TROPICAL RESOURCES

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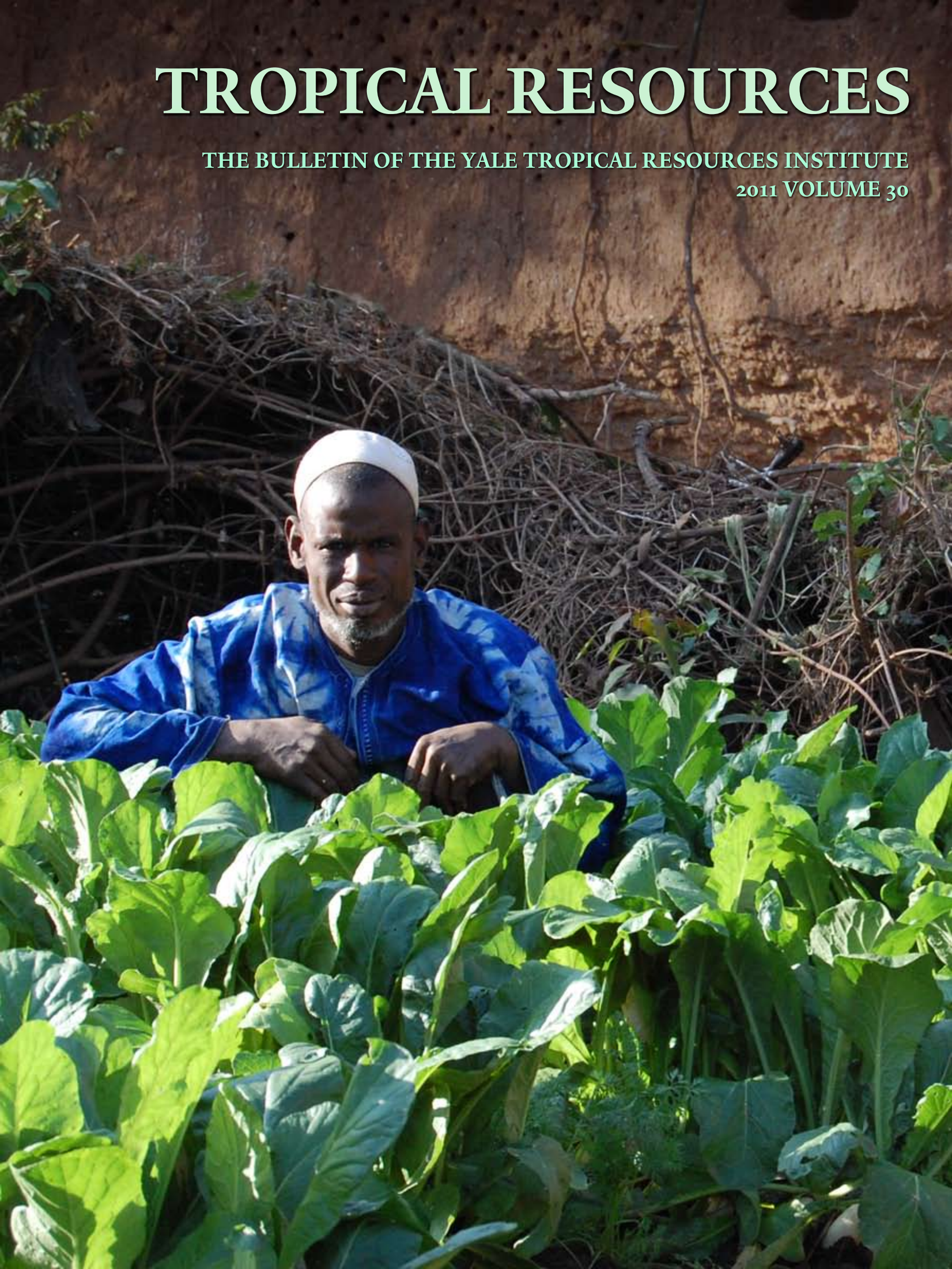

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The Bulletin of the Yale Tropical Resources Institute

Volume 30, 2011

In this issue

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All figures used in these articles are the authors' own unless otherwise indicated.

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.

TRI News Updates...

TRI Welcomes New Program Manager

In November 2010, Lisa Bassani joined the TRI staff as its Program Manager, replacing Nathaniel Delafield, who departed TRI in the fall of last year. Lisa is a graduate of the Yale School of Forestry and Environmental Studies (F&ES), earning a Master of Environmental Science degree from F&ES in 2006. Lisa comes to TRI with a wide range of research experience in both domestic and international settings. Research for her Master's thesis, completed in Panama, focused on NGO-government relationships in conservation finance initiatives and boundaries between state and non-state actors. In addition to undergraduate research conducted in Mexico, she has also carried out research on a variety of public lands issues in the United States. Prior to joining TRI, Lisa worked as a Project Manager for The Trust for Public Land's Connecticut office, with primary responsibility for completing land conservation transactions across the state. Lisa holds a BA from the University of Michigan.

TRI Awards New Sabin Fellowships

In February 2011, the Tropical Resources Institute (TRI) announced an outstanding new fellowship for international students – the Andrew Sabin International Environmental Fellowship. The fellowships will support the education and training of international students from less-developed countries, who intend to return to their home region or country to work in the field of conservation and development.

The Andrew Sabin Family Foundation generously provided funding for seven fellowships for Master's students entering F&ES in academic year 2010-2011 and for another ten students entering in academic year 2011-2012. The fellowship, administered by TRI, provides up to $20,000 in support for tuition for the second year of Master's study, and up to $15,000 in post-graduation awards for those pursuing environmental careers in their home region or country.

"Many countries in Africa, Latin America and Asia will be affected most by climate change, biodiversity loss and forest degradation," said Andrew Sabin. "I hope the fellowships will attract smart, dedicated professionals to Yale's environment school for an education, so they can return home to address these critical environmental challenges before it's too late."

Michael R. Dove, the Margaret K. Musser Professor of Social Ecology at F&ES and Director of the Tropical Resources Institute, said, "This generous and far-sighted grant from the Andrew Sabin Family Foundation will help to bring education at Yale more within the reach of prospective students in less-developed countries, which enriches the university with the perspectives of young people from other parts of the world, and contributes to the increasingly vital global exchange of knowledge and experience regarding the environment."

Seven master's students from F&ES were chosen as the first recipients of the fellowship. The 2011 Sabin Fellows, with their country of origin, are: Lakshmi Krishnan, India; Jing Ma, China; Munjed Murad, Jordan; Paulo Quadri Barba, Mexico; Kavita Sharma, India; Kanchan Shrestha, Nepal; and Shiyue Wang, China.

For more information on the Sabin Fellowship, visit environment.yale.edu/tri

A Word from the Program Manager

As the 2011 Bulletin goes to print, I will have completed my first year as TRI's Program Manager, and TRI will be approaching its 30 year anniversary (set for 2014!). These milestones inevitably invite some time to reflect upon the contributions TRI-funded research has made on the field of tropical conservation, the impact TRI has had on the hundreds of Fellows who have received our research support, and perhaps more importantly, where the road leads for TRI over the coming decades.

Not unexpectedly, the world has changed considerably during these three decades. How we communicate, how we think, and how we learn has been radically transformed with the slew of new technologies that the world has adopted since TRI began in 1984. I am reminded of this every time I walk into the main library on Yale's campus – Sterling Memorial Library – and am flanked in the lobby by the relic card catalogs on the left and the computer terminal on the right! It is really unthinkable for the current crop of students that a researcher in TRI's early days actually sat and flipped through alphabetized cards to find books of interest.

These students can access information in a nanosecond – and expect to do so at all moments of their day. And yet, the completely redefined landscape of information technology makes field research no less relevant and important than it was twenty, thirty, or even a hundred years ago. The experience in the field – whether conducting studies on the adaptation strategies of farming communities in the Yucatan or on the urban environment of dengue mosquitoes in Puerto Rico, as two of our authors in this issue have done – forces us to test our assumptions, to make heads or tails of the rich set of data that might come unexpectedly, and to apply theory learned in the classroom to process this data and to draw relevant conclusions that build upon our collective knowledge.

If done successfully, the process of research is mentally taxing and physically exhausting. But the end product is a student, soon to be back in the professional world, who can think on his or her feet, challenge orthodoxy, and push institutions (both big and small) forward. This is why after nearly thirty years and amidst many changes TRI continues to be relevant, and why the opportunities it provides remain important – even in the era of the sleek gadget.

We hope you enjoy this volume of Tropical Resources – and we look forward to the changes the next few decades will bring here at TRI!

Best Wishes,

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THE STATE OF TROPICAL RESOURCE STUDIES AT YALE/F&ES, 2011

Michael R. Dove
Director, Tropical Resources Institute

The research conducted by the Master's and Doctoral students of Yale's School of Forestry and Environmental Studies represents a snapshot of current work on tropical resources. Based on fieldwork carried out within the past year, supported by TRI fellowships, and informed by their course work and reading of the latest literature, the research by these students tells us where the field of tropical resources is today and where it is going in the future. Some of the best work carried out over the past year by F&ES students on tropical societies and environments is published here, divided into three main themes: institution building, human health, and adaptation to climate change.

I. INSTITUTION-BUILDING

The first section of the Bulletin, with papers by Geofrey Mwanjela, Adenike Adeyeye, and Juan Pablo Vallejo, concerns institution building in conservation and development projects. Institutional innovation, the creation of new, tailor-made institutions – both in communities and in government – is a ubiquitous characteristic of such projects. It is also curiously under-studied, despite the fact that, as social scientific analyses of such efforts tell us, it is horrendously difficult. Institution building is often frustrated by over-looked socio-economic differentiation within communities, which means that an entire community rarely has the same interests at heart, and by the fact that existing, working social institutions have generally evolved over long periods of time within specific local contexts. One of the most common and serious errors made in conservation and development projects is the attempt to impose newly created institutions on local communities instead of utilizing and building upon existing ones.

The newest frontier of protected area management lies in marine environments, as reflected in the increasing number of protected areas being established in near-shore zones around the world. The first article in this section, by Geofrey Mwanjela, concerns the Mnazi Bay Marine Park, established in 2000 on the southeastern coast of Tanzania. Like many protected areas created over the past couple of decades, this was an integrated conservation and development project, which sought to marry goals of environmental conservation and local socio-economic development. The park was developed around existing communities of ethnic Makonde and Makua, who had traditionally depended upon fishing for their livelihoods, supplemented by various other sorts of economic activities. In order to better conserve the marine environment, the park management sought to redirect the local communities' livelihood focus away from fishing toward other means through a program of collaborative management. To this end, the park worked with the United Nations Development Programme to create village-based environmental management committees – but one decade later, the results of this initiative are decidedly mixed. The park management did not follow through with some of the resources that it promised to the local communities. And some of the resources that were provided – for example, to establish bee-keeping projects, much-beloved by international development agencies – were unsuited to local conditions. The Mnazi Bay Marine Park project does not simply show that knowing how to protect the environment and how to develop local communities are not the same, it also shows that knowledge of protection that elides development is partial knowledge at best.

The next paper in this section, by Adenike Adeyeye, focuses on community-based sanitation initiatives to address the health hazards of open defecation, based on a case study in Ekiti State in southwest Nigeria. The initiatives here consisted of establishing Water and Sanitation Committees and Voluntary Health Promoters, to promote digging of boreholes (for hand-washing) and construction of latrines. Participation by women as well as men was deemed to be essential to the program, so the Nigerian NGO in charge of the program insisted upon equal representation by women on these committees. Equal representation did not ensure equal participation, however, which undermined the success of the program. Research by Adeyeye suggests that the NGO and local government were more concerned with being able to cite the percentages of women on committees as evidence of gender equity, than with actually ensuring that women's voices were heard. The focus on simplistic numerical measures of equity ignores the fact that women and men have different roles in the local community, and only by building upon those roles will efforts to engage women truly succeed.

The final paper in this section, by Juan Pablo Vallejo, focuses on the water resource systems of the Caribbean region of Colombia. Alternating flooding and droughts, driven by the El Niño/Southern Oscillation phenomena, have taken an ever-greater toll on the region over the past two decades. Human-led environmental degradation at both the global level, referring to climate change, and local level, in the form of the loss of 95 percent of this region's native forests, are exacerbating the situation, the end result of which is economic, social, and ecological vulnerability. The complexity of this situation has challenged the Colombian government, whose institutional response has so far been found wanting. It has focused on resource use versus resource conservation, and on coping with the damage from floods and droughts as opposed to preventing them in the first place. This de facto institutional response is far more costly than water conservation measures would be, which argues for an integrated, adaptive management strategy.

II. HUMAN HEALTH

The second section of the Bulletin concerns issues of human health and the environment (which were raised in Adeyeye's article as well). The linkage between economic well-being and the environment is much-studied; but the linkage between the physical or biological well-being of people and their environment is much less so. The articles here by Eliza Little and Ran Song et al. demonstrate how powerful such interdisciplinary studies can be.

The first article here, by Eliza Little, deals with urbanization and the spread of dengue fever in less-developed countries, taking as a case study the Municipality of Patillas in southeastern Puerto Rico. She examines the distributions and habitats of two dengue vectors in Patillas: the mosquito *Aedes aegypti*, a known dengue vector, and also *Aedes mediovittatus*, a native, tree-dwelling mosquito of Puerto Rico that is seen as a potential vector. *Aedes aegypti* favors built-up environments, whereas *Aedes mediovittatus* favors more forested ones; consequently they coexist in high-density urban environments with forest (viz., tree) patches. In a novel application of remote sensing and GIS, Little calculates the number and area of forest patches in the city and then maps onto this her field data on the distribution of the two mosquito species. The resulting analysis points the way toward a research program that would enable dengue interventions to be focused on the highest-risk urban environments.

The second article in this section, by Ran Song and his collaborators in the field, Dovi Kelman, Kimberly Johns, and Anthony D. Wright, based on a field study at Mauna Kea Tea Farms on

the Big Island of Hawaii, is an analysis of the correlation between health-benefitting chemicals in tea and two much-discussed variables of the tea plant: the age of the leaf and whether or not the plant is shade-grown. The authors find that plant secondary compounds that are important to tea-drinkers (L-theanine and caffeine) have the highest concentrations in the bud and youngest leaves of the tea plant and then diminish in concentration as the leaves age, likely because they play a role in protecting young leaves but are less needed as the leaf matures. On the other hand, another chemical of importance to some tea drinkers, epigallocatechin gallate (associated with antioxidant activity), actually increases with leaf age if the tea plant is grown under shade. This research provides empirical support for the favoring of the bud and first two leaves by tea connoisseurs and health-conscious consumers, and also for the interest shown in shade-grown tea. Demonstrating that certain empirically traceable chemicals can be used as markers for the age, quality, and health benefits of tea, this research thus contributes to the agro-ecological dimensions of a science of taste and health.

III. ADAPTATION TO CLIMATE CHANGE

The implications of climate change for society and environment in the tropics continues to draw the attention of large numbers of F&ES students. The basis for many such studies, and this holds for the articles published here as well, is that certain contemporary climatic variables can serve as a proxy for future climate change and that, accordingly, the study of these contemporary cases has predictive value. The studies here by Ana Karla Perea Blázquez, Stephen Wood, and Guilherme DePaula, all focus on the prospects for human adaptation to climate change. They show both that economic diversification within the household promotes resilience in the face of climate stress, and that the household's overall prospects for adaptation vary with its economic strata. They also show, however, that the likely impacts of climate change will co-occur with other sorts of impacts, notably economic globalization, which greatly complicates efforts to isolate the significance of climate change alone.

The first article in this section, by Ana Karla Perea Blázquez, examines existing mechanisms for adapting to climatic perturbation, especially drought, among peasant households in Mexico. She frames her study as an effort to inform planning for future climate change impacts and responses. She bases it on a case study of a number of communities in the southern Yucatan peninsula, and focuses on maize cultivation. Perea Blázquez finds a number of home-grown mechanisms of adaptation, including adjustment of the agricultural calendar, water storage, and diversification both within the agricultural system (viz., planting more varieties of maize) and outside it (by developing other sources of income, notably from wage labor). She notes, however, that the impacts of globalization on Mexico's agrarian economy make it difficult to ascertain whether these mechanisms represent adaptations to climatic versus economic stress, or more likely a combination of the two.

The next article, by Stephen Wood, is a comparative study of climatic variation on agro-biodiversity and peasant household economies, again framed as a way to assess the future impact of climate change. It is based on a study of the Fouta Djallon region of northern Guinea and southern Senegal, which encompasses a topographically driven climatic gradient, from lower temperatures and higher precipitation to higher temperatures and lower precipitation. A single ethnic group stretches across this region, which enables a comparative study of the effects of different climatic regimes to be studied while holding most other variables constant. Wood finds that agricultural practices vary across this climatic gradient, albeit not in the way one might expect. He finds that

as temperature (if not precipitation) increases, so too does crop diversity; and as this latter variable increases, so too does household income. Wood concludes that the association of diversity and income is clear, and that this is based not just on diversity of crops but on their functional roles. He suggests that the nature of the association between higher temperature and diversity is less clear, however, as other related and unrelated variables might be involved. In any case, his findings question simplistic, econometric models of direct relationships between climate change and agricultural practices and incomes.

The final article in this section and in this issue of the Bulletin, by Guilherme DePaula, concerns the impact of increasing global temperatures on residential energy use in less-developed countries, taking as a case study Brazil. Brazil's economy is booming and its middle class is growing, and so too is consumption of electricity. DePaula asks how projected rises in temperatures will affect this growth in consumption. He divides Brazil into five distinct climatic zones, and examines energy consumption by different income brackets within each zone. He uses the comparison of consumption between the less- and more-temperate zones as a proxy to model the impact on consumption of future increases in temperature. DePaula finds that household sensitivity to increased temperatures increases with income, as does, therefore, energy consumption. DePaula concludes that future increases in energy consumption in Brazil will vary according to income levels and local climatic conditions but, overall, the growth in Brazil's middle class means that the impact of climate change on its energy sector is likely to be substantial.

IV. CONCLUSION

What are the lessons of these studies? They reaffirm the truth that totalizing planning exercises are difficult and that local wisdom and initiatives are often most successful. They demonstrate that much can be gained by creatively applying old methods to new topics and new methods to old ones. They show the need to be open to surprising and counter-intuitive findings. Above all, perhaps, they show the need to develop more complex models of the world, in which multiple variables are interacting, especially socio-economic and ecological ones. The research topics here are not the research topics of old; they are hybrids, in keeping with 'messy' realities; and they are tributes to the open minds and creativity of F&ES students.

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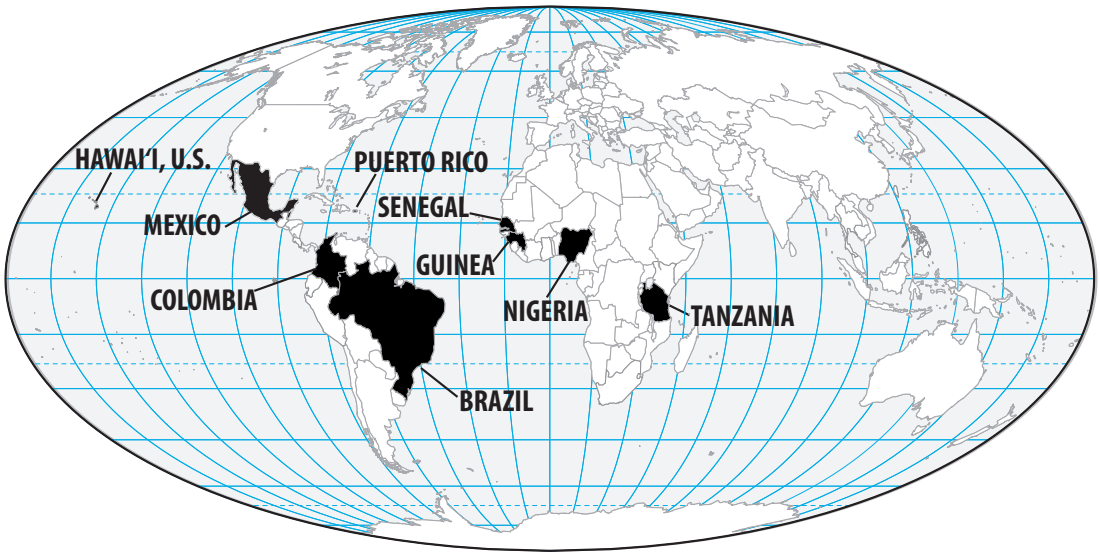
2010 TRI and Compton Fellows' research sites in this issue



Brazil:	Gil DePaula
Colombia:	Juan Pablo Vallejo
Guinea and Senegal:	Stephen Wood
Hawaii, U.S.:	Ran Song
Mexico:	Ana Karla Perea Blázquez
Nigeria:	Adenike Adeyeye
Puerto Rico:	Eliza Little
Tanzania:	Geofrey Mwanjela

Note: The delineation of international borders on this map does not represent endorsement of any particular national boundary.

I. INSTITUTION BUILDING

The Myth of Sustainable Livelihoods: A Case Study of the Mnazi Bay Marine Park in Tanzania[1]

Geofrey Mwanjela, MEM 2011

Abstract

The extent to which marine parks influence livelihood strategies and attitudes of local communities towards the conservation of marine biodiversity was studied in Mnazi Bay Marine Park in Tanzania. It was found that the park has had significant, adverse effects on people's livelihood strategies such that people have developed negative attitudes and practices towards the park and fisheries in general. This is evidenced by increased tensions between local people and park authorities and the outright rejection of the park concept in some villages. These negative attitudes pose considerable challenges to the park's success and the fishery's sustainability.

Introduction

In response to the mounting pressure on marine resources in Tanzania and elsewhere, marine protected areas have been established worldwide. In contrast with most terrestrial protected areas where people are excluded from living within the park boundaries (Adams et al. 2004, Barret et al. 2001), some marine parks include residents within the boundaries (Walley 2004). In these instances, park management must ensure that local livelihoods are not adversely affected as a result of the marine park's creation. Without ensuring protection of livelihoods of the local people living within the marine park, it is likely that local communities will reject the park and marine resources will continue to be degraded (Brown et al. 2001, Mwaipopo 2008, Walley 2004).

Although many studies have attempted to address the relationship between livelihoods and terrestrial protected areas (Adams et al. 2004, Pimbert and Pretty 2000, West 2006), few have been carried out for marine protected areas (Mascia et al. 2010). Despite the uncertainty of marine parks' impacts on local communities, the use of marine protected areas (MPAs) as a primary mechanism to protect marine resources has increased at a rate of 4.6% per year since 1984, totaling 4,435 MPAs in 2006 (Mascia et al. 2010, Silva 2006, Wood et al. 2008).

