the federal law and therefore expand production in the biome. As mentioned before, full compliance with the revised Forest Code can still legally clear 85 million hectares (Nepstad et al. 2015).
- Some producers rent other farms to expand their plantations, but the property duties are still under the landowner's responsibility and not under the producer's. Therefore, if a farm is blacklisted because of deforestation, the property owner is considered the offender. However, for the purpose of soy sales, the purchase receipt by the soy traders requires the documents of the producer, who is not legally linked to the property tenure and therefore not linked to the infraction. Thusan embargoed area can thus still provide soy to the SoyM signatories with no restrictions.[11]

In conclusion, it is clear that more needs to be done to ensure compliance and prevent soy production from threatening valuable ecosystems.

Looking ahead: what comes next?

The Forest Code is not enough

Soy traders recently extended the SoyM indefinitely until it is no longer needed—that is, when the Forest Code is fully enforced. However, given the lesser priority of environmental issues among other governmental tasks and the lag time for policy implementation in Brazil, the full compliance and enforcement of this regulation will likely take several more years. Additionally, government monitoring and control of embargoed areas is still limited. Gibbs et al. (2015) state that soy farmers are about five times more likely to violate the Forest Code than the SoyM because of the lack of law enforcement in Brazil. Furthermore, uncertainties of the new Forest Code may be spurring an increase in deforestation (Rowling 2014). Therefore, a system that combines elements of the SoyM and the Forest Code monitoring systems could be more successful and keep deforestation under control.

Other challenges for the SoyM durability

International interventions tend to be more durable if they are perceived as reinforcing national authority and existing domestic rules. Top-down approaches that conflict with national legislation and institutional frameworks have previously failed (Bueno & Cashore 2013). The SoyM tends to lose traction because it challenges domestic policies and sets a higher standard than the current Forest

[10] Personal communication with IBAMA, June 2015.
[11] Personal communication with IBAMA officials, July 2015.

Code. Full compliance with Brazil's revised Forest Code could be achieved while still legally clearing 85 million ha of forests (Nepstad et al. 2015), which does not align with the SoyM pledge for zero-deforestation in the Amazon. In addition, public subsidies that support the expansion of soy, such as the massive efforts to increase production in the Mapitoba region, may conflict with conservation initiatives. The coordination among public policies and ministries is crucial for the incorporation and durability of zero-deforestation agreements.

The voluntary nature of SoyM may also impact its adoption. The agreement represents just about 90% of the soy produced in the Amazon region because there are still traders who have not yet committed. Although this represents a considerable percentage of the total soy production, policy incentives could attract more members.

Even though the market pathway is extremely important for the implementation of a zero-deforestation agreement, it is important to recall that markets are constantly changing. China is increasingly importing soy produced in Brazil, and the previous standards established by Europe are no longer solely relevant for soy production and exports. For this reason, it is imperative that the market pathway be combined with the other pathways and with national policies.

Replicability across other countries and supply chains

Given the pioneer approach and acclaimed success of the SoyM, scientists and practitioners have reflected on how the lessons from the agreement could be repeated across regions and across commodities. In fact, the SoyM has already inspired a deforestation-free cattle ranching agreement in the Amazon. However, replication cannot merely be a repetition of the SoyM steps; it should account for the local context and supply chain specificities. The SoyM has unique aspects that should be considered when trying to identify relevant lessons and conditions that should be in place for the reproduction of this model. Some important and particular aspects of the SoyM that would facilitate the implementation of a similar agreement in other regions include: monitoring technology, available public data on deforestation and land use, political will, environmental policies, international commitments to reduce GHG emissions, collective action, law enforcement, global and increasing demand for soy, and and a limited number of major traders in the supply chain.

Conclusions and Recommendations

Corporate commitments alone are insufficient to reduce of prevent deforestation. Rather, they must be understood in relation to a broader range of policy initiatives. In this light, this paper reviewed the importance of incentives and sanctions to motivate the implementation of the SoyM, and the power of market and NGOs pressure and government rules to expand the on-the-ground impacts of this type of initiative. In order to reinforce the SoyM (and deforestation-free agreements in general) and ensure more durability of such a promising strategy, some key considerations are listed below:

Maintaining pressure

Environmental campaigns are not likely to endure after international and market pressures diminish and disappear. Environmental stakeholders need to hold governments and companies accountable to their commitments. Therefore, maintaining pressure for change is important and can be achieved by closely monitoring the implementation of the agreement, staying actively involved in the GTS (or by creating working groups or committees), and publicizing results.

Traceability and reporting

Traceability is widely recognized as a foundation for zero-deforestation agreements, but it is still costly. Partnerships between universities, NGOs, government, and soy traders could focus on developing accessible and affordable traceability systems and improving the current monitoring system.

Standardization of reporting is also important to monitor compliance and compare performance of different companies and sectors. Transparency and information sharing are critical for deforestation-free agreements in general.

Certification

Certification schemes for environmental best practices offer "carrots" to the private sector and augment existing efforts to reduce illegal deforestation. However, certification outcomes are limited by the effectiveness of the scheme and the independence of the auditors (Forest Trends 2016).

Capacity building and stakeholder engagement

Capacity building and education for the SoyM members and those across the value chain, as well as extensive involvement of stakeholders, are important for effective implementation. Raising awareness among suppliers and providing training on sustainable farming practices (including how to increase yields without clearing forest area) proves critical. Engagement and participation are also key. If all players have their seat at the negotiating table, capacity building will work to leverage everyone's participation.

Policy incentives

Since the demand for soy is continuously increasing, incentives for the intensified use of unproductive pastures or other existing cleared lands will be essential for reconciling soybean production and ecosystem protection. Incentives could reward farmers that meet key outcomes towards sustainable production. This approach includes access to low-interest loans and payment for ecosystem services (Nepstad et al. 2014).

Enforce beef moratorium

The SoyM incentivizes soy expansion into already-cleared areas, which may displace pastures and could indirectly lead to more deforestation. Effective zero-deforestation agreements in the cattle sector may decrease the risk of this indirect deforestation. Furthermore, the beef and soy moratorium could be more officially connected under a jurisdictional approach, such as REDD+ programs where governments develop sustainable land-use policies and offer private actors an opportunity to collaborate in implementing supply chain commitments (Streck and Lee 2016).

Moratorium expansion to the Cerrado

While soy-linked deforestation diminished in the Amazon biome, 20% of new soy areas created in the Cerrado led to deforestation between 2007 and 2013 (Gibbs et al. 2015). The SoyM should include the Cerrado and other regions potentially at risk in order to reduce conversion of remaining native vegetation.

Public-private partnerships (PPPs)

Combining private commitments and government regulation and incentives will foster large-scale results and good governance. Potential for PPPs also lies in integrating zero-deforestation in jurisdictional REDD+ initiatives (Streck and Lee 2016).

Law enforcement

Brazil's notable decline in deforestation provides valuable lessons on the importance of public policies and law enforcement. Decreases in deforestation rates are more likely to last if law enforcement (and the Forest Code's in particular) is put in place.

Market mechanisms can gain traction relatively easily, but they are temporary and do not necessarily solve the deforestation problem. Government policies can also be less effective due to a lack of law enforcement capacity or effectiveness. Therefore, the options presented here would likely be more effective if used in combination, since each one of the options can strengthen the others. Strategies should be designed to reinforce sovereignty, create synergies, and implement more pervasive actions.

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