STREAM FRIENDLY COFFEE: COLLABORATING WITH THE RAINFOREST ALLIANCE™ TO ADVANCE STREAM CONSERVATION IN TROPICAL AGROFORESTRY SYSTEMS

by

REBECA G. DE JESUS CRESPO

(Under the Direction of Catherine Pringle)

ABSTRACT

Sustainability certifications are an increasingly important strategy for promoting natural resource conservation and social wellbeing, especially in the developing tropics. This dissertation addresses stream protection within agroforestry systems in collaboration with the Rainforest Alliance (RA), one of the largest certification programs of tropical agricultural products. Our partnership focused on a) developing a protocol to monitor RA certification's impact on stream protection, b) gathering baseline data about the impact of streams on coffee agroforestry (one of the leading RA certified industries), and c) evaluating the effectiveness of the RA program at advancing stream protection within coffee agroforestry. We conducted this study in Tarrazu, a high elevation, high intensity coffee growing region in Costa Rica. The results of this study suggest that streams within Tarrazu coffee agroforestry systems fall within recommended physicochemical and bio-integrity criteria for aquatic ecosystem conservation, and support high levels of diversity and pollution sensitive taxa. However, these streams also present some evidence of degradation, notably an increase proportion of certain tolerant taxa (Simuliidae and

Hydropsychidae), a decrease proportion of shredder-detritivore taxa, and increases in pH, conductivity, and turbidity relative to a forested reference site. The study provides evidence of the effectiveness of RA's certification requirement of preserving a minimum of 40% shade tree cover through the coffee plantation to mitigate some of these impacts, especially if the practice is implemented at the sub-watershed scale. This dissertation concludes with a chapter that draws from literature on research partnerships to develop an NGO-Academia collaboration framework. We illustrate the use of this framework using our experience with this project and two other examples of research partnerships involving sustainability certifications. Our contributions with this project include baseline information about stream ecosystem response to coffee agriculture, the first empirical support of the effectiveness of one of RA's certification requirements at advancing stream protection, and a road map to guide future collaborative projects between academics and non-governmental organizations for science-based conservation.

INDEX WORDS: tropical stream conservation, high elevation coffee agro-forestry, shade tree cover, non-point source pollution, macroinvertebrates, bio-integrity, monitoring, Rainforest Alliance, NGO-Academia partnerships, research collaborations

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DEDICATION

To my husband, Thomas Douthat, for encouraging me to pursue this goal, and supporting me every step of the way.

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CHAPTER 1

INTRODUCTION

Sustainability certifications integrate environmental conservation and social wellbeing with economic incentives by providing price premiums to producers that comply with pre-defined best management criteria (Blackman and Naranjo 2010, Milder et al. 2014). One of the fastest growing certifying groups is the Rainforest Alliance™ (RA) (Giovanucci et al. 2008). RA is a non-profit organization established in 1987 that works primarily in tropical regions. Their mission is to conserve biodiversity and ensure sustainable livelihoods by transforming land-use practices, business practices and consumer behavior (RA 2012a). In order to encourage consumer support, RA needs to provide credible evidence of their program's social and environmental impacts. To gather and analyze this evidence, they collaborate with research institutions and academics in the social and natural sciences (RA 2012b). This project is one of these initiatives, and focuses on helping RA create a strategy to evaluate their certification program's impact on stream ecosystem conservation. RA's objectives for this project included: 1) determining which metrics to use to evaluate water quality, and 2) building a stream monitoring protocol using these metrics. RA intends to apply this monitoring protocol to asses if their certification standards correlate with indicators of stream ecosystem integrity.

The standards included in RA's program are based on 10 guiding principles: 1) Management Systems; 2) Ecosystem Conservation; 3) Wildlife Protection; 4) Water

Conservation; 5) Working Conditions; 6) Occupational Health; 7) Community Relations; 8) Integrated Crop Management; 9) Soil Conservation and 10) Integrated Waste Management (SAN 2010). Each of the guiding principles corresponds to a set of assigned standards, some of which contribute to an overall point score while others are critical and must be met on every farm. Those which directly relate to water management are included in Table 1.1.

Of the water related standards (Table 1.1) only criterion 4.5, concerning point-source pollution (i.e. from discrete pollution sources), is ‘critical’, meaning that it is absolutely required for certification by RA. The remaining criteria are more flexible, and a farm must comply with 80% of these plus all of the critical criteria in order to be certified. Accordingly, RA’s certification framework lacks clear guidelines for farm management as concerns aquatic conservation practices. This is in part a function of the fact that the creators of the Sustainable Agriculture Network (SAN) Standards lacked important baseline information that would allow for evidence-based guidelines for the management of non-point source pollution (i.e. pollution from diffuse sources, such as contaminated runoff). A gap in scientific knowledge directly related to certification standards limits the feasibility of implementing a high-impact water conservation policy. Establishing evidence-based discrete non-point source pollution requirements, requires accounting for both the specific characteristics of the certified practice, and the characteristics of the landscape in which the practice takes place. Therefore, gathering this baseline data is an essential part of building RA’s capacity for tropical stream ecosystem management.