This paper, based on data collected in the summer of 2010, seeks to address two questions: how has the creation of the Mnazi Bay Marine Park influenced the livelihoods of local communities, and to what extent has its creation changed the perception of the local people toward the marine protected area? Answering these two questions is critical to ensuring community support of the marine park over the long-term.

Geofrey Mwanjela grew up in Tanzania and holds a BS in Aquatic Ecology and Management from the University of Dar es Salaam, Tanzania. He graduated with a Master of Environmental Management from Yale University, with a focus on natural resources governance in developing countries. In the future, he hopes to work with conservation NGOs in the area of policy and on community-based conservation in Africa.

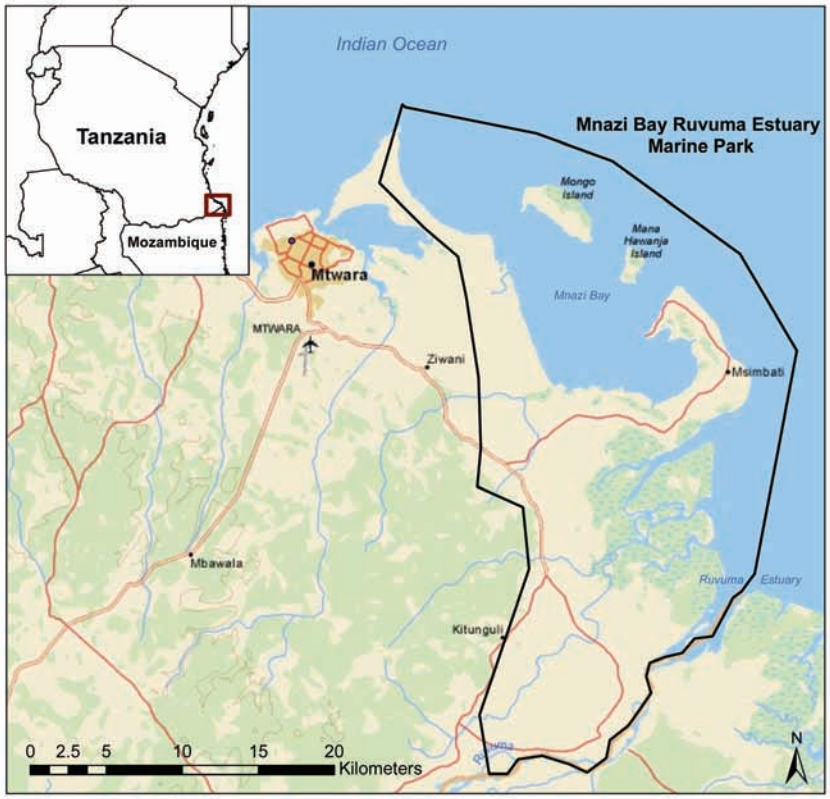


Figure 1. Map showing location of the study site.

Background

The geographic and socio-economic setting of the Mnazi Bay communities

Mnazi Bay Marine Park, located in the Mtwara Rural District (Figure 1) in the southeastern tip of Tanzania, was created in 2000 under the Marine Parks and Reserves Act, 1994 (URT 2005). The park covers 220 km^2 of land and 430 km^2 of coastal bay. Between 2000 and 2010, the number of villages in the park increased from 11 to 15 and the population increased from 28,000 to over 30,000 (Gawler and Muhando 2004, URT 2005).

There are two major ethnic groups found in the marine park: the majority Makonde, and the minority Makua. These communities depend on fisheries as the main source of income, but also practice agriculture, casual farm labor, and run small businesses (URT 1998, URT 2005). Agriculture is carried out only at small scale for both cash and food crops (Malleret 2004).

Although fishing is a major activity, until recently it has been primarily based on traditional and small-scale fishing tools. The inefficiency of traditional fishing gear and the need to increase revenue motivated the communities to use dynamite fishing, which also fueled the efforts to create this marine park (Malleret 2004, URT 1998, URT 2005).

Prior to the park's establishment, the communities were fishing as far away as Kilwa in northern Tanzania and Mozambique to the south. Periodic migration was also practiced whereby men and women fishers, as well as temporary settlers from other areas, camped in small islets inside the current marine park (Malleret 2004, Muhando et al. 1998). Temporary migration is still practiced in the islands, but to a lesser extent than during the period prior to the park's creation of fishing zones and the enforcement of restrictions, described below.

Photograph 1. A fisherman, ready for the day, towing a traditional boat.

The management of Mnazi Bay Marine Park

The park's general management plan requires collaborative management with villagers through a Board of Trustees under the Marine Parks and Reserve Unit (URT 2005). To bridge the gap between the marine park and local communities, the marine park worked with the United Nations Development Programme (UNDP) to create Village Environmental Management Programmes (VEMPs). These VEMPs exist in the first ten villages that joined the marine park, and are composed of committees that manage different roles. These include mangrove forest management and overseeing conservation activities in collaboration with village governments to coordinate patrols.

The creation of this marine park led to the restriction of the traditional fishing methods, closure of some fishing grounds, and controlled harvest of fish and other marine resources (e.g. mangrove) through the creation of four zones in the marine park. The core zone prohibits the extraction of resources. The specified user zone provides certain use rights to park residents but restricts use by non-residents. The general use zone only allows access to non-residents through permits. Additionally, an encircling buffer zone acts to protect the park from activities occurring outside its boundaries (URT 2005).

Research Methodology

Site selection rationale

Several factors contributed to the selection of the Mnazi Bay Marine Park for this study. First, because the marine park is new, there has been little research of its impacts on local communities. Second, there have been conflicts reported in some villages of the park. Third, the inclusion of people in the marine park offers a counterexample to most existing literature on protected areas because of different characteristics between marine and terrestrial protected areas. Fourth, not only is conservation essential to this marine park, as it ranks among the highest in marine biodiversity in East Africa, but additionally, communities found in the park are poor and depend on the marine resources for their livelihoods (Gawler and Muhando 2004, Malleret 2004, Malleret and Simbua 2004).

Sampling and analysis plan

I conducted this study in six villages for a period of six weeks. Five of the six villages are located in the park while the other village is located in the buffer zone. A multi-method approach was used to increase reliability of the primary data. A total of 160 semi-structured interviews were conducted with the heads of households in four villages, with 40 interviews in each village. Four villages were selected based

Table 1. The relationship between main economic activities (fisheries and agriculture) and other variables.

Dependent variable:	Fisheries			Agriculture		
Predictor variable	*p*	Coefficient (β)	Exp (β)	*p*	Coefficient (β)	Exp (β)
Marine park officials performance rate	0.048	-0.586	0.557	0.238	0.327	1.386
Village location (seafront versus inland)	0.88	-0.071	0.931	0.924	0.043	1.044
Attitude towards fishing	0.831	-0.103	0.902	0.235	-0.567	0.567
Age (above 18)	0.024	-0.889	0.411	0.012	0.965	2.625
Gender (male)	0.066	-1.379	0.252	0.027	1.388	4.001
Coping mechanism during food scarcity	0.005	1.512	4.536	0.049	-1.102	0.332
Education (formal)	0.249	-0.311	0.733	0.871	-0.42	0.958

Notes: Education, marine park officials performance rate, village location, attitude towards fishing, age, gender, and coping mechanisms were used as control variables (predictors) for both fisheries and agriculture. The value of regression coefficient (β) determines the direction between the outcome variable (fisheries and agriculture) and the predictor variable (e.g., gender) (Peng et al., 2002). β is significant at 1%, 5% and 10%. Exp (β) is the odds ratio.

on the following criteria: a village which has over time shown negative attitudes towards the park; a village that is far from the park (inland village); a village that is close to the ocean (seafront village); and a village with high dependency on marine resources (fisheries). The other two villages were selected based on two criteria: one village is the site of recently increased conflicts with the park, and the other village is located in the buffer zone but refused to join the marine park. This inclusion of villages with various characteristics during research enabled me to understand the heterogeneity of dependency on fisheries; trends and possible sources of conflicts by village and across the park; perception of the park by villages; and the patterns of livelihood diversification and strategy across the park.

Questionnaires, focus group discussions, archival research, participant observation and interviews with park officials were used as methods of primary data collection. The combination of several methodologies provided detailed information on the interaction between the marine park and communities at both household and village level. Households for interviews were selected by random sampling, and were stratified based on the occupation of the head of household (in fisheries or agriculture) and presence in the village before and after the park establishment. Focus group discussions were conducted in all six villages based on the occupation and position of villagers in the decision making process of the village. Participant observation during interviews and focus group discussions facilitated the understanding of attitudes and perceptions toward the park.

Quantitative primary data were analyzed using binary logistic regression, in which several variables were regressed to understand perceptions towards the park and patterns of livelihood strategy in villages and across the park (Stevens 2002, Peng et al. 2002).

Results and Discussion

Agriculture and fisheries were found to be the main essential livelihood strategies for the local communities in the marine park, showing equal importance among all village locations. Among all age groups and genders, both strategies appear to be significantly affected by the marine park's implementation (Table 1). This influence was detected in all villages. Because this marine park is characterized by sandy soils, which do not support agriculture very well, food security could be a serious concern. As a result, communities depend more on fishing than on farming during times of food scarcity, regardless of the village's proximity to the seafront.

Most villagers also practice a variety of productive activities. One underlying factor

for this diversity of livelihood strategies is the increased responsibility to earn money that men face when they have many wives. Other studies have also shown that multiple livelihood strategies are typically practiced in poor communities (Banerjee and Duflo 2007). This extends to small businesses and casual labor on others' farms. This finding also contradicts the assumption that only fishing households were vulnerable to the effects of the park creation (Gawler and Muhando 2004).

Because fisheries form one of the primary livelihood strategies, the local communities have raised serious concerns about restricted access to fishing. In surveys and focus groups, villagers indicated that the most significant adverse impacts of the park have been the confiscation of fishing nets that do not meet the appropriate mesh criteria and the inability of the traditional fishing boats to reach the allocated areas for fishing.

Although the creation of different zones was essential for biodiversity conservation (URT 2005), losses from the reallocation led to negative social impacts in Mnazi. Many villagers are unable to fish in the new areas that the park has allocated. They claim that new fishing grounds are located in the deeper waters far from shore where their traditional dugout canoes cannot reach.

According to villagers, the park officials made several promises during the establishment of the marine park. Villagers were promised that they would receive legal fishing nets, modern fishing boats, and development of alternative income generating activities. The nets were aimed at controlling illegal fishing of undersized fish and destructive fishing practices that were originally seen as evidence for the need to create the marine park (Malleret 2004). The boats were promised to ensure that livelihoods of the local communities living within the park boundaries would not be compromised by the new fishing restrictions. To offer alternative sources of income, the park proposed beekeeping projects and the establishment of home vegetable gardens. These activities were expected to generate tangible benefits so that people could reduce their dependency on fisheries and support the conservation goals of the marine park.

However, some of the proposed activities were not compatible with the traditional activities of the communities. Surveys and interviews revealed that beekeeping, for example, is not a traditional community activity and generates only a tenth of the revenue that fishing provides per year. Home gardening proposals are not suitable for this park due to its sandy soil type. Moreover, the

Photograph 2. Despite the failure of the park's proposed livelihood strategies, some villages have tried to initiate their own income-generating projects, like this non-functional fishpond in Mngoji village. However, the marine park rarely supports these efforts.

Table 2. The relationship between attitude towards fishing and other variables.

Dependent variable:	**Attitude toward fishing**				
Predictor variable	*p*	Coefficient (β)	Exp (β)	95 % C.I. for Exp (β)	
				Lower	Upper
Marine park officials performance rate	1.57	-0.404	0.668	0.382	1.168
Village location (seafront versus inland)	0.002	1.365	3.915	1.618	9.471
Economic activities (Fisheries and	1.47	0.385	1.47	0.818	2.643
Age (above 18)	0.678	-0.388	0.678	0.333	1.382
Gender (male)	0.042	1.538	4.656	1.054	20.564
Education (formal)	0.966	0.011	1.011	0.6	1.704

Notes: Age, education, economic activity dependency, marine park officials performance rate, village location and gender were used as controls. C.I. is the confidence interval. β is significant at 1%, 5% and 10%. The description of other variables is the same as in Table 1 above.

top-down approach by marine park officials during implementation contributed to the failure of local adoption among villagers. During the planning of park activities, there were no comprehensive educational or training programs provided to demonstrate the proposed income-generating activities, and no study was conducted to estimate their feasibility.

Evidence shows, however, that the park administrators were more concerned with conservation of biodiversity and enforcing the new fishing restrictions than they were with supporting the economic well-being of community members. Ten years since its creation, the park has failed to carry out its promises to the community. Rather, the park has focused its efforts on ensuring that the locals conform to the park regulations. The promises and hopes for livelihood improvements remain a myth and have triggered social tensions, created conflicts, and have changed some people's perceptions about the value of the marine park. For example, marine park officials often travel in groups to avoid confrontations in some villages.

The changes of attitudes and perceptions towards fishing tend to vary significantly with gender and village location (Table 2). People in the seafront villages are more likely to have changed attitudes as they showed more disapproval and frustrations with the park's creation. Men appear to be more likely to have changed attitudes towards fishing than women. This could be due to greater participation in fishing by men (Malleret 2004). However, it is difficult to conclude whether this pattern is normal or transitional because of the short period of this study. Ongoing research still occurring in the marine park should clarify this.

Prior to the formation of the marine park it was common for villagers to make decisions individually and independently about the intensity of their fishing activities. The transition towards the marine park has therefore acted as a shock to most villagers. The changes in attitudes are driven by a decline in the marine resources business and the belief that outsiders (marine park officials), who represent the state, control the resources.

Trade in marine resources was carried out extensively in villages such as Msimbati before the park's creation, with traders coming from as far as Mozambique to trade fish, octopus, and sea cucumbers (Malleret and Simbua 2004). Some villagers indicated that the period of trade before the park was the most significant economic boom of their lifetime (1980s to mid 1990s). Other villagers point to the past boom in market-based fisheries as evidence that the park's creation has reduced revenues. This is the reason why other villages such as Nalingu remain unwilling to join the marine park because they feel that revenues obtained from the fishery will diminish due to the imposition of fishery

restrictions. During the interviews and focus group discussion, many villagers commented that "the ocean has been sold, we don't own anything." These comments indicate the growth of fear of marine parks by the communities and an increasing gap between them and the marine park administration. These outcomes have led to a decline in the sense of ownership of the marine resources by the local communities.

Other factors that drive the changes in perception include the failure of the marine park to deliver promises and the information gap that exists between villagers and the park. Despite the fact that the marine park officials have actively promoted the enforcement of regulations, they remain relatively unknown by most of the community. For example, about 70% of the sampled head of households were not aware of the park regulations and the existence of park boundaries. This does not prove that the information is not available, but it does reveal that park officials are not getting their message out. Though several village committees were created to bridge the gap between the villagers and the marine park and promote conservation, fishers expressed a lack of trust in these committees and claimed that they were not their true representatives in the marine park.

Conclusion

The results reveal that interactions between the park and local communities have worsened perceptions and attitudes largely due to the failure of alternative income-generating activities and the lack of participation by local communities in the marine park management. This has fueled the rejection of the marine park by villagers and increased conflicts in villages such as Nalingu. The increased separation between the park authorities and the villagers present major challenges and prevent the marine park from achieving its goals of sustainable conservation and livelihood improvement.

Recommendations

It is not too late for the Mnazi Bay Marine Park to reverse its rejection by communities and its failure to implement income-generating activities. There is a promising window for building confidence in communities because the villages have similar cultural norms and very close relationships due to intermarriage. Approaches such as the provision of environmental education to villagers and employment of locals in the marine park management will help to build confidence and increase the participation of local communities in conservation. By overcoming the challenges addressed in this paper, the marine park should be able to set a platform for enormous change in the social structure of the marine park and promote a promising future for the local communities.

The claim is not that marine parks are bad options for conserving biodiversity and protecting livelihoods, since they offer many benefits toward achieving these goals (Sanchirico et al. 2002). Instead, this paper demonstrates that the failure to integrate livelihoods and conservation provides significant challenges to the success of any conservation area (Mwaipopo 2008). These results should provide a warning to other marine park planners: bridging the gap between local communities and the marine park administration is a fundamental requirement for sound conservation.

Endnotes

1. The complete name of the park is the Mnazi Bay Ruvuma Estuary Marine Park.
2. Throughout this paper, the term 'user' means a villager, resident, or non-resident who can have access to resources in the designated areas of the Marine Park and the term 'zone' refers to the area set aside for protection of both marine and coastal environments.

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Gender and Community-Led Total Sanitation: A Case Study of Ekiti State, Nigeria

Adenike Adeyeye, MEM 2011

Abstract

Community-led total sanitation (CLTS) has succeeded all over the world, yet it has struggled in Ekiti State, Nigeria. This report examines the role "gender mainstreaming" plays in the progress of Ekiti State CLTS projects. Interviews with CLTS facilitators, community leaders, and individual households indicate that WaterAid Nigeria focuses on equal representation of men and women within the Water and Sanitation Committees (WASCOMs) and as Volunteer Health Promoters (VHPs), two entities that implement CLTS. However, equal representation does not always translate to equal decision-making power. Without clearly delineated roles within the committees, the committees' foci naturally turn to issues with which men are most familiar, as men are more vocal than women in public spaces. As a result, issues with which women are more familiar can be overlooked to the detriment of the entire community. This report suggests that CLTS facilitators present communities with the option of electing individuals to specific roles within the WASCOM, possibly in the form of sub-committees for different aspects of the program, to ensure that all relevant issues are addressed thoroughly. Sub-committees could create a space for women and men to influence decision-making equally.

Introduction

Community-led total sanitation (CLTS) appears to be the ultimate sanitation win-win. It costs next to nothing to implement, is designed to quickly become self-sustaining, and promises to eradicate open defecation and its attending public health and environmental hazards in remote villages. It is almost entirely community driven; no household level subsidies are given (Kar and Pasteur 2005). After external facilitators enter a community and run through participatory exercises to illustrate the dangers of open defecation, the community holds elections to select Volunteer Health Promoters (VHPs) and Water and Sanitation Committee (WASCOM) members.

With over two billion people lacking adequate sanitation around the world, and time running out for developing nations to meet the 2015 United Nations targets for reductions in open defecation, nations around the world are adopting CLTS as a cost-efficient means to reach these targets. CLTS has spread from its birthplace in Bangladesh to Latin America, Africa, and other parts of Asia in little over a decade (UNDP 2006; Kar and Pasteur 2005). As a result of its widespread popularity and effectiveness, WaterAid Nigeria, an international not-for-profit organization, has implemented CLTS in rural Nigerian villages since 2004 (Robinson 2009).

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Despite all the benefits, CLTS has faced criticism. Experts have stated that it fails to address gender equity and does not ensure that women and men participate equitably in CLTS implementation (Movik and Mehta 2010). In Nigeria, many regions have succeeded in reducing or eliminating open defecation, but many more still have struggled to implement the program successfully. This report explores the possibility that CLTS's limited success in Ekiti State villages is linked to its gender mainstreaming strategy.

Theoretical Literature

Gender mainstreaming

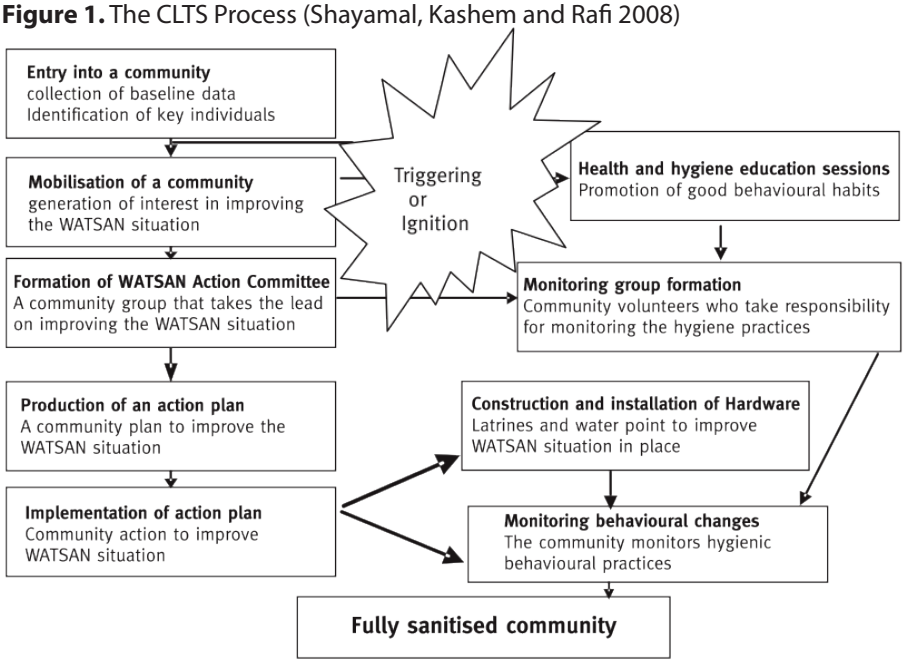
Gender mainstreaming has been a popular concept in international development policy since the 1990s. It is a reaction to the realization that women often bear much of the responsibility for implementing development projects while lacking the authority to influence decision-making and to reap the full benefits of their work (Fonjong 2001). Gender mainstreaming attempts to completely change the process of development by including a consideration of gender concerns and gender equity at all stages: project design, implementation, and monitoring and evaluation (de Waal 2006). It also requires a radical rethinking of processes and policies from community-level implementation of a project all the way up to planning and visioning at the executive level. Gender mainstreaming can result in greater female participation in typically male-dominated development projects as well as greater collaboration between the genders when implementing development projects (de Waal 2006).

While gender mainstreaming has become very popular at the policy level, such an approach often meets resistance at the regional and local levels. Local NGO staff or government staff can view gender mainstreaming as something they have to implement in order to fulfill their responsibilities to donors. They will incorporate gender mainstreaming into their projects, but they may not see how the gender mainstreaming process benefits communities or understand the theory behind gender mainstreaming. In addition, gender mainstreaming can be viewed as a threat to men in the community because "gender" is often equated with "women" (Wendoh and Wallace 2005). Men may be concerned that gender mainstreaming benefits women at the expense of men. However, NGOs that successfully mainstream gender in their development projects engage communities in conversation about gender equity using terms and examples that are easily understood, rather than often-confusing gender mainstreaming theory. They translate the concepts behind gender mainstreaming and facilitate discussion that helps communities realize the benefits that gender equity can bring (Wendoh and Wallace 2005).

Photograph 1. Male and female WASCOM members in Aba Audu.

Photograph 2. A woman speaking at the Osogbotedo community meeting.

Figure 1. The CLTS Process (Shayamal, Kashem and Rafi 2008)



Background

CLTS

CLTS begins with trained facilitators entering a community to "trigger" the community (see Figure 1). In Ekiti State, facilitators are local government or NGO staff. The facilitators employ participatory rural appraisal (PRA) methods to determine the status of sanitation coverage in the community. This includes going on transect walks with community members, observing all areas in which open defecation occurs, drawing sanitation maps that depict areas in which open defecation occurs, and calculating the amount of feces deposited on the land in a year. The goal of these exercises, according to the development practitioners who developed this program, is to evoke a sense of "disgust and shame" in the community (Kar and Pasteur 2005).

CLTS literature stresses that the project is to be as community-driven as possible. As the creator of CLTS says,

> "The facilitator should never lecture or advise on sanitation habits, and should not provide external solutions in the first instance (for example with respect to models of latrine). The goal of the facilitator is purely to help community members see for themselves that open defecation causes ill health and unpleasant circumstances (Kar and Pasteur 2005)."

The approach is supposed to assist community members in assessing the status of sanitation in their communities. CLTS facilitators are tasked with walking the fine line between shaming people and illuminating certain behaviors as shameful. The community should infer from the data generated using PRA tools that current sanitation practices such as open defecation and infrequent hand washing can lead to illness and death. This realization should then inspire community members to take action to reach open defecation-free status; the impetus for behavioral change in the community should not come from the facilitators forcing the community to adopt CLTS.

Communities then devise action plans

to reach open defecation-free status without household level subsidies. In many cases, this means using local materials to construct latrines. WaterAid Nigeria works with the Local Government Authority to ensure community level subsidies in the form of funding for borehole construction in all CLTS communities, as WaterAid Nigeria holds that access to water is a necessary prerequisite to access to adequate sanitation. With sanitation but without access to water, communities struggle to create and use handwashing stations, which are necessary to reduce incidence of fecal-oral disease transmission. CLTS further prioritizes community-based leadership of the program through its reliance on WASCOMs and VHPs. WASCOM members are elected to help the community develop a sanitation action plan, while VHPs volunteer to provide support as households implement changes in sanitation and hygiene practices.

Research sites

Most of the research took place in Osogbotedo, a village in Ekiti State in southwestern Nigeria. Osogbotedo is a Yoruba community, home to approximately 55 households and 235 people. Its residents are migrants from nearby states who come to the village to farm, and consider the villages and states they came from to be their true homes. Many choose not to invest in constructing latrines in homes they view as temporary (WaterAid Nigeria 2009). Nearby streams and rainwater (during rainy season) are the primary sources of water in most rural villages in Ekiti State, and there is little knowledge about the ways in which water can be contaminated. For instance, [community members] will say '*egbin omi l pani*' meaning the dirt of water does not kill" (WaterAid Nigeria 2009).

There were fewer visits to the other two research communities, Aba Audu and Ijesamodu. Aba Audu is an Ebira[1] Muslim community, and, like Osogbotedo, the residents came to Ekiti State from a neighboring state to farm. Ijesamodu is a larger community, and, unlike Aba Audu and Osogbotedo, its residents have lived in Ekiti State for generations.

Despite the differences amongst these communities, gender roles are clearly prescribed and consistent across the three villages. Women

Photograph 3. A latrine constructed using only local materials in Aba Audu. CLTS encourages a variety of latrine construction options so that all members of the community can improve their access to sanitation.

make goods such as palm oil or *gari*[2], trade goods at the market, and work at home. Most men farm. Women sometimes assist with farming, but mainly during the harvest period, while men work on the farm more regularly (Flinn and Zuckerman 1981). Though men are the heads of household and are the public face of the family, women are actively involved in work outside the home as well, through trading.[3] Gender mainstreaming in Ekiti State is important not only because women are responsible for much of the labor CLTS generates, but also because existing gender relations indicate that women can become more equal participants in CLTS decision-making processes.

Methodology

Data were collected through semi-structured interviews and observations in the three villages, as well as through a questionnaire administered to households in Osogbotedo. Each of the three villages fell under the jurisdiction of a different Local Government Authority (LGA)[4]. At the LGA offices, I interviewed staff involved in the CLTS implementation process using semi-structured interviews.

In the three communities, I conducted a community meeting. In two communities, Aba Audu and Osogbotedo, the meeting was open to all community members. In Ijesamodu, the meeting was limited to WASCOM members, VHPs, and local leaders. In each community, I met with all WASCOM members as a group. In Aba Audu and Osogbotedo, semi-structured interviews were conducted with people holding leadership positions in the CLTS program at the community level, such as WASCOM members, VHPs, nurses at a community health clinic, and people selling sanitation materials. In Osogbotedo, I conducted structured interviews at 20 households. Every fifth household was surveyed in an attempt to randomize the sample. Household interviews were conducted with any adult over 18 years old living in the household. All interviews at the community level took place with the assistance of a translator. Staff at the WaterAid Nigeria national office in Abuja and in the Ekiti State office provided research support, access to prior evaluations of CLTS programs, and information about the WaterAid Nigeria approach toward achieving gender equity.

Findings

Based on interview data from Osogbotedo, open defecation is a common sanitation practice. Of the twenty households interviewed, fourteen households (70%) had no access to a latrine while six households (30%) did. The fourteen households included over 87 of the approximately 235 residents of Osogbotedo[5]. All households without a latrine reported that they practice open defecation.

Sanitation-related labor

Understanding how labor is distributed within households is essential in crafting an appropriate gender mainstreaming strategy. Women's work centers around caring for children, cooking, cleaning the interior of the home, and fetching water, with children supporting women in household work[6]. Interview responses indicated that CLTS has positively impacted women's labor, particularly in fetching water. Twelve of the 20 households reported that the construction of the boreholes as a result of the CLTS project had decreased the amount of time required to fetch water per day, and 16 of the 20 reported that since the construction of the boreholes, they have enjoyed more access to water.

CLTS had a less direct impact on men's work. Men are responsible for environmental sanitation, or ensuring that the community itself looks clean and orderly without overgrown bushes. In interviews, community members discussed cutting back brush, typically men's work, as an important part of the CLTS program and a way to safeguard public health, as brush surrounding the community provides habitat

Photograph 4. A woman making palm oil in Osogbotedo. Making palm oil is one of women's main occupations in the village.

for snakes. According to CLTS facilitators and community members, men are responsible for constructing latrines or hiring contractors to construct latrines. After the construction phase is completed, they are less involved in ongoing maintenance of the latrines and are not involved in household water management.

CLTS facilitators take the gendered division of labor into account when structuring their CLTS interventions. As an LGA Program, Monitoring, and Evaluation Officer (PMEO) said, "First of all, you invite the women…If you are able to change the attitude or culture of the women, they will influence their husbands" (Akintayo Oyo, personal communication, June 30, 2010). CLTS facilitators ask the women about water sources and the quality of water, knowing that men do not have the same experience and would not have answers. Meanwhile, they talk to men about constructing hardware (latrines, bathing areas) and working with the borehole contractors, as women would not generally be involved in that work (Akintayo Oyo, personal communication, June 30, 2010).

Gender and decision-making

CLTS facilitators are tasked with making sure that women and men are represented in nearly equal numbers amongst the CLTS leadership – the WASCOMs and VHPs. Osogbotedo had a relatively even number of men and women on its WASCOM – nine men and six women. Membership in the WASCOM appeared to be fluid. Men who were not elected members of the WASCOM would attend WASCOM meetings. Though the Osogbotedo WASCOM has 15 members, sixteen men and five women attended the WASCOM meeting that took place during the research period. During the meeting, none of the women spoke; men discussed road maintenance, reported challenges in constructing latrines to the LGA, the most recent LGA staff visit, and changes in water fetching and management as a result of

the boreholes.

Though men dominate public life in Osogbotedo (and the other two research communities), households interviewed in Osogbotedo also noted the importance of women in water and hygiene-related labor. When asked who has more control over sanitation decisions in the household, men or women, 13 of 20 respondents (6 male, 7 female) said neither did, because men and women each have their own roles. One female respondent said women had more power than men because the men are always gone, while the women stay in the home. Six of 20 respondents (3 male, 3 female) reported that men had more power than women because they are responsible for giving orders.

Analysis

WaterAid Nigeria and its state and local partners clearly recognize the importance of women's equitable involvement in water and sanitation programs. Reports from WaterAid Nigeria's Ekiti State office include equity and inclusion as metrics for evaluating their work. In the 2009 third quarter report, the Ekiti State office listed two performance indicators that corresponded to their "equity, inclusion, and gender" objective. The indicators were: (1) "adequate representation of women and physically challenged persons in WASHCOM [sic] and VHP" and (2) "adequate representation of women and physically challenged persons[7] in proposed [Water Management Committee]" (WaterAid Nigeria-Ekiti State). The Ekiti State program assesses gender equity through the number of men and women occupying leadership positions in CLTS (i.e. the number of male and female WASCOM members).

The focus on male and female representation in CLTS leadership positions is important. Encouraging gender balance can empower women, since their involvement in a project is necessary to fulfill the goals established by WaterAid Nigeria and the CLTS facilitators. The requirements can give women more power in the public sphere than they would have otherwise (Meinzen-Dick and Zwarteveen 2001). However, that power does not automatically translate to a meaningful involvement in the decision-making process, and these indicators can obscure the real power dynamics within leadership bodies.

Observations indicated that women do not have the same decision-making power as men, even if they hold the same leadership positions as men. In Osogbotedo, women and men serve as WASCOM members and VHPs, but more men than women attend the WASCOM meetings. Men were the only ones who spoke during the WASCOM meeting attended in July 2010. The meeting focused heavily on typically male activities, such as road construction, rather than typically female activities, such as water management and household hygiene and sanitation.

Reviewing WaterAid Nigeria project reports and interviewing LGA staff involved in CLTS facilitation produced few details about ways that WaterAid Nigeria and CLTS facilitators encourage gender equity. LGA staff reported that WaterAid Nigeria trained them on gender equity and told them to ensure as much as possible that women and men have equal rights. LGA staff, as mentioned above, recognize the importance of engaging women from the start of the CLTS "triggering" process. Yet interviews with LGA staff reiterate the findings from WaterAid Nigeria's Ekiti State reports: the number of men and women involved in the project is the only indicator used to assess equitable engagement of men and women in CLTS projects.

Women and men have different roles and responsibilities within the visited communities, and this gendered division of labor could be used to allow women and men to participate equally and meaningfully in CLTS. The CLTS handbook notes the difference between male and female leadership: "Women natural

leaders tend to be less visible than their male counterparts in latrine construction but more active and responsible in their maintenance, establishing usage norms, and sustaining hygienic behavior change" (Kar and Chambers 2008). CLTS facilitators could encourage communities to clearly delineate responsibilities for the WASCOM and for VHPs, and to note which responsibilities are more in line with work that women usually do in the community and which are in line with typical men's work in the community. As a result communities will have established, even before the committee members are elected, areas in which women's experience suggests that women should lead and areas in which men's experience suggests that men should lead. However, care should be taken to ensure that this system does not pigeonhole members of either gender. The gendered division of labor is dynamic, and this system could allow for that dynamism through community review of delineated responsibilities at predetermined intervals.

If communities create their own rules for WASCOMs and VHPs, there will be more community buy-in, as has been seen in Aba Audu. In Aba Audu, community members elected male and female WASCOM members and agreed to follow rules that the WASCOM set, so that even in a highly patriarchal society, all community members had to respect the authority of female WASCOM members because they speak for the entire WASCOM. A similar system of respect for the knowledge and power of both genders is needed within these leadership bodies in order to achieve gender equity. If communities establish clear responsibilities for WASCOMs and VHPs while keeping the gendered division of labor in mind, there will be space for women and men to take the lead in decision-making based on their experience with the issue at hand. This will result in the most qualified WASCOM members leading the decision-making process on a given issue, while allowing all WASCOM members to participate.

Conclusion

Ekiti State has much to gain from CLTS, but as of yet, the potential health and sanitation benefits have not been fully realized. CLTS is not succeeding in Ekiti, and this may be due to the fact that women and men do not have the same decision-making power, even when they hold the same leadership positions. In a generally patriarchal society, men speak for the community and take the lead in conducting business with people from outside of the community, such as LGA staff. LGA staff and other CLTS facilitators do ensure that women and men are represented in equal numbers in CLTS leadership positions, but this does not result in women and men having the same amount of power in these leadership bodies. CLTS facilitators do need to respect the rules and norms of the communities they visit, but there are ways to help foster a more equitable distribution of power without imposing external beliefs on communities, such as articulating individual WASCOM member and VHP roles so that all members have the opportunity to exhibit leadership and make decisions.

Clearly established responsibilities for WASCOM members and for VHPs will help create a much-needed space for women to influence decision-making. This could mean creating sub-committee roles within the WASCOM. For example, one member (likely a woman) would be head of the sub-committee on water management while another member (likely a man) would be head of the sub-committee on latrine construction. Through this system, the most knowledgeable members of the committee would lead the discussion and decision-making process at all times. This is an organizational strategy that facilitators can pose to community members during triggering. Community members can decide whether to adopt this strategy and can create and modify responsibilities to fit their needs.

Endnotes

1. An ethnic group in neighboring Kogi State.
2. Coarse flour made from cassava.
3. This is consistent with research on gender relations in Yorubaland, which has found that women in Yoruba society are traditionally very independent and engaged in trade (Guyer 1980, McIntosh 2009, Oluwoye 1990, Schiltz 1982, Van Staveren and Odebode 2007).
4. Each Nigerian state is divided into Local Government Areas that are governed by Local Government Authorities, similar to county governments in the United States.
5. Thirteen of the households combined had a population of 87. The fourteenth household reported that there were too many members of the household to count.
6. Nine of the 20 households interviewed in Osogbotedo indicated that children either helped with or were solely responsible for fetching water (a task for which women are normally responsible).
7. Physically challenged individuals are included because they are disproportionately affected when there is no access to latrines and are forced to walk long distances to defecate.

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A Regional Strategy for Water Resource Management in the Caribbean Region of Colombia

Juan Pablo Vallejo, MEM 2011

Abstract

Over the last twenty years, seasonal weather events in Colombia have become an increasing challenge for the development of the country, especially because of economic, social and ecological vulnerability. Water resource systems are especially vulnerable, particularly in the Caribbean Region, in the northeastern part of the country. Environmental degradation, coupled with more frequent and severe weather events, is increasing the probability of droughts and floods. Dealing with this situation, in order to achieve economic and social progress, will be a significant challenge. Focusing on the Caribbean region, it is clear that an institutional framework that favors an integrated adaptation strategy on water resources is necessary. Such a focus will increase the resilience of environmental and socioeconomic systems to the adversities of extreme weather events, as well as secure the economic growth of one of the most productive regions of Colombia.

Introduction

Increasingly, we are witnessing the potential of nature to alter the environmental and socioeconomic conditions of humans. Meteorological phenomena previously expected to occur every 100 years are becoming more frequent and more intense, negatively impacting the living conditions of millions of people around the world. The Latin America and Caribbean region is particularly vulnerable to weather events because of deficiencies in social and economic structures, severe degradation of the environment caused by changes in land use, and extreme seasonal weather patterns. Water is the principal factor by which climate events such as "La Niña", "El Niño", and those associated with climate change, affect human and environmental systems, exacerbate existing vulnerabilities, and limit the development of nations. Colombia, located in the northwestern corner of South America and bathed by Caribbean waters, has historically dealt with extreme weather but now increasingly struggles with it. The country faces many challenges related to the management of water resources in specific zones such as the Caribbean region, mainly because environmental degradation from anthropogenic activities has damaged the capacity of ecosystems to regulate the natural cycle of water. The natural ability of the Caribbean region to deal with seasonal weather events is progressively diminishing, as evidenced by water shortages during dry periods, such as "El Niño", and water excess and floods in rainy periods, such as "La Niña".

Juan Pablo Vallejo is from Colombia and holds a BA in Economics from Universidad de los Andes, Bogotá, and a Master of Environmental Management from Yale F&ES. While at Yale, he worked with the U.N. Economic Commission for Latin America and the Caribbean on climate change and water resource management. Juan Pablo plans to combine his experience in finance and management to promote environmental sustainability and address climate change.

Methodology

This paper uses a natural resources policy process framework, for the purpose of "gaining knowledge and insight into the decision process" (Clark 2002) of the natural resource conservation and water resource management policies in Colombia. I draw on the most relevant information on biophysical settings in the Caribbean region, as well as academic and government literature on environmental policy and institutional frameworks, personal interviews, and media accounts. The purpose is to identify the drivers of environmental degradation and determine the optimal social, economic and policy framework for improving and integrating the management of water resources in the area. Finally, I identify the challenges and opportunities for such a strategy and provide recommendations for integrating environmental conservation activities with the country's development objectives.

Background

In terms of water resources, Colombia is one of the richest countries in the world, thanks to its geographic position and its variety of climates. The annual average precipitation is about 3,000 mm, an abundant volume compared to the world average of 900 mm and the South American average of 1,600 mm (IDEAM 2010a). The volume of water runoff is 58 liters/second/km^2, six times greater than the world average water supply. As a consequence, Colombia has around 1,000 permanent rivers, while, in comparison, the African continent has less than 60 (MAVDT 1996). The Caribbean Region of Colombia is comprised of nine major watersheds (Figure 1) that represent 30% of national water availability (Table 1). The Magdalena River, the largest river in Colombia, drains a large surface in the area and feeds other major and minor water bodies, canals, and mangroves, forming a complex water

Table 1. Composition of major and minor watersheds in Colombia (Ojeda 2002).

Major Hydrographic Watersheds	Quantity	
	Watersheds	Sub-watersheds
Atlantic-Caribbean Slope		
Sierra Nevada and Guajira	29	6
Magdalena – Cauca	176	220
Sinú River	29	
Atrato River	28	39
Other affluents from the Caribbean Sea	23	6
Subtotal	285	271
Pacific Slope		
Baudó River	8	
San Juan River	16	21
Dagua – Naya – Guapi – Micay Rivers	17	24
Iscuandé – Patía – Mira Rivers	14	40
Other affluents from the Pacific Ocean	16	
Subtotal	71	85
Eastern Colombia Slope		
Catatumbo River	17	36
Arauca River	5	10
Orinoco River	5	55
Amazonas River	4	32
Subtotal	31	133
Total	**387**	**489**

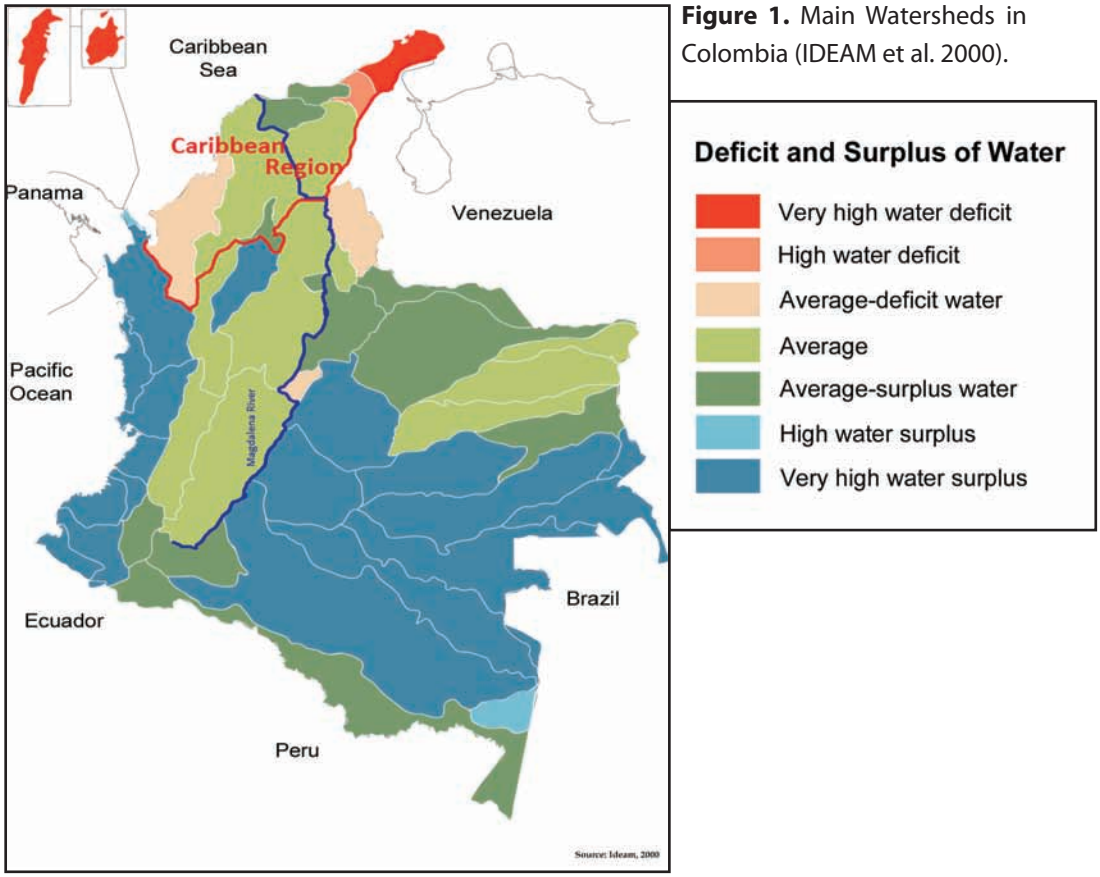

Figure 1. Main Watersheds in Colombia (IDEAM et al. 2000).

system (Figure 2) that has the ability to expand and contract during the year according to the precipitation regime (IDEAM 2010b).

The complexity of the hydrological configuration of the Caribbean region makes it very reactive to seasonal weather events, especially when these are more intense and last for larger periods of time, probably in part as a consequence of climate change. In August 2009, during a national symposium on the evaluation of natural risks in Colombia, IDEAM's Director reported, "The intensity and frequency of extreme events is increasing in Latin America, and in Colombia, located in a region affected by the warming of Pacific waters, the impact is much stronger than any other country of the region (Caracol 2009)." At that time, the country was suffering from the impacts of the "El Niño" Southern Oscillation (ENSO), a meteorological phenomenon characterized by increased temperatures and reduced precipitation (IDEAM 2010b).