Accordingly, this dissertation focuses on two main objectives: 1) Creating monitoring tools to assess the effectiveness of RA's certification program, and 2) Gathering baseline data for science based non-point source pollution management practices. While RA certifies a variety of land use practices, we focused our objectives on agroforestry systems (crops interspersed with trees), in particular coffee farming. We chose coffee because despite being a leading export crop in the tropics (Taugourdeau 2014, FAO 2011), there are very few studies documenting the effects of coffee agriculture on streams (see Verbist et al. 2010, Vázquez et al. 2011).

Our work is divided in two chapters that address our objectives in coffee agroforestry systems, and a chapter that documents our experience developing this project within an NGO-Academia partnership:

- Chapter 2: Stream Friendly Coffee: Evaluating the impact of coffee agroforestry on high elevation streams in the Pirris Watershed, Costa Rica
- Chapter 3: Shade tree cover criteria for water quality conservation in the Rainforest Alliance coffee certification program: a snapshot assessment of Costa Rica's Tarrazú coffee region.
- Chapter 4: Building effective partnerships between Non-Governmental Organizations and Academia: Applying a collaboration framework to projects that evaluate sustainability certification

We started our collaboration by creating a multi scale monitoring tool called the Farm Stream and Watershed (FSW) assessment protocol (Appendix 4.1), using existing methodologies for evaluating farm practices (RA's practices survey), stream ecosystems

(Hauer and Lamberti 1998), and watershed impact (Heppinstall 2011). Chapter 2 applies the stream and watershed evaluation components of the FSW protocol in Costa Rica to gather baseline data about the impact of coffee farming on streams in high elevation regions. The baseline data we collected provides insights about effective approaches for monitoring the impact of coffee agriculture on aquatic ecosystems, and the need to further evaluate ecosystem services from coffee land use.

A practice that enhances the potential of coffee farms to provide ecosystem services is the reforestation of farms with shade trees (Moguel and Toledo 1999). Accordingly RA requires the reforestation of coffee farms at a minimum of 40% shade tree cover (SAN 2010). Although shade trees have been shown to help mitigate non-point source pollution (Verbist et al. 2010), no study has assessed whether RA's 40% minimum is adequate for this purpose. In Chapter 3, we address this information gap by comparing non-point source pollution indicators of sub-watersheds that have ~40% or more shade tree cover and sub watersheds that do not comply with RA's 40% minimum. The results of this chapter provides empirical data about the suitability of one of RA's standards for managing non-point source pollution in high elevation coffee growing regions.

Chapter 4 builds off of the need to better understand the dynamics of NGO-Academia collaboration. During the course of our collaborative project, we became interested in the process of meeting RA's objectives for monitoring tools, while simultaneously developing ecological research towards a PhD dissertation. Capturing this process, and the benefits and challenges of such partnerships forms the basis of Chapter 4. For this we apply an NGO-Academia framework for guiding the collaborative process, developed by synthesizing existing literature on strategies for academic-practitioner research partnerships (Roper 2002, Lundy 2003, Sabatier et al. 2005, Clark and Holliday 2006). We use this framework to describe our collaboration and two other projects involving NGO-Academia partnerships for assessing the impact of certification programs.

REFERENCES

Blackman, A., & Rivera, J. (2010). The evidence base for environmental and socioeconomic impacts of "sustainable" certification. Resources for the Future: RF-DP-10-17.

Clark, W.C. and L. Holiday, eds. 2006. Linking Knowledge with Action for Sustainable Development: The Role of Program Managers. Washington, D.C.: National Academy Press.

FAO, 2011. FAOSTAT Agriculture Data. http://faostat.fao.or. Accessed 03/19/2015.

Giovannucci, D., A. Byers, and L. Pascal. 2008. Adding value: Certified coffee trade in North America. In Pascal, L. (Ed.). Value-adding standards in the North American food market: Trade opportunities in certified products for developing countries. FAO.Rome, Italy.

Hauer F.R and G.A. Lamberty (eds.). 1998. Methods in Stream Ecology. 2nd edition. Academic Press. Burlington, MA.

Hepinstall-Cymerman, J. 2011. Drainage Basin Delineation and Morphometric Analysis. The University of Georgia course: FANR 3800. Lab 11: Watershed Modeling.

Lundy, M. 2003. Learning alliances with development partners: A framework for scaling out research results. In: Scaling up and out: Achieving widespread impact through agricultural research. Pachico, D. and S. Fujisaka (eds.). Cali, Colombia. Centro Internacional de Agricultural Tropical. 293p. Publication No. 140. Economics and impact Series. ISBN 958-694-064-0.

Milder, J. C., Arbuthnot, M., Blackman, A., Brooks, S. E., Giovannucci, D., Gross, L., ... & Zrust, M. (2015). An agenda for assessing and improving conservation impacts of sustainability standards in tropical agriculture. *Conservation Biology*. 29(2) 309-320.

Moguel, P., & Toledo, V. M. (1999). Biodiversity conservation in traditional coffee systems of Mexico. *Conservation Biology,* 13(1), 11-21.

Rainforest Alliance (RA) 2012b.Our work: Measuring our impact: http://www.rainforest-alliance.org/work/impact. Accessed 03/19/2015.