In contrast, the second half of 2010 was the rainiest period in over 30 years due to a prolonged and intense cool and rainy period known as the "La Niña" Southern Oscillation (LNSO). This event caused major floods in rural and urban areas of the Caribbean region, affecting more than 1,300,000 people and causing the death of around 200 (IDEAM 2010c). It has been the worst natural disaster in the history of the country, and the President declared a state of emergency in 28 of the 32 departments of Colombia (Colombia Humanitaria 2010).

In sum, the period 2009-2010 showed that the Caribbean region of Colombia is not properly adapted for extreme weather events. This happens not only because of the severity and intensity of such patterns, but also because human interventions and socioeconomic activities have modified the water networks and

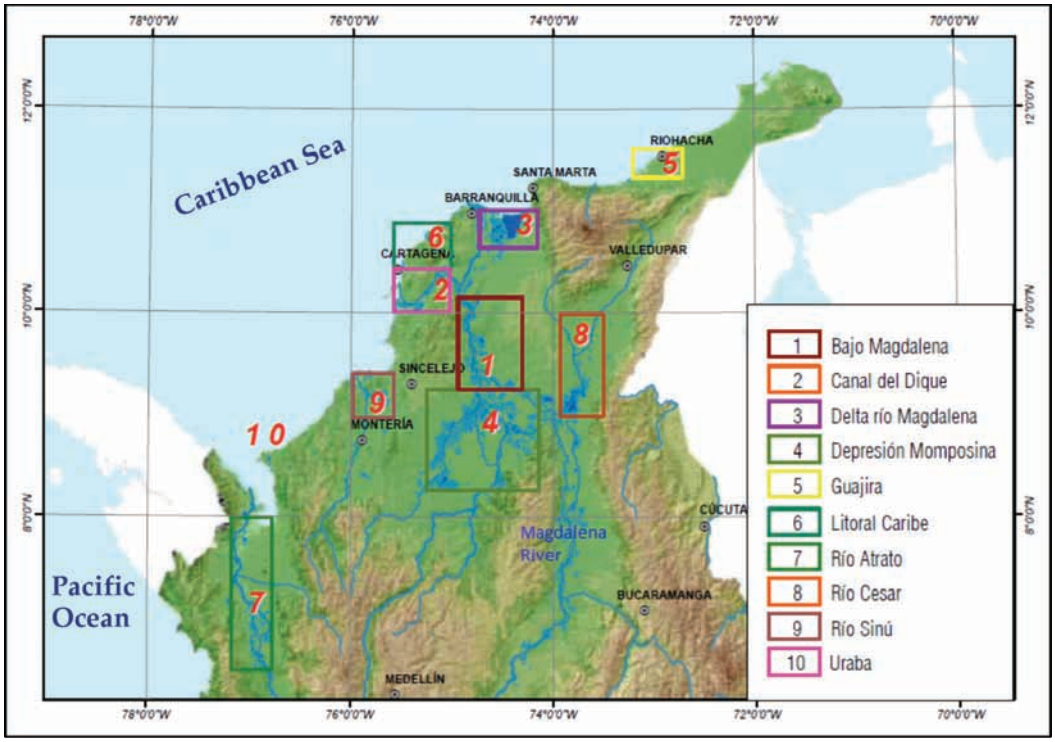

Figure 2. Wetland Systems in the Caribbean Region (IDEAM et al. 2010b).

degraded the ecosystems that are responsible for maintaining the balance of water resources.

An example of the aforementioned human impact is the fact that the Caribbean is the region of Colombia with the greatest rates of deforestation; in the period 2000-2005, 9.3% of the forest was lost while the national average was 4.2%. Forest coverage is being replaced mainly by the expansion of secondary vegetation (38%), grasslands (36%), and agricultural land (15%) (Moore Foundation 2010). Expansion of the major economic activities of the area, such as logging, agriculture and ranching, are responsible for the degradation of the natural systems that are fundamental for maintaining the water balance in the region.

The situation described above highlights the urgent need for policies to prevent environmental deterioration and efficiently manage water. This can only be achieved by strengthening national and local environmental institutions and including environmental consciousness in the development goals of the country.

Analysis

The Policy Framework

In 2010, the Vice-Ministry of Environment, Housing, and Territorial Development launched a National Policy for Water Resource Management in Colombia (MAVDT 2010), with the goal of guaranteeing the conservation and sustainability of the ecosystems that regulate the water cycle.

However, this policy does not address the need for alternative livelihood options and land use practices that prevent environmental degradation. Nor does it evaluate the behaviors and relationships that the population has with the environment, including water resources. Clearly, the water resources and livelihood needs of the population are both of utmost importance, and clarifying and securing the common interest must be the goal of policy and decision making.

In addition to the inability of policy to address the water resources and livelihood needs of the people, national and regional

governmental institutions lack capacity to make decisions about interventions in the water infrastructure. Mr. Jose Vicente Mogollón, former Minister of the Environment states: "The water resource management issue in the Caribbean region has been deeply studied for fourteen years; however, technical incapacity from the environmental institutions explains why no relevant interventions have been made" (Mogollón 2011). Bureaucracy, corruption and a lack of institutional coordination have become a major impediment for the execution of proper environmental and infrastructure improvement plans.

For example, the effects of 2010's rainy season were devastating in part because of a failure in the existing water infrastructure, the breaking of the "Dique Canal" (Figure 3), an artificial levee that was built in colonial times but never improved despite several technical proposals to do so. The extreme and prolonged rainy season, coupled with upstream environmental degradation and deforestation, overwhelmed the structurally weak levee. As a result, the agriculture, fishing and ranching communities surrounding the canal became inundated; the tragedy, often compared to 2005's Hurricane Katrina (Semana 2010), is a clear example of the government's failure to design proper policies and take responsibility for upkeep of water infrastructure to prevent natural disasters. Additionally, the example shows the institutional indifference to the social and economic implications of such disasters.

Seemingly thoughtful and comprehensive policy guidelines abound in Colombia, but there is still considerable weakness in the definition of responsibilities, social inclusion, application, appraisal, and enforcement. Additionally, environmental sustainability and natural resource conservation are not central tenets of the national development strategy, and environmental issues will continue to be obscured if economic and political interests are prioritized over basic values and human rights. Even though the goal of policy is to protect common interests, it is clear that current efforts related to ecosystem conservation and water management are suffering from a lack of political will, thus exacerbating poverty and inequality in one of the most vulnerable regions of Colombia.

Findings

Historically, environmental sustainability has not been a priority of the political agenda or institutional configurations. Functions and responsibilities that correspond to

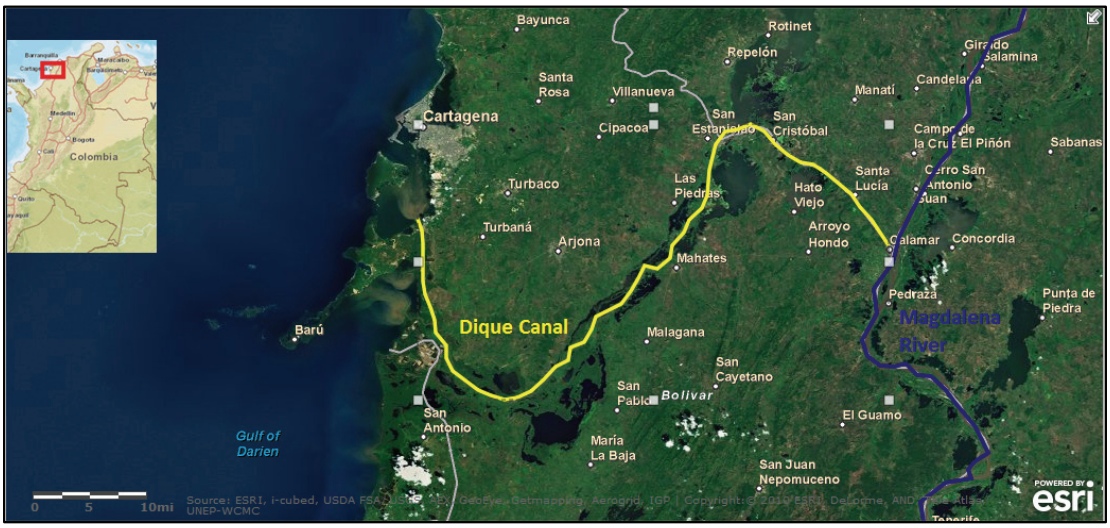

Figure 3. The Magdalena River and "Canal del Dique" (Source: ArcGIS 2011).

environmental authorities fall under the shadows of institutions with greater political impact and control. In 2002 for example, the Ministry of Environment and the Ministry of Housing, two independent institutions, were combined, reducing the budget for environmental research and capacity building. Former Minister of the Environment, Mr. Manuel Rodríguez Becerra, describes this situation: "The sacrifice of environmental protection with the objectives of short-term economic growth and the weakening of the first environmental authority [Ministry of Environment, Housing, and Territorial Development] are the main reasons for the deterioration of environmental policy in Colombia" (Rodríguez B. 2007).

Environmental policy in Colombia focuses on using natural resources, rather than environmental conservation. Water, from a policy perspective, is therefore valuable in terms of the resource it provides to productive sectors (from a supply standpoint). In this sense, water policy centers on management to benefit economic and political interests, rather than management to achieve social equality and environmental progress. Similarly, natural resource policy is "vulnerable to political decisions and, therefore, to political changes. Decisions about government priorities, funding, appointments, political will and relations with civil society, all affect the Ministry of Environment" (Mance 2007).

Environmental policy in Colombia is highly dependent on the dominant political agenda which prioritizes short-term economic progress. Foreign direct investment, infrastructure building, and the development of particular economic sectors are thought of, by those in power, as providing more immediate and measurable results which reflect well on political leadership. In fact, the National Development Plan of Colombia for the period 2010-2014 proposes five areas crucial for development, translated as "Locomotives for growth and employment": 1. Innovation; 2. Agriculture and rural development; 3. Transport infrastructure; 4. Mining and Energy; 5. Housing and urban development (DNP 2010). There is significant cause for concern that existing environmental institutions will be unable to control and monitor the environmental aspects of this five-pronged approach, let alone their potential inability to withstand the pressures of particular constituencies to prioritize economic profit over common interests.

Under this national initiative, the Caribbean region faces an important challenge because it is a zone where logging, agriculture, mining, and ranching have been traditionally practiced. These activities have already led to a 95% loss of native forest, making the Caribbean the most environmentally deteriorated region in Colombia (Rodríguez B. 2005). Enhancing these sectors without first addressing water management issues could aggravate the current situation because such activities are responsible for the major loss of ecosystems which deregulates the water cycle.

The irony is that, in the long-term, growth in the aforementioned sectors will likely lead to an economic decline that will prevent the region's progress and development. Losses from climate related events in the period 1970-2000 represented around 2.66% of the GDP (year 2000 base) (IDEAM 2010a), and the devastation from the 2010 rainy season will require about USD $15 billion in humanitarian aid, reconstruction and prevention, nearly 6% of the GDP (DNP 2011). Meanwhile, the government's investment in preventing and managing natural disasters between 2005 and 2007 was equivalent to just 0.15% to 0.24% of GDP.

Challenges, Opportunities, and Recommendations

The most urgent challenge for the Caribbean region, in terms of water resource management, is to prioritize the development of an environmental agenda in Colombia that

includes natural resource conservation as a key element of development. In order to strengthen environmental institutions and environmental policy, stakeholders from the public and private sectors, as well as civil society, must develop a common agenda. The current situation can be used as an opportunity to improve governance and enforcement around water resource management issues, so that projects that have positive environmental, social, and economic impacts can prevail in the long term.

Policy change related to land tenure, valuation and use is critical. Land should be valued for the environmental services it provides, not just as a resource for transformation and exploitation. Options for improvement include:

1. Creating market incentives and economic conditions that incentivize land conservation practices. Currently, agricultural economics require maximum exploitation of land, with little concern for conservation.

2. Prioritizing conservation initiatives focused on water resource management in the Caribbean region, given the vulnerabilities of natural and human systems.

3. Increasing funding for policy research and development, implementation, monitoring and control. This could be given priority in the development goals of the Caribbean Region.

4. Developing education programs for communities that derive economic benefit from environmental over-exploitation. In addition to the aforementioned recommendations, a change in attitude and cultural behavior is necessary. Water should be viewed as a tool for integration, equality, and progress.

Finally, it is necessary to begin including climate change issues in environmental policy. Although there is still no definitive evidence that climate change is a driver of more extreme and prolonged seasonal weather phenomena like "La Niña" or "El Niño, climate change is a central topic in the international agenda. The Economic Commission for Latin America and The Caribbean estimated that the overall impact of climate change in this region could represent an annual loss of around 1% of regional GDP under a business as usual scenario (ECLAC 2010). Therefore, linking the issues of natural resource conservation, land use management, institutional enhancement, and environmental governance to discussions on climate change will encourage national and international authorities to develop adaptation strategies. Given the centrality of water resources in the economic and social fabric of the Caribbean region of Colombia, initiatives for water resource management adaptation need to start immediately, even as institutional gaps are filled. In other words, the interactions of water resources and society require adaptive management in the Caribbean region of Colombia.

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II. HUMAN HEALTH

Characterizing the Urban Environment of Dengue Mosquitoes in Patillas, Puerto Rico

Eliza Little, MESc 2011

Abstract

Aedes aegypti is a mosquito of particular importance because it is implicated in dengue transmission in tropical urban areas around the world. More than half of the world's population now lives in urban areas with continued urban growth expected. Much has been done to curb *Ae. aegypti* populations through integrative vector control. However, the efficacy of vector control methods may be undermined by the presence of alternative, competent species. In Puerto Rico a native tree dwelling mosquito, *Ae. mediovittatus*, has been shown to be a competent dengue vector in laboratory settings and its habitat has been found to overlap with *Ae. aegypti*. GIS and remote sensing have proven to be effective in identifying suitable mosquito habitats in ex-urban settings. This research discusses their utility of analyzing heterogeneous urban landscapes and the features present therein that drive the abundance and distribution of these important *Aedes* species. Analysis suggests that the use of high-resolution remote sensing can be used to determine the environmental drivers of the distribution of *Ae. aegypti* and *Ae. mediovittatus.* Although these species tend to segregate into different habitats, their habitats do overlap. Further exploration of areas of overlap is necessary to determine the involvement of *Ae. mediovittatus* in this dengue disease system.

Introduction

This project is inspired by the observations that the variability of environmental characteristics across a landscape affects the distribution of species and their interactions, and that the ineluctable growth of urban ecosystems provides new nodes for disease ecology.

Eliza Little graduated from McGill University with a B.A. in Environmental Science in 2005. She worked as a field biologist for 3 years before returning to do a Joint Masters at Yale between the Schools of Epidemiology & Public Health and Forestry & Environmental Studies. There she specialized in disease ecology, studying epidemiology, urban ecology, GIS, and remote sensing. She will continue studying disease ecology next year on a Fulbright Research grant in Bangalore, India.

The World Health Organization (WHO) estimates that more than 2.5 billion people in the world are at risk for dengue fever (WHO 2009), representing a thirty-fold increase in the last 50 years (CDC 2009). The emergence of dengue as a significant disease coincides with rapid urbanization over the same time period. Currently, dengue is prevalent in 100 countries with an estimated 50-100 million cases of dengue fever per year (WHO 2009), with most of these cases occurring in Asia, Africa and Latin America. Between 2000 and 2030, Asia's urban population will increase from 1.36 billion to 2.64 billion, Africa's from 294 million to 742 million, and that of Latin America and the Caribbean from 394 million to 609 million. As a result of these shifts, developing countries will have 80 per cent of the world's

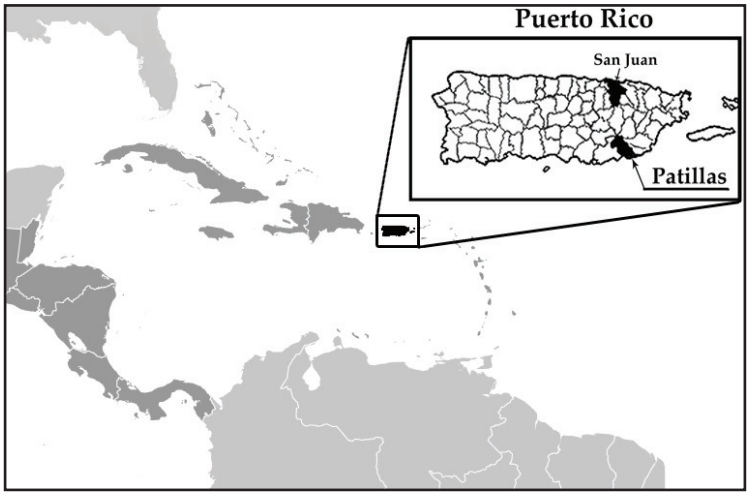

Figure 1. Location of Patillas, Puerto Rico

urban population in 2030 (UNFPA 2007). In developing countries, where urbanization may outpace the government's capacity to provide essential services such as running water and sanitation, the risk of dengue transmission may increase.

This research combines satellite remote sensing with geospatial analytical tools that map the environmental drivers which determine the spatial distribution of dengue mosquitoes across an urban area. Broadly, the main goal of this research is to characterize the environment within urban areas in Patillas, Puerto Rico, and determine the distribution and abundance of dengue mosquitoes. Specifically, we aim to define the environmental determinants of *Ae. aegypti* and *Ae. mediovittatus* and what environmental conditions promote their co-occurrence. We hypothesize that *Ae. aegypti* will be more closely associated with urban areas while *Ae. mediovittatus* will be more likely to occur in forested areas, and that their co-occurrence will occur at the edges of both habitat types or in urban areas with a high tree canopy.

Dengue transmission mechanisms and spatial characteristics

Dengue is a viral fever transmitted by the bites of infected mosquitoes (the vector) mainly of the genus *Aedes*, species *aegypti* (Hotez et al. 2008; WHO 2009). Unfortunately, there is currently no vaccine for the treatment of dengue. Best practices for dengue prevention are integrated vector control methods including reduction of vector breeding containers and community education and empowerment (Gubler 2006). It is difficult to sustain community par-

Photograph 1. View through town to Lake Patillas. This picture illustrates the typical architecture style of the area and that much of the area is forested.

ticipation strategies integral to the success of these programs especially in inter-epidemic years (Lloyd 2003).

Aedes aegypti has emerged as the most important dengue vector worldwide due to its behavioral and ecological traits. Not only is *Ae. aegypti* susceptible to dengue viruses, it relies on blood meals, is highly anthropophilic, and has a high frequency of biting multiple hosts over the course of its lifetime (Harrington et al. 2001). *Aedes mediovittatus*, also called the Caribbean treehole mosquito, is associated with arboreal vegetation (Cox et al. 2007; Smith et al. 2009) similar to the more widely distributed species *Ae. albopicuts* (Honorio et al. 2009). *Ae. mediovittatus* has been implicated in the transmission of dengue based on the observations that it readily feeds on humans, and supports dengue virus replication and vertical transmission through generations (Gubler et al. 1985).

Mosquitoes are sensitive to ecological processes that determine their distribution in the environment. Accordingly, the ecology of *Aedes* species should inform vector control measures in order to adequately direct resources to the areas of greatest need (Wilson 2002). The spatial overlap of *Ae. mediovittatus*, *Ae. aegypti*, dengue viruses, and humans in urban environments has not been determined. Based on the known geographic range of both mosquito species, it is reasonable that these two species overlap spatially. And, because *Ae. mediovittatus* bites humans, it is likely that this mosquito species can become infected with dengue viruses (Freier and Rosen 1988). Although the role of *Ae. mediovittatus* remains unknown, it should not be ruled out as an important vector in the transmission dynamics of dengue in Puerto Rico, especially in urban areas with high canopy cover.

The recent launches of satellites capable of recording high-resolution remote sensed

Table 1. *Aedes* species by BG observation.

Presence of *Aedes* species	Frequency	Percent
Neither species	403	32%
Ae. mediovittatus	241	19%
Ae. aegypti	334	26%
Both species	288	23%

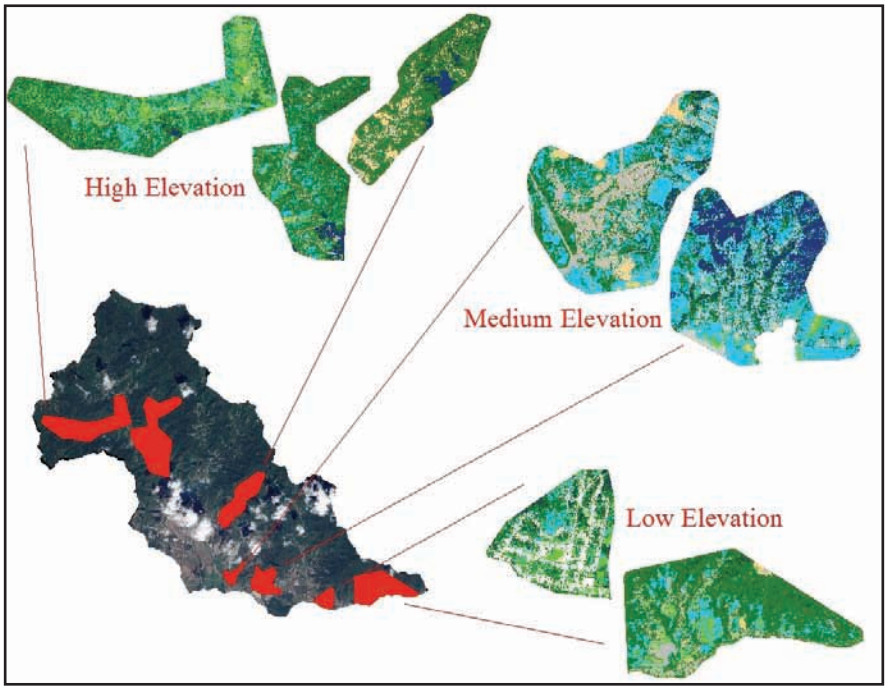

Figure 2. Maximum Likelihood Classification by location.

Table 2. Results of multinomial logistic regression using metrics generated with FRAGSTATS.