Rainforest Alliance (RA). 2012a. About us: Our mission. http://www.rainforest-alliance.org/about. Accessed 03/19/2015.

Roper, L. 2002. Achieving Successful Academic-Practitioner Research Collaborations. *Development in Practice*. 12: 338-345

Sabatier, P.A., Focht, W., Lubell, M., Trachtenberg, Z., Vedlitz, A., & Matlock, M. (2005). Swimming upstream: Collaborative approaches to watershed management. Cambridge, MA: MIT Press.

Sustainable Agriculture Network (SAN). 2010. Sustainable Agriculture Standard. http://www.rainforest-alliance.org/agriculture/standards. Accessed 03/18/2015.

Taugourdeau, S., le Maire, G., Avelino, J., Jones, J. R., Ramirez, L. G., Jara Quesada, M., ... & Roupsard, O. (2014). Leaf area index as an indicator of ecosystem services and management practices: An application for coffee agroforestry. Agriculture, Ecosystems & Environment, 192, 19-37.

Vázquez, G., Aké-Castillo, J. A., & Favila, M. E. (2011). Algal assemblages and their relationship with water quality in tropical Mexican streams with different land uses. Hydrobiologia, 667(1), 173-189.

Verbist B, Poesen J, van Noordwijk M, Widianto, Suprayogo D, Agus F, Deckers J.2010. Factors affecting soil loss at plot scale and sediment yield at catchment scale in a tropical volcanic agroforestry landscape. *Catena.* 80: 34-46.

TABLE 1.1. Summary of RA certification standards that influence aquatic ecosystems (SAN 2010)

Guiding Principle	**Criteria Related to Water Quality**
Ecosystem Conservation	2.6: Protect aquatic ecosystems by establishing buffer zones. Conserve natural water channels, and maintain their natural vegetative cover or, in its absence, restore it.
Ecosystem Conservation	2.8: Establish permanent agroforestry systems with overall canopy density of at least 40%.
Water Conservation	4.4: Treat all wastewaters generated
Water Conservation	4.5: Comply with specified parameters before discharging wastewater into natural water bodies (Critical Criterion).
Integrated Crop Management	8.1: Prioritize the use of non-chemical pest control methods.
Soil Conservation	9.1: Execute a soil erosion prevention and control program.
Soil Conservation	9.2: Give priority to organic fertilization and fertilize according to soil characteristics.

CHAPTER 2

STREAM FRIENDLY COFEE: EVALUATING THE IMPACT OF COFFEE AGROFORESTRY SYSTEMS ON HIGH ELEVATION STREAMS IN THE PIRRIS WATERSHED, COSTA RICA

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ABSTRACT

Coffee farming is an important land use type in tropical highlands, yet there are few studies addressing its impact on aquatic ecosystems. The goal of this study was to provide descriptive baseline data to fill this information gap. We monitored physicochemical parameters and benthic macroinvertebrate families for one year on 15 sub-watersheds dominated by intense coffee farming and one forested reference site within Costa Rica's Pirris watershed. We followed three approaches to assess the impact of coffee farming on streams. The first was a *Target Condition Approach*, were we used biotic integrity indices and target physicochemical values from existing government guidelines to determine the status of our study streams. The second approach was a *Reference Site Comparison,* where we compared a sub-set of our coffee streams (N=6) with a forested sub-watershed in terms of physicochemical and bio-integrity metrics. Our last approach was conducting a Stream Visual Assessment Protocol (SVAP) to estimate visually the condition of our study sites, and to determine the suitability of this tool for rapid monitoring of streams in coffee growing regions. To address this latter goal, we compared SVAP scores with physicochemical and bio-integrity data using Spearman correlations. Results from the *Target Condition Approach* suggest that coffee farming has low to moderate impact on stream ecosystems. Conversely, the *Reference Site Comparison* showed notable differences between the coffee streams and the reference site, including higher proportion of pollution tolerant macroinvertebrates, decreased proportion of shredder taxa and higher levels of water conductivity, pH and turbidity. The SVAP classified most of our sites as having "Fair" habitat quality and was only correlated to the proportion of shredders ($r=0.50$, $p=0.05$). Our results suggest that

intense coffee farming may lead to moderate impairment of local streams, and that the impacts are best detected by following a *Reference Site Comparison* approach. Although the SVAP may be a suitable tool for assessing habitat degradation of streams in coffee growing regions, the subtle changes in water quality and bio-integrity that we found in our study sites are not adequately identified by using this approach.

INTRODUCTION

Global demand for coffee has driven significant land use transformation in the tropics, with close to 10 million hectares across 80 countries devoted to coffee production (Clay et al. 2004, FAO 2014). While coffee has been traditionally grown at elevations that range between 500-1700 masl, expanding specialty markets favor varieties grown at elevations above 1350 masl (Rueda and Lambin 2013, Fischer and Victor 2014). Moreover, climate warming is impacting Arabica coffee at lower elevations due to drier conditions and greater vulnerability to pests (Avelino et al. 2006, Rahn et al. 2014). Because of market and ecological pressures, predictive models suggest that coffee farming landscapes will expand into higher elevations, potentially altering existing forested montane ecosystems (Bunn et al. 2014). These changes could be minimized, however, if coffee is grown in combination with shade trees, to create coffee agroforestry systems. Previous studies have shown that coffee agroforestry promotes conservation of arthropod, bird, bat, and non-volant mammal biodiversity (Perfecto et al.. 1996, Donald 2004, Jha et al. 2014), as well as ecosystem services such as pollination, nutrient cycling and carbon sequestration (Jha et al. 2014).

To date, our knowledge about the ecological impact of coffee agroforestry systems originates from studies conducted in terrestrial environments, but less is known, about coffee agriculture's impact on aquatic ecosystems. High elevation coffee often coincides with the headwaters of tropical watersheds, thereby influencing ecosystem properties across the entire river network (Vannote et al. 1980, Greathouse and Pringle 2006). Therefore, understanding the effects of coffee agroforestry on aquatic ecosystems is important for conservation purposes throughout watersheds extending to the coast.

Currently, there is a lack of understanding about how stream ecosystems in high elevation regions respond to the impact of coffee land use. In general, the studies that link coffee industry with streams have mainly focused on the impact of effluents from coffee processing facilities (Medina-Fernandez 2004, Ndaruga et al. 2004, Fernandez and Springer 2008). Much less is known about whether and how coffee agroforestry land use alters stream condition. Documented causes of stream impairment from coffee farming include riparian habitat degradation, erosion from unpaved farm roads, and leakage from agrochemical inputs, such as pesticides, nitrogen-based fertilizers, and lime (Clay et al. 2004, Castro-Tanzi et al. 2012). Conversely, because of the vegetation structure of coffee agroforestry, aquatic ecosystems near coffee plantations may be better protected from anthropogenic impact than streams draining other land uses also common in tropical highlands, such as ex-urban housing construction, row crops, and cattle ranching (Zeltzer 2008, Giraldo et al. 2014).

Existing literature regarding coffee's overall impact on aquatic ecosystems is limited and conflicting (Table 1). Some studies suggest that streams within coffee agroforestry systems show good water quality and healthy stream biological assemblages (Sagastizado-Mendez 2001, Guerrero-Bolano 2003), while data from other studies suggest moderate to severe impact of coffee farming on streams (Galindo et al. 2012). Some studies report degraded integrity of streams draining coffee plantations, relative to streams within other crop systems (Ordaz et al. 2010); others suggest that streams within coffee farms exhibit similar conditions to streams in protected areas, and show greater ecosystem integrity compared to competing agricultural land uses, such as cattle ranching and rice farming (Rahayu et al. 2009, Giraldo et al. 2014).

Two common attributes in previous studies looking at the relationship between coffee agriculture and aquatic ecosystems (Table 1), is their lack of attention to the confounding influence of both upstream land use practices and different management practices within the coffee farms. Only a few of the studies evaluating the impacts of coffee farming on aquatic ecosystems have characterized the basin scale percentages of coffee land use in the drainages of the streams under evaluation (Martinez et al. 2009, and Vasquez et al. 2011). Moreover, details about the type of coffee farm influencing these streams (e.g. rustic-shade coffee farm, conventional high intensity coffee farm, etc.) are rarely provided (but see Sagastizado-Mendez 2001, Renderos-Duran 2001, and Medina Fernandez 2004). Moreover, of the nine studies we found documenting the impact of coffee agriculture on streams (Table 2.1), only two (Constantino and Galindo 2012, and Giraldo et al. 2014) focus on streams within high elevation coffee regions (i.e >1350 masl).

Our study evaluates the impact of high elevation coffee farming on streams by linking landscape level attributes to on-site measures of stream condition. We focus on the coffee growing region within the Pirris watershed in Costa Rica, which has fairly uniform, high intensity, farming practices, that have been described extensively by previous studies (Castro-Tanzi et al. 2012, Meylan et al. 2013). Specifically, we evaluate physicochemical and biological integrity parameters in 15 sub-watersheds within the Pirris Watershed, draining high elevation (1350-1700 masl) coffee agroforestry (=>50% coffee; <10% urban; 17-66% shade tree cover).

To evaluate the impact of coffee agriculture on streams, we used three approaches: a) Target Condition, b) Reference Comparison, and c) Stream Visual Assessment. Our goal was to provide baseline information about the impact of this type of land use on water quality and stream biota, gain insights about which practices may cause aquatic ecosystem impairment, and outline suitable monitoring strategies to detect aquatic ecosystem degradation in coffee growing regions.

METHODS

Study Site

The Pirris watershed covers 46,654 ha on the central Pacific slope of Costa Rica (Figure 2.1). The main coffee growing region within the Pirris is referred to as Tarrazú, and it comprises about 22% (10,288 ha) of the watershed in three contiguous municipalities (Tarrazu, Dota, and Leon Cortes). Rainfall in the study region averages 2,400 mm/yr (ICAFE 2012). Soils are composed mostly of highly erodible Ultisols of alluvial origin (ICAFE 2012, USDA-NRCS 1998). Holdridge Life Zones across our study sites include Lower Montane Very Humid, Lower Montane Humid, and Pre-

Montane Very Humid (Table 2.1).