	Relative Risk	Standard Error	z-score	P-value	95% CI
Presence of *Ae. Mediovittatus*					
Trees	1.22	0.15	1.65	0.099	(0.96, 1.55)
House Density	0.82	0.13	-1.22	0.223	(0.60, 1.13)
Forest Area (Avg)	1.12	0.15	0.85	0.398	(0.86, 1.47)
Forest (NP)	1.65	0.21	3.95	< 0.001	(1.29, 2.12)
Presence of *Ae. aegypti*					
Trees	1.57	0.23	3.1	0.002	(1.18, 2.10)
House Density	2.54	0.39	6.16	< 0.001	(1.89, 3.42)
Forest Area (Avg)	0.36	0.14	-2.59	0.01	(0.17, 0.78)
Forest (NP)	1.52	0.22	2.9	0.004	(1.15, 2.02)
Presence of both *Aedes* species					
Trees	2.6	0.54	4.65	< 0.001	(1.174, 3.91)
House Density	2.34	0.39	5.26	< 0.001	(1.01, 1.02)
Forest Area (Avg)	0.26	0.09	-3.74	< 0.001	(0.13, 0.53)
Forest (NP)	2.58	0.4	6.07	< 0.001	(1.90, 3.50)

imagery have made it possible to assess the utility of such imagery to study the environmental drivers of *Aedes* species. Unfortunately, the use of high resolution remote sensing for determining the spatial extent of mosquito vectors is lacking, especially in urban areas (Chowell et al. 2008, Troyo et al. 2009). Remote sensing can be used to inform our understanding of the dynamics of disease vectors, and the structured methodology of using such technology may provide a mechanism for targeting control programs to areas of greatest risk (Chowell et al. 2008).

Study location

The study was conducted from May to August 2010 in the municipality of Patillas in South Eastern Puerto Rico (Figure 1). Patillas is 125 km^2 ranging in terrain from coastal to mountainous with peaks of 900 m. According to the US census 2000, the total population of Patillas is 20,152 with a density of 164 people per square kilometer with a mean age of 32 years old and a median household income of USD 12,021. The selection of Patillas as a study site is based on the availability of preliminary data indicating presence of both *Ae. aegypti* and *Ae. mediovittatus*. Dengue is endemic in Puerto Rico with epidemics occurring every 2 to 3 years since before 1985 (Gubler et al. 1985) and surveillance in Patillas has shown that dengue is endemic to this area (Barrera et al. 2008).

Methodology

BG-Sentinel traps were used to capture adult mosquitoes between May and August of 2010. Trap sites were selected by locating one house per 100m^2 sampling grid. The value of the sampling grid is based on the maximum flight range of *Ae. aegypti*. Trap placement was restricted to areas in close proximity to buildings to only include areas that were inhabited and where dengue transmission was likely to occur.

We used the WorldView2 satellite sensor, which was recently launched on October 8, 2009. WorldView2's features include high spatial resolution of 1.82 m (2 meter output pixels) and an 8-band multispectral image. Based on the maximum flight range of *Ae. aegypti*, the spatial resolution provided by WorldView2 is important for analyzing the fine-

scale environmental drivers of these mosquito species. The WorldView2 image was acquired on March 25, 2010 and processed using ENVI 4.7 and 4.8. Supervised classification using a maximum likelihood algorithm was used for the classification of vegetation into 4 different categories. Overall the classifications had excellent accuracy ranging from 80% to 99%, with associated kappa coefficient (.73 to .9) (Figure 2).

Further processing of classification to generate predictive variables was accomplished using a combination of Arc GIS 10, FRAGSTATS, and Geospatial Modelling Environment (GME).

Findings

The presence of *Aedes* species by observation is represented in Table 1. A total of 1,266 observations and 22 different variables from 243 different landscape-patches were analyzed to assess what environmental drivers influence the distribution and abundance of *Aedes* species. The model with the lowest Akaike Information Criterion (AIC) had predictive value (chi square = 183, 9 df, $p<0.0001$). The model included the following predictive variables: proportional area of the forest class (trees), house density, the average forest-patch area, and the number of forest-patches within the landscape-patch (Table 2).

This model indicates that the relative risk of the presence of *Ae. mediovittatus* compared to the base outcome of either species present is significantly predicted by the number of forest patches. The presence of *Ae. aegypti* or the presence of both *Aedes* species present compared to the base outcome of neither species present increases with the increasing proportional area of the forest class (trees), house density, and the number of forest patches, but decreases with increasing average forest area. Surprisingly, the cohesion metric did not surface as a main predictor of *Aedes* species. The FRAGSTATS generated metrics of average area of forest class-patches and the total number of those forest class-patches at the scale of 100 m may do a better job of explaining the patchiness of the forest class than a cohesive metric that would indicate the connectivity between patches.

Photograph 2. A Patillas resident's backyard showing the high tree canopy and many potential containers to collect water suitable for immature development of dengue mosquitoes– including tarps, chairs, grill, and buckets.

Analysis

Mosquito abundance was collected from 243 BG traps over 5/6 sampling periods, for a total of 1266 observations. Female *Ae. aegypti* and *Ae. mediovittatus* numbers were converted into categorical values. For *Aedes aegypti*, the mean number of female mosquitoes was found and a categorical variable of high (above the mean) or low (below the mean) was used for the analysis. For *Ae. mediovittatus*, a categorical value of presence versus absence was used for the analysis due to the high percentage of traps that did not capture any *Ae. mediovittatus* females.

Landscape metrics were calculated within a 100 m radius of the BG trap used to trap the mosquitoes. For this research, the circular area around each BG trap is identified as a landscape-

patch. In all, there are 243 landscape-patches corresponding to 243 BG traps.

A pixel count for each class—soil, grass, scrub, tree, and urban—was calculated for each landscape-patch. These pixel counts were then converted into the proportional area each class represented within the landscape-patch by dividing by the total pixels of that landscape-patch. The proportional area gives an overall value for each class within the landscape-patch but it does not give any information as to the distribution or form that the area takes.

A class-patch, forest or urban, is defined as a contiguous grouping of like-neighbored pixels. For each landscape-patch, the total number of class-patches, the class area distribution statistics, and a cohesion metric were calculated using FRAGSTATS (McGarigal 2002) for the two focal classes (forest and urban). Class metrics represent aggregate metrics for each focal class analyzed. The number of patches is a simple measure of the extent of fragmentation of the class-patch type but does not give a measure of area or distribution of class-patches. The class-patch area distribution is characterized by the mean, area-weighted mean, median, range, standard deviation, and coefficient of variation for each focal class.

Preexisting data included a GIS file of all structures within Patillas. Within Arc GIS these structure points were subjected to kernel density, then focal statistics were calculated for all pixels to count the total kernel density within a 100 m radius, and finally the extraction of these values to the BGs resulted in a structure density within each landscape-patch.

All predictive variables were normalized by subtracting the mean and dividing by the standard deviation. A multinomial logistic regression analysis run in Stata 10 was used to determine the environmental drivers of the presence of *Ae. mediovittatus*, *Ae. aegypti*, or both species compared to the base outcome of neither species present. A multi-model approach was used to select the model with the lowest Akaike Information Criterion (AIC), which selects the most parsimonious model that fits the data.

The final multinomial logistic regression models for *Ae. aegypti* and *Ae. mediovittatus* suggest that the two mosquito species segregate into different habitats within this area of Puerto Rico. *Ae. aegypti* favors areas that are dense in structures and trees high in the number of patches but low in forested area, and *Ae. mediovittatus* prefers areas that have a high number of tree patches.

Conclusion

It seems that these two *Aedes* species do segregate in heterogeneous areas with *Ae. aegypti* more abundant in urban areas and *Ae. mediovittatus* in forested areas. Coexistence occurs in areas with a high proportion of forest-patches that are broken into many forest class-patches and high housing density. However, the mosquito trapping collected many more *Ae. aegypti* than *Ae. mediovittatus*, which may have skewed the model predicting both mosquito species to the criteria that influence *Ae. aegypti*. Using the information from this model, areas with high tree patchiness could be identified and a focused trapping schedule for these areas may provide for a greater number of *Ae. mediovittatus* to be collected as necessary to assess if these mosquitoes carry dengue viruses. Using high-resolution remote sensed imagery to classify heterogeneous urban environments to generate an array of landscape metrics provides useful information to determine the distribution and abundance of *Aedes* mosquito species. A multinomial logistic regression analysis can be used to assess predictive variables of the occurrence of these species, which in turn could be used to focus intervention efforts on areas of greatest risk.

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Hawaiian Tea: The Relationship Between Chemical Concentrations, Leaf Age, and Levels of Shade

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Abstract

Using samples collected from a Hawaiian tea plantation, this investigation explored the relationship between tea leaf age and shade levels on the relative concentrations of three naturally occurring compounds—L-theanine, caffeine and epigallocatechin gallate (EGCG)—all of which are reported to have positive effects on human health. A High-Pressure Liquid Chromatography (HPLC) method was developed that utilized a reverse phase C-18 stationary phase and a mobile phase composed of water and acetonitrile to quantify the relative amounts of the three natural compounds. The analyses showed that the concentration of L-theanine and caffeine decreased as leaf age increased in moving from the bud to first and then second leaf. EGCG concentration increased in moving from the bud to first, and second leaves. Shade was found to have an influence only on concentrations of EGCG, exhibiting a positive correlation. Antioxidant activity, as determined using the Ferric Reducing Antioxidant Power (FRAP) assay system, was found to correlate positively with EGCG concentrations. This is the first investigation of its type using Hawaiian tea samples. The present findings show that certain chemical components of tea can potentially be used as markers for the age, quality and authenticity of various teas.

Introduction

In recent years, the consumption of green tea (*Camellia sinensis*) products, particularly as a drink, has become increasingly popular in western cultures because of its reported positive health effects (Dulloo et al. 1999, Venables et al. 2008, Yamamoto et al. 1997). In contrast to coffee's long history of production in Hawaii, tea in Hawaii has been produced only in very limited quantities and has failed to enter the global market. However, recent interest has developed for producing high quality teas that can be grown and processed by smallholders and marketed in conjunction with tourism and regional cuisine (Gradisar et al. 2007). In order to achieve this end, it is essential to develop analytical methods to determine the effects of agricultural practices on the levels of desirable natural constituents that are biosynthesized by the plant.

Tea contains a group of polyphenol compounds known for their antioxidant

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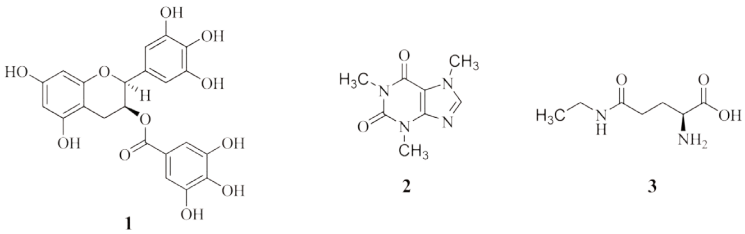

Figure 1. Chemical structure of epigallocatechin gallate (**1**, EGCG), caffeine (**2**) and L-theanine (**3**).

properties (Gradisar et al. 2007, Morley et al. 2005). One such compound is epigallocatechin gallate (1, EGCG) often reported as the most abundant of its class found in tea leaves (Dalluge et al. 1998; Lu et al. 2009). Caffeine (2) and L-theanine (3) (Figure 1), one of the biosynthetic precursors of catechins like EGCG (Kimura et al. 2007), are two other naturally occurring substances also reported to have positive health effects. Caffeine is best known for its ability to stimulate the central nervous system (Lovett 2005). L-theanine is an amino acid that has been found to reduce mental and physical stress (Kimura et al. 2007), and may act as an immune system booster by increasing production of anti-bacterial proteins (Rios et al. 2001).

Recent studies of tea leaves have revealed a relationship between leaf age and concentrations of natural compounds. Young leaves are defined as the bud and the two leaves underneath the bud; all other leaves are considered to be old leaves (Lu et al. 2009, Chiu et al. 2005, Rios et al. 2001, Lin et al. 1996). Three of these studies clearly demonstrated that young leaves contain more antioxidants than older leaves (Chiu and Lin 2005, Lin et al. 1996, Rios et al. 2001).

To counteract the deleterious effects of potentially harmful reactive oxygen species (ROS), aerobic cells have developed complex antioxidant systems based on low-molecular weight scavengers and specifically adapted enzymes. The major enzyme systems—superoxide dismutase (SOD), catalase, and peroxidase (Halliwell 1999, Halliwell and Gutteridge 1999)—are the primary intracellular antioxidant defenses in living organisms. However, cells also maintain a variety of non-enzymatic antioxidants for this purpose, such as ascorbic acid (vitamin C), reduced glutathione (GSH), tocopherols, carotenoids, flavonoids, phenols, and aromatic amines (Halliwell 1999, Mallick and Mohn 2000). A variety of assays have been developed to measure the contribution of specific antioxidants, as well as the total antioxidant activity present within living cells.

Numerous studies have been conducted to determine how levels of the catechin polyphenols in tea vary according to the tea varieties, agricultural conditions and processing. However, there have not been similar studies that evaluate changes in polyphenols, caffeine and L-theanine using a single analytical method. This current study aimed to develop a high-pressure liquid chromatography (HPLC) method to further investigate young tea leaves to compare the concentrations of one specific polyphenol, EGCG (1), as well as caffeine (2) and L-theanine (3) in extracts of the bud and the first and second leaves of selected tea plants. A second aim was to assess and confirm that EGCG levels in all investigated samples and pure compounds were correlated with antioxidant activity. It was hoped that the results would provide definitive evidence of whether compounds having positive effects on human health are found in the bud in higher concentrations than in the leaves underneath. Such a finding could be useful to growers in validating claims that certain tea products are better for human health than others. For example, "silver needle" white tea or Yin Zhen tea contains only the buds and is claimed to be one of the healthiest teas on the market. To the best of our knowledge there has been no study

of tea undertaken that has looked specifically at concentrations of the three natural products investigated as we report here, and certainly not for tea grown in Hawaii.

Some prior studies have also shown that higher shade levels seemed to increase the L-theanine and caffeine levels in tea leaves (Hirai et al. 2008, Ohta et al. 1996, Suzuki et al. 1985), while causing a decrease in the catechin (polyphenol) levels (Saijo 1980). To further investigate these findings for plants used in the current study, a specific selection of leaves was grouped and analyzed according to shade levels in order to determine whether or not a similar trend could be observed. Such findings could have ecological implications arising from the agricultural conditions used in tea production.

Materials and methods

Study site selection

On the Big Island of Hawaii, favorable geography and climate in certain regions have allowed many small tea farms, run by dedicated and enthusiastic growers, to produce fine, locally grown tea products. For this study it was essential to select a study site that was growing tea in an area that had varying shade levels and was also producing a green tea considered by local growers to be an above average product. Several farms were visited and those with too little or too much shade were ruled out. Discussions with local experts and growers led us to select the Mauna Kea Tea farm, whose owners granted us permission to use their plants in this investigation.

Tea leaf collection

Fresh leaves were collected from the Mauna Kea Tea farm on the Big Island of Hawaii. The farm is owned and operated by Takahiro and Kimberly Ino and is located at 46-3870 Old Mamalahoa Highway, Honokaa, Hawaii 96727, USA. The average elevation is 590 m and atmospheric temperature typically falls between 10 and 25°C. Annual rainfall ranges from 196 to 245 mm per year and falls mostly between December and April.

The selected study area on the plantation had an approximate area of 300 m^2 and a northeast-facing slope. Young seedlings, generated from cuttings in order to maintain varietal characteristics (variety: Mauna Kea #1, MK1), were transplanted from nursery into this field, and had never been harvested. The field was mostly open to the sky, except on the northwest and southwest sides where ohia lehua (*Metrosideros polymorpha*) trees form a canopy over some tea plants.

Samples were collected on July 12 and July 25, 2010. The weather on both days was cloudy. Three sets of replicate samples were collected on July 12 and nine on July 25. Samples were grouped according to prevailing shade conditions of the parent plant. Shade level (canopy closure) was determined with a

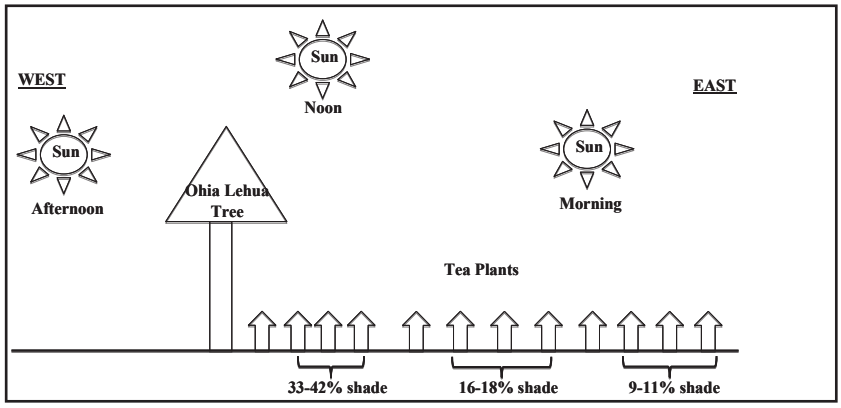

Figure 2. Diagram showing positions of tea plants relative to shade trees and progression of sun from morning to afternoon.

Photograph 1. Collecting tea samples in the field.

concave densiometer. Leaves collected from areas of heavy shade were from the edge of the northwestern canopy. Those collected from areas of less shade were further away from the canopy, and thus had more time exposed to direct sunlight (Figure 2).

All leaf samples were collected from tea plants ranging in height from 0.8 – 1.0 m. All samples were undamaged by pests, and each contained a complete bud and the first two fully expanded leaves underneath. Samples were carefully labeled with ribbons and placed into a bamboo bag that allowed good aeration. Samples were kept cool and well aerated and returned to the laboratory for processing within 5 hours of collection.

Leaf preparation

A microwave oven (Sanyo, model: EM-S2589S) was used to quench all enzyme activity in collected leaves (Zee et al. 2003); each sample was microwaved three times for 30 seconds each time. After all enzyme activity had been quenched, samples were dried in an oven (Fisher Scientific, model: 3511-1FS) until they had lost 70-75% of their weight, assumed to be loss of water. After leaf stems had been removed, dried samples were powdered and resultant material was accurately weighed. Weighed powders were extracted with a mixture of methanol and water (70:30 v/v, 10 mL) for 30 minutes at room temperature. At the end of this period samples were filtered employing 8µm 2V grade Whatman prepleated qualitative filters (Fisher Scientific Co.) prior to HPLC analysis.

Chemicals and reagents

References standards of L-theanine (>99%), epigallocatechin gallate (EGCG, >95%), and caffeine (>99%) came from the Sigma Chemical Company (St. Louis, MO). Ultrapure water was prepared using a Millipore Direct-Q purification system and used in HPLC analyses as mobile phase A. HPLC-grade acetonitrile was purchased from ACROS Organics (New Jersey) and used in HPLC analyses as mobile phase B.

HPLC-PDA analysis

A Shimadzu HPLC system consisting of a degasser, a liquid chromatograph, auto-sampler, a photodiode array detector, column oven, and LC Solution software was used for all HPLC analyses. A 150 × 4.6 mm, 5 µm Ultra II C-18 column (Restek, Bellefonte, PA) was used for all HPLC separations. The elution program used for all analyses was: 0-2 min: 2% acetonitrile, 98% ultrapure water; 2-20 min: percentage of acetonitrile increased linearly from 2% to 20%; 20-25 min: percentage of acetonitrile increased linearly from 20% to 21%; 25-35 min: 50% acetonitrile, 50% ultrapure water; 35-40 min: percentage of acetonitrile decreased linearly from 50% to 2%; 40-45 min: 2% acetonitrile, 98% ultrapure water.

For all analyses the injection volume was 10 µL/min, with a flow rate of 1 mL/min and oven temperature of 25°C. The PDA detection wavelength range was set between 190 and 290 nm.

HPLC method validation

Individual calibration curves were created for each of the standards, which were L-theanine, caffeine and EGCG, dissolved in a mixture of methanol and water (70:30 v/v). For each standard, a range of stock solutions was prepared.

FRAP antioxidant assay

The FRAP assay employed was modified from a previous protocol (Benzie and Strain 1996, 1999). The working FRAP reagent was produced by mixing 300 mM acetate buffer (pH 3.6), 10 mM 2,4,6-tripyridyl-S-triazine (TPTZ) solution, and 20 mM $FeCl_3$.6H2O in a 10:1:1 ratio and heated to 37°C prior to use. The 300 mM acetate buffer was prepared by mixing 3.1 g of sodium acetate trihydrate (NaOAc.3H2O) with 16 mL glacial acetic acid and made to 1 L with doubly distilled (dd) H_2O. The TPTZ solution was prepared by mixing equal volumes of 10 mM TPTZ with 40 mM HCl.

For the actual assays 150 µL of FRAP reagent was added to each well of a 96-well microtiter plate. A blank reading was then taken at 595 nm using a Bio-Rad microtiter plate reader. To each well 20 µL of sample (tests were done in triplicate) was then added, incubated for 8 min at room temperature and read at 595 nm. Triplicate standards of known FeII concentrations were run simultaneously using concentrations between 50 to 1000 µM of $FeSO_4$.7H2O. A standard curve was plotted and the FRAP values, in µM, for each sample were determined. Since results may vary between plates, a new standard curve was prepared for each plate.

HPLC method development

For the investigation an analytical HPLC method was required that would enable the unequivocal determination of the amounts of L-theanine, caffeine and EGCG in the aqueous methanol extract made from dried and powdered tea leaves of various ages. With the equipment available the methods of choice were to employ a PDA detector, a stationary phase of C-18 reversed phase material, and a gradient elution employing a mobile phase consisting of water and either methanol or acetonitrile. After several trials a system was selected that generated good peak shape, produced excellent baseline separation of the three compounds of interest, had a recycle time of approximately 45 minutes, and used water and acetonitrile as the mobile phase components.

Identification and quantification of L-theanine, caffeine and EGCG in tea leaves

Peak, and hence compound, identification in tea leaf extracts was achieved by comparing HPLC retention times, and peak shapes in chromatograms of standards with those found in the chromatograms of prepared extracts. Quantification was done through calibration of external standards by HPLC. Calibration curves of EGCG and caffeine were obtained at a detection wavelength of 280 nm, while for L-theanine the wavelength employed was 200 nm. All calibration curves were linear over the range of concentrations examined. The relative standard deviation percent (RSD%) values were below 5% in the test of inter-day repeatability, and below 5.09% for intra-day repeatability. Thus, it was concluded that the employed method was reliable and reproducible. Here, it should be noted that it is likely that any catechin polyphenol that has the same overall HPLC characteristics as EGCG will probably contribute to all of the measurements related to EGCG.