Coffee production in Tarrazú averages nearly 36,000,000 kilos per year (ICAFE 2012). Farms are configured in a shade monoculture pattern, whereby coffee is grown with one or two heavily managed shade tree species. The most commonly used shade trees in Tarrazú are *Erythrina poeppigiana*, a nitrogen-fixing legume, and *Musa spp*. (i.e. banana plants) (Castro-Tanzi et al. 2012). This intensive configuration of coffee plantations is characteristic of highly productive coffee regions (Moguel and Toledo 1999).

In terms of geomorphology, farms tend to be on steep slopes, reaching up to 60% (Castro-Tanzi et al. 2012). The most commonly applied agrochemicals are nitrogen based fertilizers, applied at an average of 212 kg/ha/y (±SD50), and lime, applied at an average of 658 kg/ha/y (±SD445) (Castro-Tanzi et al. 2012). Most of the coffee farms in Tarrazú belong to one of three cooperatives: Coope Dota, Coope Tarrazú and Coope Llano Bonito. All cooperatives are Starbucks CAFÉ certified. Coope Tarrazu and Coope Dota also participate in the Rainforest Alliance (RA) certification program. These certifications encourage the application of erosion control measures, reforestation with shade trees, and reduction and/or responsible use of agrochemical inputs (SAN 2010, Starbuck Coffee Company 2014).

We focused our study on sixteen study sites on 3rd and 4th order streams. Out of these, 15 drained coffee dominated sub-watersheds (hereinafter "coffee streams") and one drained an intact forest in a privately owned reserve area. Within the sub-watersheds of the coffee streams (Figure 2.1b), coffee agriculture was the dominant land use type (≥50%), while forest ranged from <1% to 26.7%, urbanization ranged from 1% to 5.6%, and other land uses (i.e. pastures and exposed soil) covered from 9% to 31% (Table 2.1). Mean shade tree cover within coffee farms across the sub watersheds was 40.22% (±14.85). Land cover in the sub-watershed of the reference site was 100% forest.

Stream Assessment

We sampled streams four times in 2013 based on historical rainfall patterns of the study region (IMN 2015): 1) April (end of dry season), July (transition period), October (peak rainy season), and December (beginning of dry season). During each sampling event we collected data on stream physicochemical parameters, bio-integrity, and habitat at three equally spaced points across stream reaches, where stream reach length was 12X stream width (USDA-NRCS-1998). The average of these three within-stream samples was used as the value of each sampling event in each stream.

To characterize stream physicochemical parameters, we measured turbidity, conductivity, and pH using a YSI 6850 multi parameter probe, and percent of fine substrates (% fines) using a Wolman Pebble Count (Wolman 1954). Turbidity and % fines indicate watershed erosion (EPA 2012 a, b). Conductivity is an indicator of agrochemical pollution (EPA 2002), and pH indicates watershed liming (Bradley and Ormerod 2002).

We used benthic macroinvertebrates as biological indicators of integrity, because they show predictable responses to agrochemical and sediment pollution (Chang et al. 2014). To collect macroinvertebrates, two people handpicked individuals from representative microhabitats for one hour using a 500 μm D-Net. We also collected one Surber sample (500 μm) from the best available riffle (Karr and Chu 1998). Samples were combined and preserved in 70% ethanol and individuals were identified to the family level (Merritt and Cummins 1996, Springer et al. 2010).

<u>Data analysis</u>

We first explored the general trends of changes in physicochemical variables across the four sampling events. Then for the analyses below, we used the mean of each stream's physicochemical variables across the four sampling events, except for % fines. This variable was measured only during December, once sediment had settled after the rainy season.

For bio-integrity we combined data from all four sampling events to calculate Chao's family richness and Simpsons's diversity index in EstimateS (Colwell 2005) and % Dominance in PAST (ver 2.17b, Hammer et al.. 2001). We calculated Hilsenhoff's Family Biotic Index (FBI) (Hilsenhoff 1987) and the Biological Monitoring Working Party Group (BMWP) index (Hawkes 1998), both of which characterize streams based on the proportion of pollution tolerant vs. pollution sensitive taxa. The BMWP focuses on presence/absence of families, while the FBI incorporates relative abundances. We also classified Functional Feeding Groups using guidelines from Ramirez and Gutierrez-Fonseca (2014), supplemented with data from Merritt and Cummins (1996).

a. Target Condition Approach

For the Target Condition Approach we compared values for physicochemistry and bio-integrity indices (FBI and BMWP) from coffee streams, to target values established as benchmarks for stream ecosystem conservation. For physicochemical variables, the targets were based on guidelines from the Costa Rica Ministry for the Environment's (MINAE) ruling on optimal levels for stream ecosystem conservation (MINAE 2007). We also applied target values from the US Environmental Protection Agency for Conductivity levels adequate to sustain aquatic life (EPA 2010), and targets for deposited sediment or % fines (Rowe et al.. 2003). The target values for the bio-integrity indices were based on each metric's cut-off for designating streams as having "Good" water quality (100 for the BMWP index, <5 for the FBI index).