Results and Discussion

Relationship of natural component levels, leaf age and shade

Using the developed HPLC method, concentrations of L-theanine, caffeine and EGCG were determined in the aqueous methanol extracts made from the buds, first,

Table 1. Mean level of theanine, caffeine, and EGCG as % of dry weight (± SD) of green tea leaves of various ages.

	Bud	1st leaf	2nd leaf
Mean % Theanine of dry tea leaf weight	0.71 ± 0.19	0.51 ± 0.13	0.40 ± 0.11
Mean % Caffeine of dry tea leaf weight	2.86 ± 0.52	2.58 ± 0.53	1.92 ± 0.39
Mean % EGCG of dry tea leaf weight	5.98 ± 1.32	7.15 ± 1.90	7.18 ± 1.82

[a]EGCG - Epigallocatechin gallate
[b]SD - Standard deviation

and second leaves of different tea samples. The results of these analyses are shown in Table 1 and Figures 3-4. The mean percentage of each compound reflects the weight of each compound extracted from dried and powdered leaves.

From the data presented in Table 1 the differences in % L-theanine extracted from dry green tea leaves of various ages and shade levels were found to be statistically significant, as were

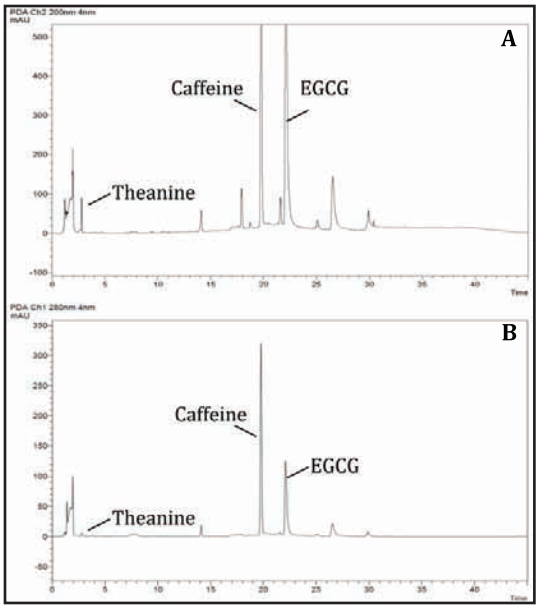

Figure 3. Typical HPLC-RP18 chromatogram of tea leaf bud extract showing detection at 200 nm (**A**) and 280 nm (**B**).

the levels of caffeine (Table 1, Figures 4A and 4B). These findings clearly show that the concentrations of both L-theanine and caffeine decrease in going from the bud to the second leaf of the plant and that there is no obvious correlation with shade level.

From the information in Table 1, Table 2, and Figure 4C, the differences in % EGCG extracted from dry green tea leaves of various ages and shade levels were found to be statistically significant. These results show that the levels of EGCG increase with leaf age when correlated with shade level. When shade is not considered as a variable there appears to be no statistically significant correlation between leaf age and EGCG levels in the leaves examined.

Many tea experts worldwide suggest that green teas of the finest quality and flavor are made from selecting the bud and the next two leaves, or simply the bud alone, from actively growing plants. Our results suggest that the levels of L-theanine, caffeine and EGCG are, due to their concentrations, playing a significant role in helping determine this quality. Indeed, there is some suggestion that of all the amino acids founds in tea, L-theanine is the one responsible for the exotic flavor of green tea (Lin et al. 1996). At this stage optimal levels of the substances examined in this study for producing fine quality tea are not known. A next step would be to compare these levels among teas

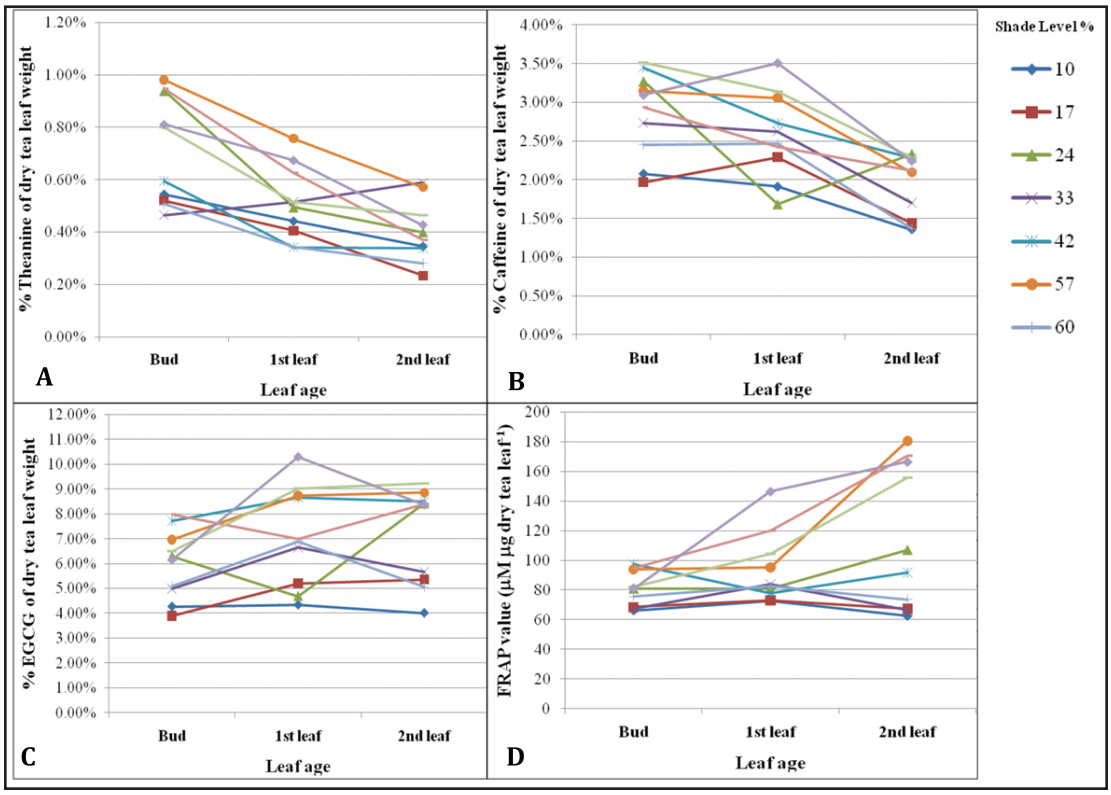

Figure 4. Levels of (**A**) theanine, (**B**) caffeine, and (**C**) epigallocatechin gallate (EGCG) at various leaf ages and various shade levels. (**D**) Total antioxidant activity of green tea extracts from tea leaves of various ages and shade levels presented as FRAP value in µM/µg dry tea leaf.

that are agreed upon by a group of professional tasters to be of low, medium and high quality to assess if these three substances are in some way determinant.

Also associated with the quality of tea and tea products are their reputed antioxidant properties. The ferric reducing antioxidant power (FRAP) assay is a direct test that measures the total antioxidant levels in a given sample (Benzie and Strain 1999). The FRAP assay uses antioxidants as reductants in a redox-linked colorimetric method. In this method the reduction of FeIII, as part of the ferric tripyridyl-s-triazine (FeIII-TPTZ) complex, to FeII is measured colorometrically. The assay was selected because it is considered a robust and direct method of assessing the "total" antioxidant activity of a given system, as no activity-changing interactions between antioxidants occurs in the system (Benzie and Strain 1999). The antioxidant activities of L–theanine, caffeine, EGCG and ascorbic acid are given in Table 2 and Figure 4D, and show that, among the compounds examined in

Table 2. Total antioxidant activity presented as mean FRAP value in µM per µg dry tea leaf (± SD) at various leaf ages compared to theanine, caffeine, EGCG, and ascorbic acid.

	Mean FRAP value (µM μg^{-1} dry tea leaf)
Bud	80.8 ± 11.1
1st leaf	93.7 ± 22.6
2nd leaf	114.2 ± 46.2
Theanine	0.09 ± 0.04
Caffeine	0.09 ± 0.04
EGCG	71.3 ± 0.0
Ascorbic acid	59.6 ± 6.3

[a]EGCG - Epigallocatechin gallate
[b]SD - Standard deviation

this study, only EGCG can be considered an antioxidant.

In this respect, the amount of EGCG present in the extracts when compared to the levels of L-theanine and caffeine may also be significant. Clearly, levels of EGCG increase with leaf age but this is only significant when correlated with shade. Not surprisingly, the antioxidant activity of extracts examined using the FRAP assay correlates well with the levels of EGCG found. That is, the differences in antioxidant activity of extracts made from green tea leaves of various ages and shade levels (Table 2 and Figure 4D) were statistically significant. This finding shows that antioxidant activity, like EGCG concentrations, increases with leaf age when associated with shade.

Effect of shade

Another interesting observation from this study is that natural shade has a direct positive correlation with the concentration of only one of the three natural chemicals investigated. Natural shade not only influences the amount of sunlight received by tea leaves, but also affects other environmental conditions such as air temperature, humidity, and soil chemistry. These factors are also important for the actively growing tea plant and could influence leaf chemistry in different ways. It has been suggested that shade levels increase the L-theanine and caffeine concentration in tea leaves (Hirai et al. 2008, Ohta et al. 1996, Suzuki et al. 1985), while at the same time cause a decrease in the catechin levels (Saijo 1980). The results of the current study neither support nor refute the deductions concerning L-theanine and caffeine but seem to be contrary to the findings concerning the catechin EGCG. Future studies will further investigate these variables for other leaf selections and at other locations.

Ecological implications

In order to survive and reproduce, plants must protect themselves—especially their most vulnerable sections and actively growing parts—from predators and disease. The three natural products investigated in this study, particularly caffeine (Nathanson J.A. 1984) and L-theanine, may be playing a role in defending young leaves and the growing tips from predation. The concentrations of these two compounds decrease as leaf age increases, suggesting that their role is less important in more mature leaves than in younger ones.

Future Investigations

This study was primarily undertaken to provide a basis for quality evaluation of Hawaiian tea samples and to determine if there was a relationship between tea leaf age, chemical content (caffeine, L-theanine and EGCG), shade levels, and antioxidant activity.

The ultimate aim is to use these data and subsequent methods to compare this and other varieties of tea grown in other parts of Hawaii under different conditions. The results of this study are a starting point for more detailed investigations of tea grown in Hawaii. Future studies should be attempted at different locations with more precise control of shade in order to see if these observed trends are more widespread. We also plan to examine volatile constituents of tea as well as other chemical components that can help inform professional assessments of tea quality.

The developed HPLC method was shown to be a reliable and reproducible way for the determination of the chemical components L-theanine, caffeine, and EGCG found in relatively high concentrations in young tea leaf extracts. From this determination it was concluded that leaf age has an obvious effect on the concentrations of the three compounds present in the bud and first two leaves of the plants investigated. L-theanine concentrations decrease when going from the bud, to the first, to the second leaf of the plant. In contrast, caffeine concentrations do not decrease

significantly in going from the bud to the first and second leaves. The reasons underlying this variation will need to be studied further. In the absence of shade as a variable, EGCG levels do not vary significantly with leaf age. However, when shade is considered as a variable, concentrations of EGCG clearly increase with leaf age. The significance of these findings is in showing that certain chemical components of tea can potentially be used as markers for the age, quality and authenticity of various teas, and may possibly be manipulated by the agricultural conditions of the tea plant.

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III. ADAPTATION TO CLIMATE CHANGE

Household Level Adaptation in the Southern Region of the Yucatan Peninsula

Ana Karla Perea Blázquez, MEM 2011

Abstract

The negative impacts of climate change are expected to affect the poorest communities least able to cope with the increasing alterations in the weather (Huq and Reid 2007). In Mexico, projections show that the amount of total annual rainfall will decrease in many parts of the country towards the end of this century (INE-SEMARNAT 2010). One of the major impacts that farmers will face is the changing cycles of rain and rainfall patterns that influence their crop and harvest success (Jennings et al. 2009).

This research project identifies the ongoing adaptation strategies of ten small-scale farming communities in the southern Yucatan Peninsula. The interviews conducted in these communities show that the predominant strategies are changes in the agricultural calendar, diversification of productive activities, and migration. Delays in the rainfall season may be critical to the livelihoods of families or households dependent on seasonal agriculture. For that reason, it is important to better understand the existing adaptation mechanisms of local farmers and analyze if these can be complemented with additional adaptation practices and/or technologies.

Introduction

Impacts associated with climate change are expected to primarily affect the poorest communities least able to cope with the increasing alterations in the weather (Huq and Reid 2007). Delays in the rainfall season may be critical to the livelihoods of families or households dependent on seasonal agriculture. In places where drought is becoming more frequent, farmers need either to adjust their agricultural practices to the changing environmental and climate conditions (Baas and Ramasamy 2008), look for off-farm income-generating activities, de-intensify agriculture, or perform a combination of all the above. For that reason, it is important to better understand the existing adaptation mechanisms of local farmers and analyze if these can be complemented with other practices and/or technologies.

During the months of May – August 2010, I worked with the College of the Southern Frontier (ECOSUR) on a project that aims to identify ongoing adaptation strategies in rural sector communities of the Southern Yucatan Peninsula. This project was designed as part of a larger project that is being conducted between ECOSUR, Clark University, Rutgers University, and the University of Virginia named "New Knowledge About Ecosystem-Level Response to Increased Frequency of Large-Scale Natural Dis-

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turbance Driven by Climate Change (EDGY)." EDGY "seeks to understand the social and ecological impacts of natural disturbances across the Yucatan Peninsula of Mexico" and includes as one of its research objectives learning about "household responses, social impacts, vulnerability, and adaptability for maize subsistence farmers in the region" (EDGY 2010).

My research project describes the ongoing agricultural adaptation strategies at the household level in ten small-scale farming communities in the southern Yucatan Peninsula. The analysis focused on maize cultivation because of the high cultural and economic value that it holds for farmers in this region. The research also addresses the topic of potential drought-adaptation policies and practices, such as the dissemination of improved weather forecasts, that could be implemented in the region.

Background

Agriculture is among the most vulnerable sectors to climate change (Parry and Carter 1989, Reilly [1995] as cited in Smit and Skinner [2002]) because climate is a strong determinant of agricultural productivity (Adams et al. 1998). It is expected that the Yucatan Peninsula will have the highest annual temperature anomalies in the country towards the 2080s. These projections include also enhanced probabilities of drought in the region (Anderson et al. 2008), defined as the decrease in rainfall and increase in the dry period compared to the average or normal rainfall or length of the dry period (INE–SEMARNAT 2009). Historically, drought in the Yucatan Peninsula has been associated with water scarcity, crop failure, food scarcity and increases in the prices of basic commodities (Mendoza et al. 2007).

Adaptation, defined as "a process, action or outcome in a system (household, community, group, sector, region, country) in order for the system to better cope with, manage or adjust to some changing condition, stress, hazard, risk or opportunity" (Smit and Wandel 2006) will be critical for dealing with the impacts of climate change, especially increased and variable rainfall.

Rainfall variability and changing seasonality

Photograph 1. Harvested maize in one of the households in Laguna Kaná.

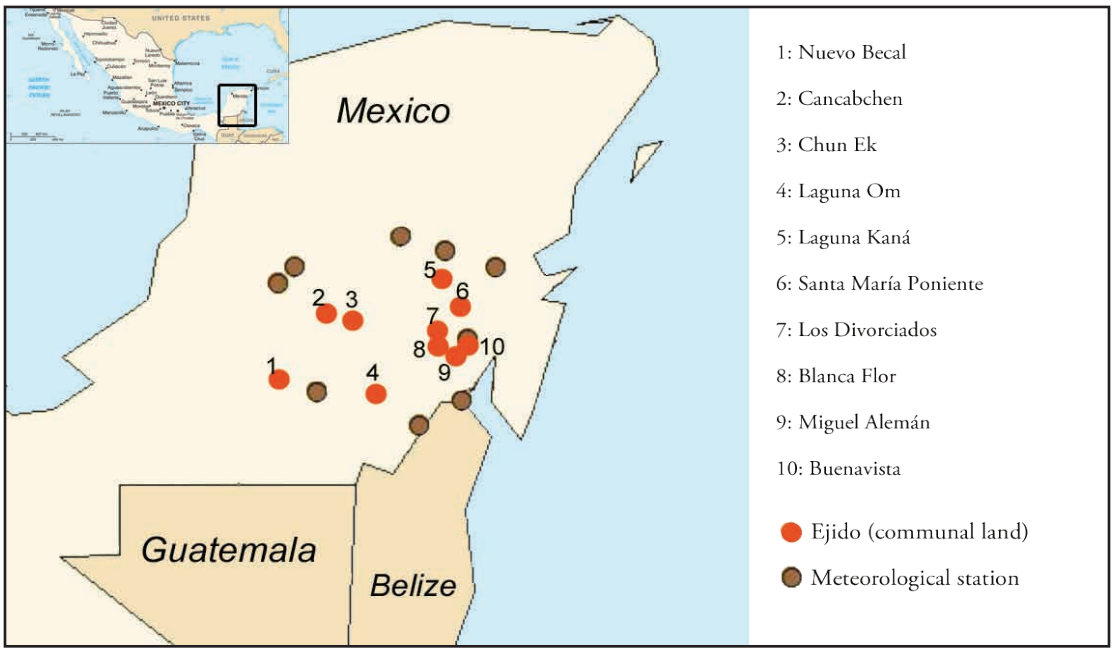

Figure 1. The figure shows the communities that were chosen in the study region as well as the climate stations in the region. Source: ECOSUR.

are two of the main impacts that subsistence farmers in developing countries will face over the next decades (Jennings and Magrath 2009). For small-scale agriculturalists, perceptions of climactic variability are combined with social and economic factors (Smit and Skinner 2002), such as access to markets, capital and technical assistance (Adams et al. 1998), to produce appropriate self-adaptation strategies.

These self-adaptation strategies are also informed by institutional adaptation approaches and policies. The institutional approach to cope with drought in Mexico has included "a complex set of agricultural subsidies and emergency relief measures" (Liverman 1999) that failed to bring an adequate response in the context of the country's agricultural policy. In the last decades, financial restructuring and the liberalization of markets and trade have intensified the environmental and economic uncertainties and risks while reducing the productive capacity of poor farmers and increasing their dependence on purchased maize (Liverman 1999; Appendini and Liverman 1994).

Institutionally-designed adaptation strategies should consider the uncertainties associated with local and regional climate (Risbey et al. 1999) as well as unintended social, environmental, and economic impacts of the adaptation techniques (Adams et al. 1998). In order to successfully implement agricultural adaptation strategies, it is crucial to understand these uncertainties, as well as the links among farmers' practices, potential adaptation options, current farm-level and government decision-making processes, and perceptions and management of risks (Smit and Skinner 2002).

Site

This project was conducted in the context of the EDGY project which included 22 communities in the southern part of the Yucatan Peninsula. The communities are located in the path of 2007's Hurricane Dean. From these 22 communities this adaptation research project selected 10 communities, based on centrality of maize production to economic activities as well as the presence of climate stations in the region.

The 10 communities included in the project are: Nuevo Becal, Cancabchen, Chun

Ek, Laguna Om, Laguna Kana, Santa Maria Poniente, Los Divorciados, Blanca Flor, Miguel Alemán, and Buenavista.

Methodology

My research focused on 150 households from the ten communities described above, all of which were previously included in the EDGY project. Because of EDGY's ongoing research, I was able to access existing baseline data about my sample population in terms of land tenure, economic activities and members in each household.

To learn about the adaptation techniques in each household, a questionnaire was designed. In addition to the questionnaire, the research team and I conducted informal interviews with the authorities in each community to learn more about their participation in federal programs (such as the environmental services program, ecotourism, reforestation, training, etc).

Results

Farmers in the 10 communities produce maize through a traditional system called *milpa*. In this swidden, or rotational, system, maize is frequently grown in combination with other crops, mainly beans and squash. The adaptation strategies identified in the communities relate mainly to adjustments in the agricultural calendar, income diversification, and water and maize storage. Other activities that were mentioned as ways of coping with climate change-related drought included planting homegardens, saving money, and/or changes to planting techniques. The main adaptation techniques identified in the communities are explored in detail below.

Adjustments in the agricultural calendar

The 10 communities in the study lack irrigation systems and thus depend on rainfall for their crop success. For this reason, the timing of planting and the type of maize planted are important factors that may affect the success of the milpa. Adjustments in the agricultural calendar mainly include delaying the start of the planting, secondary planting in the same season, or adjusting their planting dates according to what they observe in the

Photograph 2. Farmers in the study site produce maize through a traditional swidden system called *milpa*.

year's weather. The number of farmers that mentioned that they have been adjusting their agricultural calendar in response to the rainfall variability represents 57% of the total farmers interviewed. Some farmers added that they had begun to divide their milpa in plots that they would plant in different months in order to reduce climate risk.

Only 17% of the farmers stated that they have made changes to their planting techniques. The principal change noted by researchers involved the adoption of the *mecanizado*, a program promoted by the government, which involves agriculture that uses hybrid maize, machinery and fertilizers on the same parcel of land over time. The program contrasts with the traditional system of the milpa which includes land rotation and a fallow period. In regard to the farmer's crop choices, 57% of the farmers interviewed said that they knew about maize varieties that needed less water for their development. From this group however, only 44% of the farmers mentioned using those varieties.

Water storage

About 40% of the farmers in the sample store water as a way to cope with drought. Water storage activities were influenced by the characteristics of the community (e.g. some communities have natural lagoons where farmers take their cattle for water) and their productive activities, mainly because the water storage spoken of by farmers relates to storing water for cattle, bees or animals.

Water storage involves making *jagueys* (small lagoons to store water for cattle) and/or storing water in containers and water fountains. Farmers did not think that storing water for irrigation would be feasible because of the large areas of the milpas. They did, however, consider implementing irrigation systems as the most likely solution to address rainfall variability.

Income diversification

The productive activities of the majority of the farmers in the study region have historically included the cultivation of milpa, forest management, beekeeping, small-scale livestock production, charcoal, and gum production. However, there is an increasing dependence of wage labor to generate cash income. When asked about if they had to find another job (permanent or temporary) to cope with drought, 74% of the farmers answered yes. The main options chosen by farmers are to engage in *jornales* (wage labor) in other milpas or cattle ranches both within and outside their own *ejido* (communal land). In some communities cattle and honey production have become more important economic activities than maize production, while in others, these activities provide alternative income for some maize farmers.

Weather forecasts

One of the alternatives to promoting adaptation to drought is the use of climate forecasts to provide early warnings that allow farmers to make decisions related to the type of crops and best time for planting. Personnel from the National Institute of Forestry, Agriculture, and Livestock Research (INIFAP) mentioned that the institute had already started an extension program with the objective of communicating rainfall forecasts to allow farmers to plant in the most suitable month. However, in the case of farmers in the sample, 85% said that they did not get advance warnings of drought.

When asked whether having this type of information would make a difference in the timing of their plantings, 62% of the farmers answered that having information about a coming drought would not change their decision to plant. One of the farmers responded, "How can someone know if a drought is coming? Only God knows about that." Other farmers

stated that even when a forecast predicted the lack of rain, they would still plant, hoping that the forecast was not accurate: "We are farmers you see, our job is to plant maize." On the other hand, 30% of the farmers said that they would modify their planting dates if they were provided with drought forecasts.

Analysis

Based on the local adaptation strategies described above, government policies and programs for adaptation should complement existing mechanisms. Areas of focus should include income diversification strategies, water storage, training, and dissemination of information. In terms of livelihood diversification, adaptation policies could involve creating new markets for cash crops, livestock, honey, and gum. Milpa, livestock and honey production are complementary activities in each annual cycle not only because they utilize common resources (e.g. nearby forests are a food source for bees, and milpa fallows can be planted with grasses) but also because the timing or labor requirements may allow a farmer to successfully engage in all of them.

Adaptation policy might also encourage livelihood diversification through non-agricultural activities, as this process is already underway in the studied region. Policies and programs focused on forest conservation and restoration through payments for environmental services may constitute an important source of income. Another example of diversification of economic activities is wage labor and work outside the communities. According to Eakin (2006), the diversification into off-farm activities may be considered an adaptation strategy depending on the frequency in which these activities are carried out. If agricultural households engage in off-farm activities on a permanent basis, the additional income may help farmers reduce household vulnerability to climate risks and change. The reduction of vulnerability will also allow farmers to engage in agricultural activities that otherwise would be unavailable (Eakin 2006).

Though income diversification was identified in this study as a strategy for adaptation to drought and rainfall variability, it is impossible to state that the farmers are engaging in different and additional economic activities exclusively because of climate change. In fact, it is very difficult to isolate climate change impacts from economic globalization (O'Brien et al. 2000). Other studies such as the one conducted by Radel et al. (2010) suggest a tendency of smallholder households to withdraw from agriculture to engage in commercially oriented activities such as cattle ranching and intensified maize production on larger areas. The authors mention the possible influence of education, expectations and cash income requirements in the tendency to leave traditional agricultural practices.

Livelihood diversification outside the communities may also promote the extinction of traditional agricultural activities. Though some farmers mentioned how important it was to plant a milpa each year, and 77% of them stated that they would continue to do so in the future, the younger generations are not as interested, finding agriculture a high risk activity which involves a lot of investment and work but provides little in return. The younger generations may very well decide to work outside of their communities, migrate to another country, and lose the traditional knowledge associated with milpa.

In terms of water storage, adaptation policies and programs might want to explore alternative water storage systems or assess the feasibility of different irrigation systems that could provide farmers with water to reduce the risk of rainfall variability. Other adaptation strategies include training and agricultural extension focused on the advantages and disadvantages of traditional agriculture versus mechanized agriculture, allowing farmers to make informed decisions. Dissemination of

information, training and agricultural extension may help to fill gaps in the information that farmers have about varieties and crop options and should be directed to empowering farmers.

Improving the dissemination of information and communication of weather forecasts that could help farmers plan their planting dates might be another policy lever. However, one of the main challenges related to the use of weather forecasts is the issue of trust: farmers should be aware that the forecast is only a probability and that it may be inaccurate. An inaccurate forecast in a given year may destroy the farmers' trust in the validity of the forecasts in subsequent years. The farmers that stated that they would be willing to make decisions based on a weather forecast constitute an opportunity to improve the communication of climate information.

Conclusion

The ongoing adaptation techniques in the region include adjustments in the agricultural calendar, diversification of income and productive activities (including on-farm and off-farm activities), water storage, and mixing different maize varieties to reduce the risks associated with drought and rainfall variability. Though farmers have been coping with climate variability through different strategies, there is uncertainty if the pace of climate change and economic globalization will give them enough time to adjust to the increasing rainfall variability that results in the loss of their harvests, seeds and traditional agricultural practices.

Current practices in the region may be complemented with other adaptation strategies such as income diversification, water storage, training, and the dissemination of information. Farmers may improve their decision-making processes if they can participate in the design of adaptation programs and understand what is happening with the climate at the local, national and international level.

Constraints for adaptation techniques in the region include the lack of information, uncertainties related to climate and markets, and the lack of an appropriate institutional framework. For these reasons, the success of certain adaptation techniques will depend on the extent to which farmers are involved and their necessities, experiences, and expertise acknowledged. Success may also be influenced by the synergies that can be created at the institutional level and in the way that agricultural uncertainties are addressed.

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Farming the Fouta Djallon: The Effects of Climate on Agrobiodiversity and Household Economies

by Stephen Wood, MESc 2011

Abstract

The Fouta Djallon is a region of northern Guinea and southern Senegal that contains a dramatic topographically-driven climate gradient over a relatively small land area. Despite this variation in climate, the region is inhabited by a single dominant ethnic group whose agricultural and land use practices are fairly common across the area. The natural climatic variation in the Fouta Djallon paired with fairly uniform agricultural and natural resource use creates a natural experiment in which to explore the effects of differences in climate—which vary across the region—on agriculture and household economies. In this paper I use an original data set to study the effects of a variation in climate on agricultural biodiversity and household economies.

Introduction

Research in the climate sciences shows, almost unequivocally, a change in global climate by 2100. Though the precise pattern of this change is not certain, some warming is expected (IPCC 2001, IPCC 2007). Given this likelihood, it is important to ask what the effects will be on humanity's well-being and the ecosystems on which we depend.

Poor communities are particularly vulnerable to climate change, given their sparse economic resources available to invest in adaptation. These communities, especially in developing countries, are often engaged in economic activities that are directly affected by changes in climate. More than any continent, Africa's population is at risk from climate change due to dependence on vulnerable economic sectors; much of the continent's population lives in rural areas and depends on agriculture (Jaeger 1991).

It is now apparent that changes in climate negatively affect African agriculture at the continental level (Kurukulasuriya et al. 2006, Schlenker and Lobell 2010). These results hold for high-resolution, national-level studies in South Africa and Cameroon (Deressa et al. 2005, Gbetibouo and Hassan 2005, Molua 2009), though the direct mechanism through which climate affects agricultural profitability is not clear. Though national level studies give insight into dynamics that continent-wide analyses might miss, analysis at the national level in Africa may miss important sub- and international factors, such as ethnicity. Countries tend to be bad proxies for cultural groups; the borders established in the colonial era reflect colonial economic interests more than real cultural, ethnic, or geographic divisions. Sub-national studies of the effect of climate on agriculture have not been conducted in Africa because the variation needed to conduct such a study generally occurs on a large spatial scale.

In this study, I use an original, sub-national

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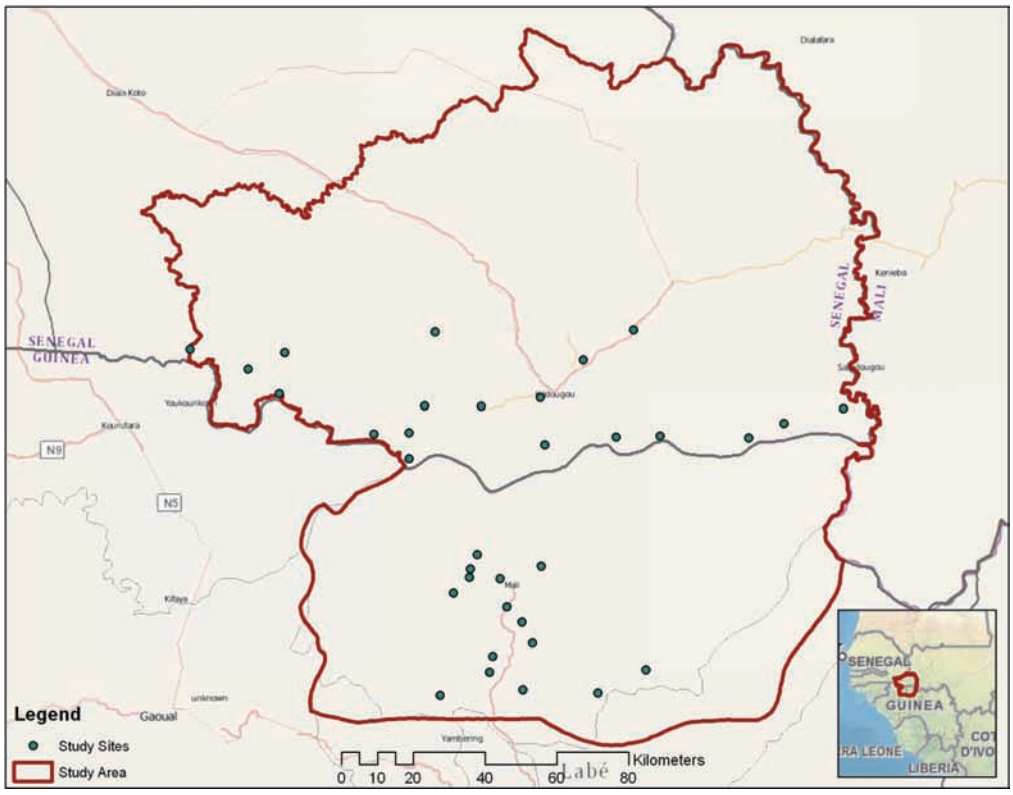

Figure 1. Map of the study area.

data set for a region of northern Guinea and southern Senegal with a drastic climate gradient to examine a hypothesis for the mechanism of the effect of climate on household economies. I posit that climate negatively affects agricultural biodiversity, which positively determines household well-being (Cavatassi et al. 2011, Netting 1993:146-156) as well as providing public benefits, such as genetic resources for seed breeding or developing medicines (Heal et al. 2004, Oldfield 1989). The natural topographical and climatic variabilities within the study zone capture the effects of changes between climate zones on agricultural biodiversity while other important factors remain constant, such as ethnicity.

Conceptual Model

Much prior research on the effect of climate on agricultural profitability in Africa has employed a Ricardian model. This Ricardian approach improves upon previous production function models by allowing farmers to adjust their crop choices over time and in response to a difference in climate, thus maximizing revenue. The production function approach, because it ignored crop transitions, overvalued the damages to agriculture from climate change.

According to theory, each farmer will maximize net revenue given various exogenous constraints on his farm, such as climate and soils. The farmer will choose a particular crop and inputs that maximize net revenue for their land. This is given as:

$$\max R = \int P_{qi} Q_i(X_i, L_i, K_i, C, S, G) - \int P_x X_i - \int P_l L_i,$$

where R is annual net revenue, P_qi is the market price for crop i, Q_i is a production function for crop i, for which X_i is a vector of inputs, such as seed and fertilizer, L_i is a vector of labor (hired and owned), K_i is a vector of capital, such as plows, C is a vector of climate

variables, S is a vector of soil characteristics, G is a vector of socioeconomic variables, P_x is the price for inputs X, and P_l is the price for labor L (Mendelsohn et al. 1994, Seo and Mendelsohn 2008, Wang et al. 2009). The goal of the Ricardian technique is to look at changes in net revenue of land for agricultural land across climatic gradients, particularly variation in temperature and precipitation.

I use a similar hedonic-based approach to study the effects of climate on agrobiodiversity by substituting three measures of crop diversity: the number of crops grown, number of varieties known, and number of varieties grown, for net revenue. I apply similar control variables to the regressions for agrobiodiversity. I then regress net revenue on the three measures of agrobiodiversity to test the hypothesis that increased on-farm diversity is associated with higher household well-being (Cavatassi et al. 2011, Netting 1993).

Data and Methodology

I used a spatially explicit data set of 127 farmers collected from 38 villages. Sixteen villages are from the prefecture of Mali in northern Guinea, four villages were from the region of Tambacounda in eastern Senegal, and the remaining 18 villages were from the region of Kedougou in Senegal (figure 1). The surveys were conducted between June and September 2010. Although this is the most difficult time of year to access villages and many farmers are busy working in their fields, we were able to collect data on all of the sales from previous harvests. Had we conducted the survey at the height of the dry season, we would not have had information on the large amount of goods sold to buy materials for planting early in the rainy season. The surveys were conducted by the author with the help of two research assistants, one based in the town of Kedougou, Senegal and the other based in Mali, Guinea.

The villages surveyed span a topographical, ecological, and climatic gradient, ranging in elevation from sea level to 1,300m, in mean annual temperature from 17°C to 30°C, and in precipitation from 400mm per year to

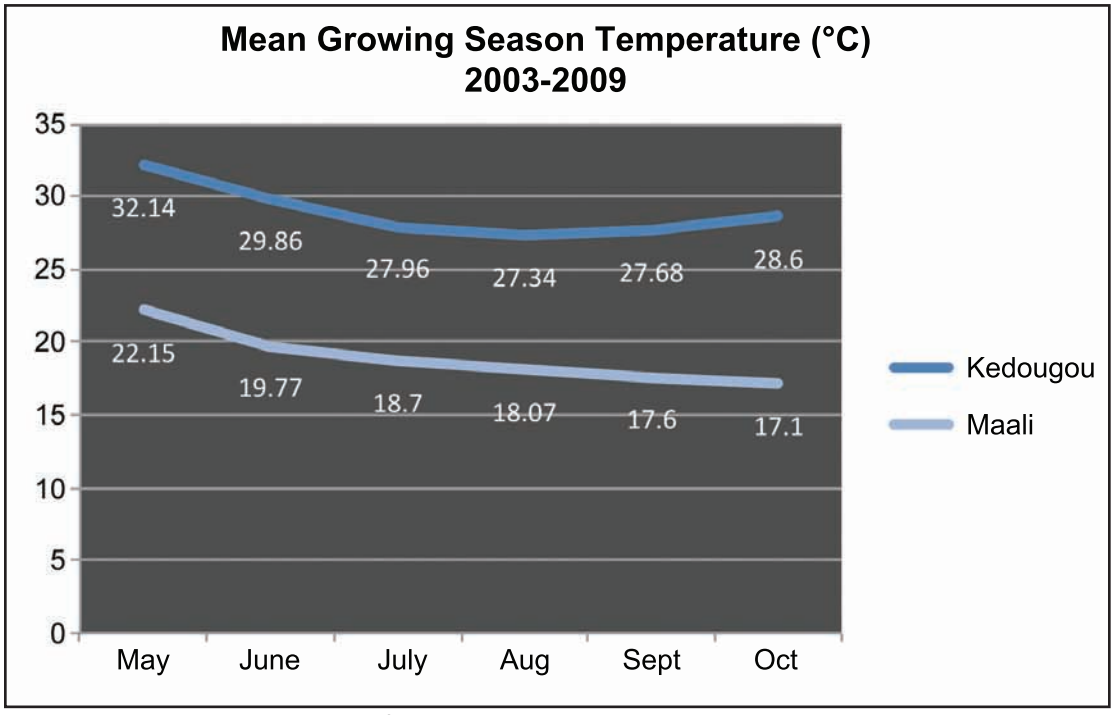

Figure 2. Monthly temperatures of the study sites.

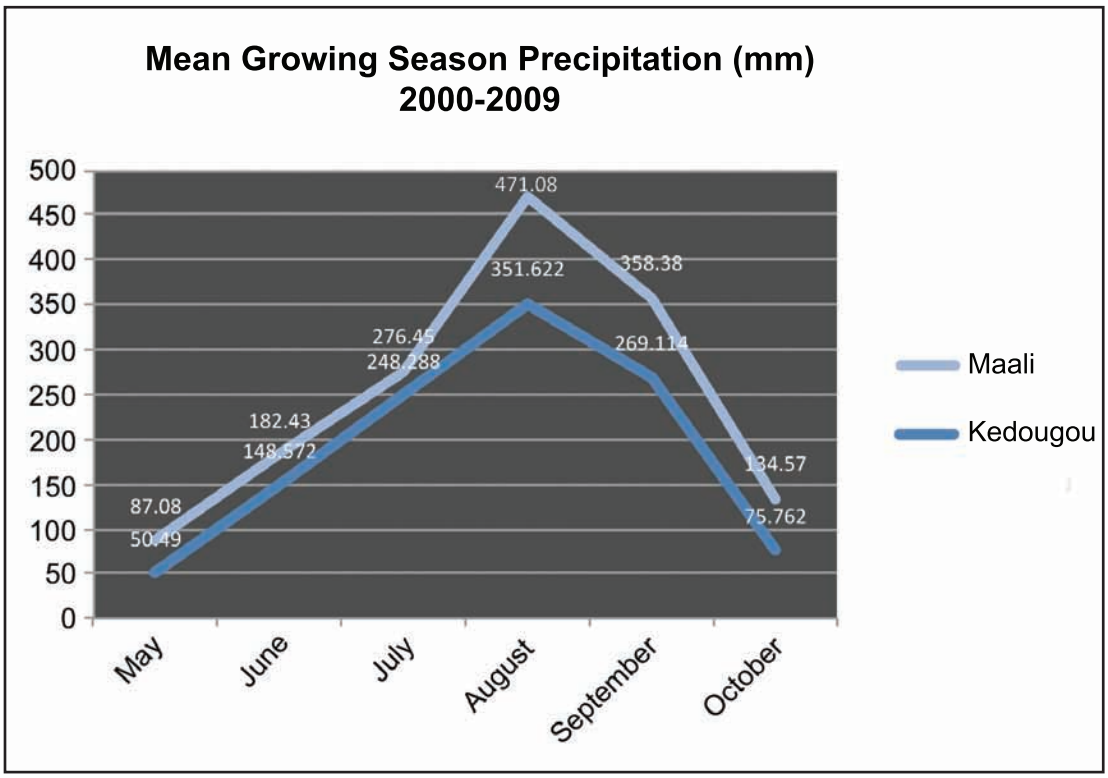

Figure 3. Monthly precipitation at the study sites

2,000mm per year (figures 2 and 3). The study zone was stratified into three zones along this ecological gradient. Koussanar is the furthest north in Senegal and has a Sahelian climate and topography: it is flatter, hotter, and drier than the region of Kedougou in southern Senegal. Kedougou shares the border with Guinea, has a slightly higher elevation of about 300m and has higher precipitation than Koussanar, although temperature is similar. The prefecture of Mali in northern Guinea reaches an altitude of 1,300m. Precipitation in Mali is much higher than in Kedougou and temperatures are much lower (figures 2 and 3).

The surveyed villages were selected at random from regional village lists provided by local health workers and agricultural extension agents. These lists are more thorough and up-to-date than the existing government lists, which exclude smaller villages and seasonal farming communities.

In each community, the chief of the village was asked to identify two large volume farmers and two small volume farmers as well as one average farmer to be surveyed. Farmers were surveyed as long as a minimum of three identified farmers were available. If the minimum number were not available, the surveyors returned later in the day or at another date. The survey included questions on production levels, inputs, demography, local infrastructure, soil, environmental change, wage rates, and other socio-economic variables.

Climate data were taken from weather stations throughout the study zone. These data, while fairly precise, are somewhat inconsistently recorded and span only a five year period. These data, therefore, are supplemented with temperature and precipitation data from the African Rainfall and Temperature Evaluation System (ARTES) (World Bank 2003).

Previous studies have divided climate data according to the four seasons that are familiar in the northeast United States. In this study

zone, however, there are three seasons, only two of which are arguably relevant: the rainy season and the dry season. Climate data were categorized according to these seasons, since the climate data generally exhibit collinearity between months (Mendelsohn et al. 1994). Previous climate studies in Africa have faced the challenge of trying to compare seasons across the equator (Kurukulasuriya et al. 2006). This relative seasonal simplicity is an advantage of this study.

The analysis of climate in these data was based solely on temperature. Precipitation has an obvious effect on agriculture, but was excluded from the analysis because of correlation with temperature. This correlation is due to the fact that the climate difference between southern Senegal and northern Guinea is driven exclusively by a topographical gradient.

Results

Using three separate measures of agrobiodiversity—number of crops grown, total varieties known, and total varieties grown—I find that climate has a strongly significant impact on the level of biodiversity on a farm in the study area.

For the number of crops grown, I find that a ten degree increase in temperature is associated with an increase in one and a half crops, controlling for the number of children in school—a proxy for household well-being – and whether or not the farm is on a hill—a proxy for the quality of the land (table 1). For the number of total varieties known, I find that a ten degree increase in temperature is associated with an increase in 4.1 varieties known, using the same control variables (table 1). For the number of varieties grown, I find that an increase in ten degrees is associated with an increase in 1.3 total varieties grown (table 1), using the same control. Although the effect of temperature on crop diversity is highly significant, the effect of precipitation is not. This is shown in the regression tables.

Also, consistent with some of the anthropological literature on crop diversity, I find that higher crop diversity is clearly and

VARIABLES	(1) numberCropsGrown	(2) totalVarsKnown	(3) totalVarsGrown
meanStationTemp	**0.154**	**0.410**	**0.130**
	(0.0296)	**(0.115)**	**(0.0671)**
meanStationPrecip	0.00107	0.00293	-9.63e-05
	(0.000555)	(0.00224)	(0.00107)
kidsInSchool	0.0889	0.278	0.307
	(0.0344)	(0.176)	(0.1000)
farmOnHill	0.830	1.364	1.157
	(0.188)	(0.723)	(0.525)
Constant	-2.443	-7.453	-0.0128
	(1.354)	(5.225)	(2.752)
Observations	127	116	89
R-squared	0.357	0.187	0.196

Robust standard errors reported in parentheses
Key covariates in bold

Table 1. Effects of climate on agrobiodiversity. The table shows the effect of a unit increase in the independent variables in the first column on three dependent variables (columns 2-4), each of which is a different measure of agrobiodiversity. Results in bold indicate key results of the effect of temperature on agrobiodiversity.

Table 2. Effects of agrobiodiversity on net revenue, reported in the West African CFA franc. The table shows the effect of a unit increase in the independent variables in the first column on net agricultural revenue. Columns 2-4 each represent a different model specification, each with a different measure of agrobiodiversity. Results in bold indicate key results of the effect of agrobiodiversity on net revenue.