b. Reference Comparison Approach

We compared physicochemistry and biological integrity values from coffee streams to the reference stream draining intact forest. We were only able to identify one accessible reference stream that was similar in size, life zone and gradient to our coffee streams. Time constraints, accessibility, and scarcity of preserved forest within the study region limited our ability to find suitable replicates for this reference stream. Although this is a limitation of our study, it represents the best currently available information on the Pirris Watershed and other studies with similar constrains have been able to provide valuable information about anthropogenic impacts on stream ecosystems in the past (Shields et al.. 1994, Cross et al.. 2006)

The reference site is a 3rd order stream within a privately owned forest reserve in the Lower Montane Very Humid Life Zone. For comparisons, we only used a sub-set of 3rd order coffee streams ("focal coffee streams", N=6) that fell within the same life zone, using Barbour et al.'s (1995) approach of comparing sites of similar order and ecoregion (Reynoldson et al.. 1997). To further corroborate the similarity of our reference site with the focal coffee streams, we conducted a Non Metric

Multidimensional Scaling procedure in PAST (ver 2.17b, Hammer et al. 2001), using the Bray Curtis similarity index and macroinvertebrate assemblage data, similar to Reynoldson et al.'s (1995) BEAST model approach.

Biological integrity comparisons between focal coffee streams and the reference site reflected criteria and predictions included in generic multi-metric indices, such as Gerritsen (1995) and Karr and Chu (1998) and are listed in Table 2.3. The physicochemical criteria we used for comparison, as well as their expected responses to coffee farming (Table 2.3) were based on results from previous studies of streams draining coffee farms (Sagastizado-Mendez 2001, Martinez et al. 2009).

c. Stream Visual Assessment

With each of the 16 streams, we conducted a version of the USDA-NRCS Stream Visual Assessment Protocol (SVAP, USDA-NRCS-1998), adapted for Costa Rica (Mafla-Herrera 2005). The SVAP consists of 15 assessment elements that include water appearance, riparian condition, and substrate embeddedness (among others). After visually surveying the stream, we ranked each element on a scale of 1-10 (poor to excellent), after which scores were averaged to obtain an overall score for the stream's condition. Out of the SVAP's 15 elements, we evaluated 13 (Appendix 2.2) and omitted fishing pressure and fish habitat, as most sites had very low fish abundance due to elevation and presence of a large dam downstream. To evaluate the accuracy of the SVAP and the possibility of applying this tool for widespread monitoring among coffee farm land owners, we compared mean SVAP scores across seasons with averages for physicochemical measures and the biological integrity measures described above. For this we conducted Spearman rho correlations in PAST (ver 2.17b, Hammer et al. 2001).

RESULTS

General Trends

Physicochemical trends through the sampling year in our 15 coffee streams and the reference site (Figure 2.1) are shown on Figure 2.2. In the coffee streams, turbidity values were the lowest in the dry periods of April (3.93 NTU±0.91) and December (3.83 NTU±1.51). Turbidity increased with the onset of the rainy season in July (8.74 NTU±6.13) and reached its highest value during the peak of the rainy season in October (12.44 NTU±1.47). Conductivity was highest during the dry period that preceded the onset of the rainy season (328.29 µS/cm ±92.24), dropped steadily with the rainfall during July (176.08 µS/cm ±48.89) and October (145.35 µS/cm ±37.27) and started rising slightly again in December (178.95 µS/cm ±43.62). pH values dropped only during the peak rainy season of October (7.07±0.26) and remained slightly basic during April (7.82±0.19), July (7.97±0.26), and December (7.74±0.23).

Compared to the coffee streams, our reference stream showed the opposite trend; turbidity values were highest before the onset of the rainy season in April (3.46 NTU), and decreased with rainfall in July (2.4 NTU), October (1.23 NTU), and December (1.6 NTU). Conductivity and pH showed comparable trends in the reference stream relative to coffee streams, but values were lower in the reference stream. The highest conductivity values in the reference stream were found in April (106 µS/cm). We observed lower values in July (47.6 µS/cm), October (41 µS/cm) and December (58.3 µS/cm). pH, was the lowest in the month of October (6.48), and slightly basic in July (7.47) and December (7.17), similar to what we observed in coffee streams. pH was not measured in the month of April due to equipment failure.

Macroinvertebrates

We identified a total of 19,281 individuals throughout the year in our 16 study streams; taxa, families, functional feeding groups (FFG) and relative abundances are listed in Appendix 2.1. The dominant FFGs were Collector Gatherers (41%), followed by Filterers (30%), Predators (17%), Scrapers (6%), Shredders-Detritivores (5%) and Shredders-Piercers of live plant tissue (1%). The families comprising the greatest percentages of the sampled individuals were Simuliidae (Diptera, 18.3%), Baetidae (Ephemeroptera, 15.2%), Leptohyphidae (Ephemeroptera, 13.6%) and Hydropsychidae (Trichoptera, 10.6%).

NMDS analysis of macroinvertebrate assemblages showed no significant difference among the 15 coffee streams, but significant difference between the coffee streams and the reference site (Figure 2.3a). However, the same analysis, conducted only with the focal coffee streams (N=6), which were more structurally similar to the reference site, showed no significant difference in macroinvertebrate assemblages with the reference site (Figure 2.3 b), which supports our prediction of similarity between these streams based on stream order and Life Zone.