	(1)	(2)	(3)
VARIABLES	Net Revenue	Net Revenue	Net Revenue
numberCropsGrown	**54,562**		
	(25,574)		
Guinea	133,674	152,753	92,812
	(47,289)	(50,612)	(63,702)
householdsInCommunity	1,630	1,656	1,875
	(750.7)	(794.4)	(1,087)
timeToClosestMarket	1,078	1,396	1,046
	(456.4)	(474.7)	(553.5)
agWorkersInHH	28,683	25,791	24,461
	(8,813)	(8,115)	(12,269)
totalVarsKnown		**23,580**	
		(7,397)	
totalVarsGrown			**26,832**
			(12,969)
Constant	-355,773	-380,219	-247,651
	(126,506)	(125,875)	(115,426)
Observations	96	87	68
R-squared	0.329	0.358	0.302

Robust standard errors reported in parentheses
Key covariates in bold

significantly associated with higher incomes. For an increase in one crop grown, there is an associated increase in annual net revenue of $100 US (table 2). An increase in one variety known about is associated with an increase in annual net revenue of $50 US (table 2). And an increase in one variety grown is associated with an increase in annual net revenue of $50 US (table 2). All of these analyses control for country, village size, the time required to travel to the nearest market, and household labor supply.

Discussion

The primary finding that higher mean temperature is associated with greater agrobiodiversity may seem to be counterintuitive. One might think that more temperate climates would be able to support a wider range of crops and, thus, have higher crop diversity. These results show, however, that in warmer climates a wider range of crops are grown and, less significantly, a wider range of varieties. Why might a warmer climate support a wider range of crops? One possible explanation is that very few farmers in northern Guinea grow millet and sorghum varieties because it is too cool and dry. Also, the wide variety of agroecological zones in northern Guinea—within the same climate zone—mean that although there is a wide variety of crops grown in northern Guinea, any given farmer is quite specialized in the crops that are within his agroecological zone. Another possible explanation is that farmers in southern Senegal could be growing more crops in order to buffer against shock—in a warmer region, seasonal temperature increases might be more likely to negatively affect some crops, in

Photograph 1. A farmer in his carrot and parsnip garden in Medina, Senegal.

which case it would be advantageous to have a wider variety of crops. More research in the social and natural sciences needs to be done to determine the precise explanation of the direct effect of climate on agrobiodiversity.

The observed effect of climate on agrobiodiversity could also be an indirect effect, due to unobserved factors that co-vary with climate. For instance, Senegal is warmer than Guinea, but it also happens to be more economically developed. Because Senegal has more developed market infrastructure, there is a greater number of crops with higher economic value. Farmers therefore choose more diversity on their farm in order to maximize their net revenue. I controlled for this effect, to some extent, by including a measure of household well-being: the number of children in school. There is likely, however, a still-unobserved effect of economic development on agrobiodiversity that is independent of the number of children in school.

Although there is a clear and significant relationship between climate and temperature, it is not clear to what extent the relationship is driven by climate per se or by factors that co-vary with climate, such as economic development. After controlling for some of the differences in economic development, there is strong reason to think that climate does play a role, in and of itself, on agricultural diversity. However, it is likely that there is an as-of-yet unobserved effect of climate covariates on agrobiodiversity. Future research in economics and ecology needs to be done in order to tease out more precisely the relative effects of climate *per se* and economic development on agrobiodiversity.

The effect of agrobiodiversity on household economies, however, is clear and significantly positive. Depending on the measure of crop diversity, an increase in one more crop or crop variety is associated with an annual increase in net revenue of between $50 and $100 USD. By contrast, the negative effect of climate on net revenue is predicted to be around $28 USD per annum (Kurukulasuriya et al. 2006). Increasing on-farm diversity, therefore, could be an effective tool for climate adaptation.

Conclusion

If a change in global and local climates is expected in the future, decision makers

need to think carefully about how to protect the most vulnerable populations to these changes. For small-scale West African farmers, climate adaptation programs have focused on diversifying revenue developing agricultural practices and inputs that are less sensitive to climate variability than traditional practices. The results from this paper show that increasing on-farm diversity could be an effective strategy for adapting to climate change. It is unlikely, however, that species richness itself matters as much as increasing the number of crops that play important functional roles, such as nitrogen fixation or drought resistance. More research is needed in both the natural and social sciences to determine what the important functional roles are in this agroecosystem, how local communities value them, and how they are likely to change with climate.

Acknowledgements

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Distribution of Climate Change Impacts on Household Electricity Consumption in Brazil

Guilherme DePaula, MESc 2011

Abstract

This paper analyzes the interaction between income distribution and climate change impacts in the Brazilian energy sector. The research findings suggest that an emerging middle class with growing per capita incomes will increase sensitivity of the household electricity sector to a warming climate. In Brazil the analysis identifies the southeast state of São Paulo as the most sensitive for its relatively high-income levels, low average temperatures, and low ownership ratio of air conditioners. When considering income distribution effects, mitigation policies resulting in higher electricity generation costs could reduce adaptation capacity and increase expenditures in electricity subsidies to low income consumers.

Introduction

What is the economic impact of increasing temperatures on residential energy use in developing countries? How are these effects distributed across income classes? Several studies have investigated the effects of global climate change (GCC) on energy consumption, as the energy sector is both sensitive to climate change and central to the policy debate on reducing emissions of greenhouse gases. As the research on the impacts of GCC transitions from developed to developing countries, the distributional aspects of GCC impacts across social classes become more relevant to the discussion of adaptation and mitigation strategies, due to the large income inequalities in these developing countries. The objective of this paper is to analyze these distributional aspects focusing on the household electricity sector.

Regional economic inequality, an expanding middle-class, and global warming have a combined effect on the energy sector of a developing country. As Brazil's economy grows, the middle-class expands and electricity consumption grows rapidly (Achao et al. 2009). A warming climate as a result of global climate change also drives growth in household electricity consumption for air conditioning. The combination of these different drivers suggests a significant and unequally distributed impact on energy consumption in Brazil. Figure 1 illustrates the climate and income variations in Brazil in the context of energy use. Brazil has five regions with distinct climate conditions (Appendix A). The difference in mean annual temperatures between state capitals in the north and south regions is around 8°C. Average annual temperature is approximately 26 °C in the north region and 18°C in the south region. A high income household consumes almost six times more energy in the north region during the summer than a low income household. The difference is much smaller but still significant in the south region. The data also suggests a large difference in the climate sensitivity of energy use for different income classes. A high income

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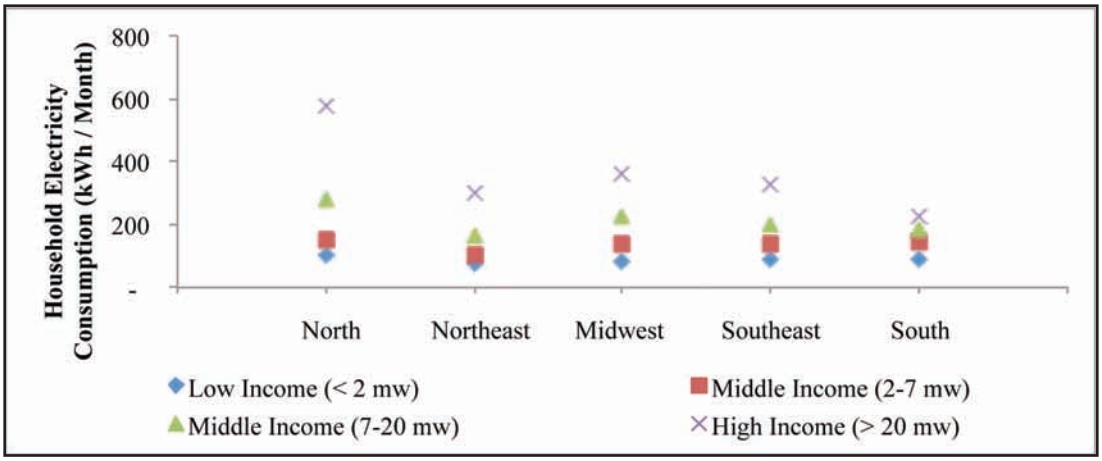


Figure 1. Average household electricity consumption in Brazil during summer months by income class and geographical region. Calculated by author from POF 2003 data for 27 capitals in Brazil (IBGE, 2003). Households classified into income classes by monthly income calculated in number of minimum wages (MW). Minimum wages in Brazil are defined in monthly basis.

family living in the warmer north region uses almost three times more energy than a high income family in the south region. In contrast there is little difference in energy use for low income households living in different regions with diverse climates (Appendix A).

Economic Model

The analysis presented on this paper is based on the results of an econometrics energy expenditure model applied to Brazil. A detailed background on the economic model used as well as model specifications and econometric results can be found in DePaula and Mendelsohn (2010). This section summarizes the intuition behind the models and key results.

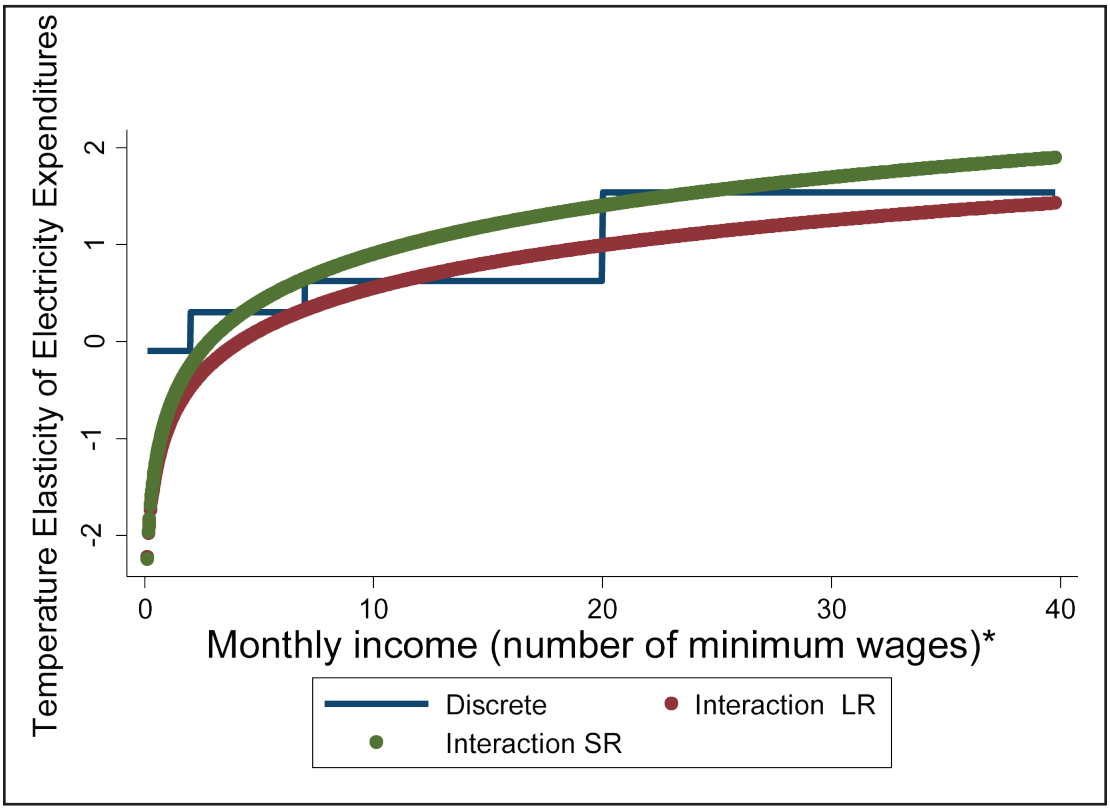
Households consume electricity through appliances and equipment, such as air conditioners, furnaces, refrigerators, and computers. Electricity expenditures of a family depend on its stock of appliances, electricity prices, income levels, building characteristics such as insulation and size, and temperature. Families from different socioeconomic conditions and geographical locations have different levels of electricity consumptions, reflecting different habits and uses of equipment.

Electricity consumption is sensitive to climate variations especially for space conditioning. As temperatures increase as a result of GCC, consumers will adapt in different ways to a warmer climate. Consumers can change their thermostat and accept warmer internal temperatures. Families can purchase air conditioning equipment or increase the use of existing space conditioning systems. Over the long term consumers could adjust building characteristics such as more reflective roofs and better insulation systems. As consumers adapt in different ways to higher temperatures, the resulting changes in energy use and expenditures will vary depending on climate and socioeconomic conditions. The econometric models estimate the variation on household electricity expenditures as a result of climate differences.

The analysis used cross-sectional data from two surveys on household expenditures completed by the National Institute of Geography and Statistics, the official statistics agency in Brazil (IBGE 2003, IBGE 2009), and station level climate data from the Brazilian National Institute of Meteorology (INMET) (Ramos, A. M., L. A. Rodrigues dos Santos, L.

T. Guimarães Fortes 2009). The socio-economic data from the household surveys was integrated with climate data from INMET by city. Normal temperature (30-year average temperature from 1961 to 1990) data from INMET is available from meteorological stations at the city level and the data from the POF survey allows for identification of households located in state capitals and the national capital, totaling 27 cities and metropolitan regions. Since the POF survey does not disclose city information other than state capitals, we did not include household data from other municipalities nor rural households. The benefit of focusing on the 27 capitals is to closely match the normal temperature for each household with energy expenditures and other socio-economic information. Of the 27 state capitals in the sample, 11 are metropolitan regions with more than one city.

Figure 2 replicates graphically the results for three econometrics models (DePaula and Mendelsohn 2010). The green and red lines represent the long run and short run elasticities of electricity expenditures to normal temperature based on models using interaction variables for climate and income, and the blue line represents the elasticities for a discrete model by income class. The elasticity shown in figure 2 represents the sensitivity of electricity



*The monthly income is stated in number of minimum wages and ranges from 0 to 40 minimum wages per month. A minimum wage in Brazil is about R$400 per month, so a household that earns 10 minimum wages earns R$4,000 per month.

Figure 2. The temperature elasticity of low income households is not significantly different from zero, but middle and high income families have a long run temperature elasticity of 0.8 and 1.6 respectively (DePaula and Mendelsohn 2010). The climate income relationship indicates that as the middle class, in an emerging economy such as Brazil, expands and average household income grows, the impact of warming in the energy sector will become substantial.

expenditures in percentage terms to a 1% increase in average temperature. The graph shows that temperature elasticity of electricity expenditures grows with income and is larger in the long run model.

Geographical Distribution of Impacts

The city level statistics in Table 1 illustrate the variation in the sample and the complexity of the relationship between climate and energy expenditures. City level mean temperatures vary by approximately 13 degrees Celsius, with a high of 30.1 in the northeastern city of Fortaleza and a low of 16.8 in the southern city of Curitiba. Other climate variables also have significant variations. The two cities located close to the equator, Manaus and Fortaleza, have little variation in mean monthly temperatures during the year. In contrast, southern cities such as São Paulo and Curitiba have a much larger difference between summer and winter temperatures. The average wind intensity of the coastal city of Fortaleza is three times higher than the wind intensity of Cuiabá, located inland.

Households adapt to changes in climate by buying air conditioners and fans. The highest level of air conditioning (AC) ownership is in Manaus, where temperature and humidity is high through the year. In contrast, the cooler cities of São Paulo and Curitiba, with the highest variations in monthly temperatures, have surprisingly low levels of AC ownership, despite their relatively high household incomes. AC ownership is also low in Fortaleza, which has the highest mean annual temperature and one of the lowest household income averages. The statistics for Fortaleza suggest that the coastal location with higher wind intensities has an effect on household adaptation to climate, and fan ownership could be the primary adaptation method for low income families.

Climate change impacts will vary geographically according to income levels and climate conditions in different cities. Figure 3 shows the estimated electricity demand for temperature sensitivity for 5 cities in Brazil in comparison to the country's average. Local sensitivity is estimated using mean income and temperature for each city. Since the econometric models were estimated for the entire country, local elasticities are good approximations only for small climate variations.

Figure 3 illustrates the large distribution of residential energy demand vulnerability to increasing temperatures. Fortaleza, located in the relatively poorer and warmer northeast region is about three times less sensitive than

Table 1. City Statistics.

	Sample B: POF 2009					
	North Manaus	Northeast Fortaleza	Midwest Cuiaba	Southeast Rio de Janeiro	Southeast Sao Paulo	South Curitiba
Electricity expenses (R$/month)	75	53	116	95	80	75
Household income (R$/month)	2,434	2,151	3,367	3,542	3,866	3,148
Climate						
Normal temperature (C)	26.7	30.1	25.8	23.8	18.5	16.8
Temperature difference (C)	1.7	1.2	4.6	5.2	6.5	7.7
Wind Intensity (ms-1)	2.5	3.2	1.7	2.4	2.7	2.3
Relative humidity (%)	83.1	78.8	73.1	79.1	78.4	80.7
Appliance Ownership						
Air conditioning	48%	5%	28%	34%	2%	1%
Fan	79%	70%	86%	89%	49%	39%
Number of observations	556	548	376	946	1,095	405

Notes: Climate variables represents annual means based on data from meteorological stations for 1969 to 1990 (INMET, 2009). First word of column headings indicates region and second word indicates city. Temperature difference is measured as the difference between the highest and the lowest monthly mean temperatures for a city.

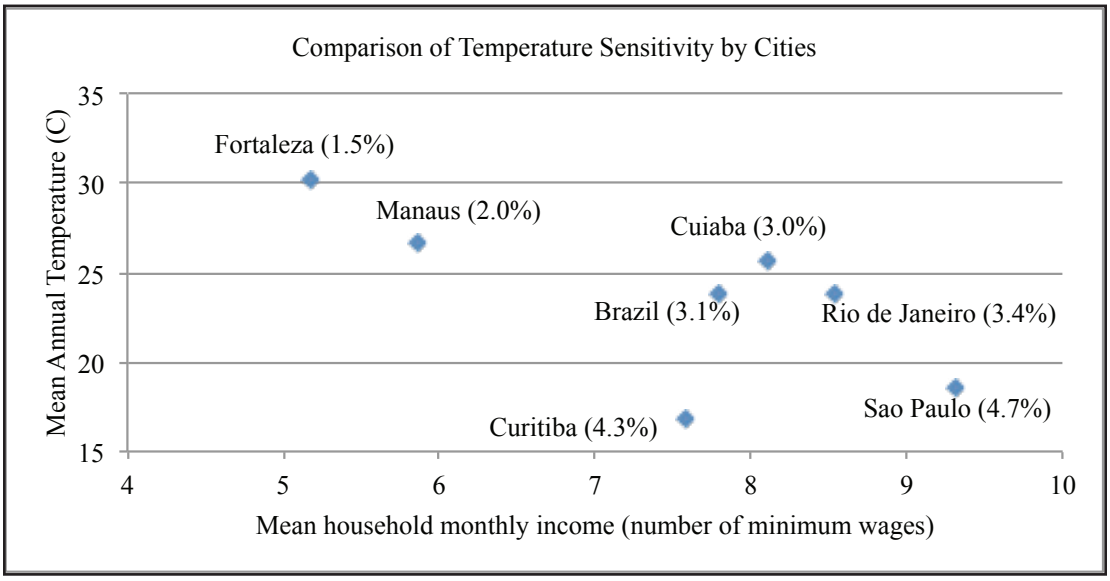


Figure 3. Temperature sensitivities in parentheses. Figures calculated using 2009 LR temperature elasticity of electricity expenses. Temperature sensitivity is defined as the percentage change in electricity expenditures resulting from 1 degree Celsius increase in mean annual temperature. City sensitivity reported for a household with average income.

São Paulo, the richer metropolitan area in Brazil located in a subtropical climate. The calculation of local sensitivity assumes uniform warming resulting from GCC. The vulnerability of São Paulo is surprising given its relatively high-income levels but consistent with São Paulo's low air conditioning and fan ownership ratios. Sao Paulo's relatively larger winter/summer temperature difference and relatively lower relative humidity, considering mean annual temperatures, help explain its low diffusion of AC ownership. The rates of appliance ownership in São Paulo indicates that additional socio-economic factors including housing standards, appliance technology, AC installation costs, and consumption habits affect AC diffusion.

Policy Implications

The distribution of climate change impacts in the energy sector has implications for GCC mitigation policies in emerging economies. First, mitigation policies can affect affordability of energy services, which is important not only for economic development but also for the capacity of low-income households to adapt to increasing temperatures. Secondly, the negative feedback of warming on energy consumption is largely concentrated in middle to high-income households and varies geographically, leading towards more differentiated policies by income and location. Policies that account for distribution of income and GCC impact could reduce negative impacts in energy affordability and increase electricity conservation potential.

Low-income households have lower adaptation capacity to increasing temperatures and will likely have to accept higher internal temperatures in their homes. This unmeasured welfare effect for low income households could be significant, especially in warmer regions. Mitigation policies that increase electricity prices through the use of expensive supply technologies, such as wind and solar energy in urban areas, could have the adverse effect of reducing affordability of electricity or increasing government expenditures in electricity subsidies. Targeted policies such as energy efficiency programs for low-income

households and conservation incentives differentiated by consumption levels are a better fit for economies with large variation in income and GCC impacts.

Finally, the results indicate there is an opportunity for emerging economies to influence their future pattern of energy consumption ahead of a significant expansion of the middle class in the next few decades. The analysis above suggests that measuring and targeting efficiency of end-use energy services for low to middle-income households are an important tool for policy design. Policy analysis would benefit from additional cost-benefit studies of targeted regulations and technological solutions as well as quantification of energy service efficiencies for middle class families in emerging economies.

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Amy Higgins	India	Ryan Sarsfield	Brazil
Alder Keleman	Bolivia	Tina Schneider	The Philippines
Rachel Kramer	Madagascar	Kanchan Shrestha	Nepal
Lakshmi Krishnan	India	Paul Thomson	Kenya
Harrison Leaf	Kenya/Uganda	Theodore Varns	Argentina
Ainsley Lloyd	Ghana	Leigh Whelpton	Namibia
Jing Ma	China	Sarah Wyatt	Colombia

The Compton Foundation's Program aims to contribute to the capacity-building of young professionals from Central and South America and Sub-Saharan Africa, to improve policies and programs relating to peace, population, sustainable development, and the environment in their home countries. This year's recipients and their countries are:

	Home Country	*Country for Summer Research*
Paulo Barreiro-Sanjines	Bolivia	Costa Rica
Carla Chizmar	Panama	Brazil
Rita Effah	Ghana	Ghana
Daniela Marini	Argentina	Argentina

The Andrew Sabin International Environmental Fellowships support the education and training of international students from less-developed countries, who intend to return to their home region or country to work in the field of conservation and development. This year's recipients and their home countries are:

	Home Country
Paulo Quadri Barba	Mexico
Lakshmi Krishnan	India
Jing Ma	China
Munjed Murad	Jordan
Kavita Sharma	India
Kanchan Shrestha	Nepal
Shiyue Wang	China

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