Stream Visual Assessment

Most coffee streams (9/15) rated as fair (6-7.4) in the SVAP. A third of our sites rated as good (7.5-8.9) and one site rated as being in poor condition. Our reference stream was rated as good (Figure 4). Scores for the 13 assessed variables within the SVAP for all of our sites are listed in Appendix 2.2.

Stream Integrity Assessments

a. Target Condition Approach

Overall, our coffee streams fell within acceptable target values for aquatic ecosystem conservation for all parameters evaluated during the sampling year (2013) (Table 2.3). Evaluated separately, some sites did not meet target values: four sites exceeded the Conductivity target (i.e 300 µS/cm), four sites exceeded the % fines target (i.e 20%), one site exceeded the FBI index target (i.e 5.0), and 2 sites fell below the recommended BMWP value (i.e. 100).

Annual averages for turbidity across all of coffee streams (N=15) ranged from 3.29-14.75 NTUs, with a mean of 7.56 (±3.38) NTU. Conductivity ranged from 133-288.83 µS/cm and averaged 192.76 (±46.67) µS/cm. Our pH ranged from 7.27-7.93 and averaged 7.63 (±0.21). Deposited sediment (% fines) ranged from 9% to 24% with a mean of 17.6 (±4.40). For our family level macroinvertebrate indices, we found that the FBI values ranged from 3.4 (excellent-organic pollution unlikely) to 5.2 (fair-fairly substantial organic pollution likely) and averaged 4.2(±0.49) (good-some organic pollution probable). The BMWP values ranged from 86 (moderate pollution) to 132 (excellent water quality), and averaged 111 (±12.85) (good water quality).

b. Reference Site Comparison

All of our physicochemical metrics showed the predicted response to agricultural impact in coffee streams relative to the forested site. The year-long mean turbidity in the focal coffee streams was 6.52 (±1.49) NTU compared to 2.17 NTU (±0.99) in our reference site. Mean conductivity was 209.98 (±44.82) µS/cm compared with 63.25

(±35.2) µS/cm in the reference site. pH averaged 7.67 (±0.17) in the focal coffee streams vs 7.04(±0.50) in the reference stream (Table 2.4). Percentage of fines averaged 16.67% in focal coffee streams and measured 15% in the reference site.

Four out of ten biological metrics exhibited the predicted response, while the rest showed a trend opposite to predictions. We saw higher mean values in the focal coffee streams relative to the reference stream for richness (34 coffee vs 29 forest), diversity (0.85 coffee vs 0.74 forest), % Predators (17 coffee vs 6 forest), % members of the family Simuliidae (16 coffee vs 8 forest), % Hydropsychidae/Trichoptera (63 coffee vs 39 forest), % EPT taxa (54 coffee vs 46 forest) and FBI values (4.20 coffee vs 4 forest). We saw lower mean values in the focal coffee streams relative to the reference stream for % dominance (0.2 coffee vs 0.3 forest), % Shredders (7% coffee vs 32% forest), % Baetidae/Ephemeroptera (53% coffee vs 95% forest) and the BMWP index (117 coffee vs 94 forest). Details about the macroinvertebrate families reported in our focal coffee streams and the forested reference site are included in Table 2.5.

c. Stream Visual Assessment Protocol

Spearman rho correlations between the SVAP scores and the physicochemical parameters in all our coffee streams and the reference site were non-significant (Table 2.6). In terms of the biological integrity metrics, we observed a trend for higher % of shredders in streams with higher SVAP scores (r_s=0.50, p=0.045). None of the other biological metrics showed correlations with the SVAP values (p>0.05).

DISCUSSION

Overall, our results suggest that coffee agroforestry has low to moderate impact on high elevation streams of the Pirris watershed in Costa Rica. We found that over the course of a year, all measured physicochemical and biological integrity parameters fell within target ranges recommended by previous studies and based on regulatory tools for stream ecosystem conservation (e.g. MINAE 2007). Changes in stream ecosystems associated with coffee farming were better detected by comparing focal coffee streams with our forested reference site. These changes included higher values for all physicochemical parameters assessed (i.e. greater non-point source pollution), higher macroinvertebrate richness, and diversity, and a decrease in the percentage of shredders relative to other Functional Feeding Groups.

Most of our findings on macroinvertebrate assemblages and physicochemical parameters correspond to what other studies have reported in streams within coffee farms. For example we found a dominance of collector gatherers, which coincides with previous studies in Colombia (Chara-Serna et al. 2009, Galindo et al. 2012). The dominant families in Tarrazu (i.e. Simuliidae, Hydropsychidae, Baetidae) also were commonly observed in coffee streams surveyed by Chara-Serna et al. 2009). Similar to our findings, Giraldo et al. (2014) report higher proportion of the families Hydropsychidae and Simuliidae, two tolerant collector-gatherer taxa, in coffee streams relative to forested streams. In terms of physicochemistry, we report higher pH, conductivity and turbidity in coffee streams relative to the reference stream, a pattern also observed on streams in Veracruz, Mexico (Vasquez et al. 2011), and Chimaltenango, Guatemala (Medina Fernandez 2004). Studies by Vasquez et al.

(2011) and Galindo et al. (2012) showed trends that differed from our findings. For example, for their monthly samples, Vasquez et al. (2011) reported conductivity values in coffee streams that ranged between 66 and 165 µS/cm, which is notably lower than what we report in our coffee streams. The authors do not specify the type of coffee farms influencing these streams, but it is possible that the lower conductivity in these farms may be related to more rustic shade coffee systems in their study region, or lower agrochemical inputs through the year. Moreover, Galindo et al. (2012) report a dominance of the family Chironomidae, in their coffee streams, whereas in our study this family only represented about 2.4% of our total sample (Appendix 2.1). The authors report persistently low flows in many of their sampling sites that could lead to more anoxic conditions and the dominance of this family, which is considered tolerant of low oxygen conditions (Walshe 1948).

Most of the measured parameters were uncorrelated with the SVAP scores. The absence of a correlation may reflect low variability among our sampling streams. For example, Galindo et al. (2012) showed a significant correlation between the SVAP and stream integrity metrics, but their study had 108 streams distributed evenly across the categories Excellent, Good, Moderate and Poor, while most of our streams ranked as Fair. Other studies suggest that habitat indices like the SVAP may be limited for predicting water chemistry (De Jesus and Ramirez 2010) and biological condition (Hughes et al. 2010), except in cases where there is extreme physical degradation of the habitat. For example, one of the parameters in the SVAP evaluates signs of nutrient enrichment in the form of algal growth. Although we report high levels of conductivity, which can signal nutrient enrichment, the residence time of such agrochemicals within the stream may be too low to lead to excessive algal growth that would be visually evident. Therefore, the SVAP may not be a reliable tool for detecting subtle changes in biotic or abiotic traits in coffee streams, especially if these changes are influenced by landscape scale impacts. The SVAP, however, is reliable for detecting habitat changes at the reach scale, such as riparian degradation, which are aspects that farm owners may have more control over. Based on findings from previous studies (Galindo et al. 2012) and the limited evidence from our study, the tool is still recommended as a way to engage farmers in stream ecosystem management, and to help them become familiar with common signs of stream impairment on their properties.

The only correlation we found with the SVAP was with the percentage of shredders. This trend may be associated to two components of the SVAP, "riparian condition" and "canopy cover", which were rated as poor in many coffee streams. Therefore, a reduction in shredder abundance in coffee streams may be attributed to degradation of the riparian condition, and the availability of high quality leaf litter, within coffee farms. Most riparian zones in our coffee streams were composed of invasive grasses or coffee shrubs (*Coffea arabica*) interspersed with shade trees (mostly *Erythrina poeppigiana*). Previous studies suggest that both *E. poeppigiana* and *C. arabica* leaves have traits that characterize low quality litter for macroinvertebrate consumption. (Mungia et al. 2004, Ardon and Pringle 2008, 2009). Accordingly, the six focal coffee streams that we used to make comparisons with the reference stream, were all 3rd order, headwater streams, expected to have close to a third of macroinvertebrates within the shredder FFG (Vannotte et al. 1980). Instead, we observed a poor representation of shredders and a prevalence of collector gatherers, while the forested reference site (also 3rd order) showed the expected proportion of shredders based on its position in the landscape.

Aside from shredder percentages, and riparian condition, other parameters that may be used as indicators of the impact of coffee land use include: turbidity, conductivity, % fines, pH, % Simuliidae, Hydropsychidae/Trichoptera, and the FBI. A subset of these parameters could be assessed against specific values such as we did in the Target Condition Approach (i.e. physicochemistry and the FBI). The rest of these indicators (% Simuliidae, Hydropsychidae/Trichoptera, % Shredders) need to be assessed in relation to comparable reference sites. As evident from this study (where there is only one reference stream), finding suitable reference sites in coffee growing regions may be difficult, as remaining forests may be inaccessible or in areas otherwise unsuitable for coffee farming. However, our study was limited in terms of time, which constricted our ability to detect adequate forested stream replicates. For coffee growing regions participating in payment for ecosystem services programs, or which are highly dependent on the consumption of local water sources, carefully planned monitoring programs that include replicated reference sites, or matched pairs of sites, selected using landscape attributes such as forest cover and life zone, should be a priority.

Many aspects of the Reference Comparison Approach showed responses opposite to predictions based on generic criteria from existing literature. For example, we observed higher richness, diversity, % Predators, % EPT taxa, and BMWP values in the coffee streams. Higher % EPT may be attributed to the higher % of

Hydropsychidae in coffee streams, a tolerant family within the Trichoptera order. Higher % Predators, Richness, and Diversity may be due to moderate nutrient enrichment and greater food availability in coffee streams due to agrochemical inputs. For example, Vasquez et al. (2011) reported higher diversity of diatoms in streams draining coffee farms relative to forested streams, suggesting a boost in primary productivity due to this land use. Cross et al. (2006) found increases in abundance of macroinvertebrate primary consumers (e.g. Collector Gatherers) and secondary consumers (i.e. Predators) in headwater streams experimentally enriched with nutrients relative to control-forested sites. Also, Justus et al. (2010) found higher macroinvertebrate richness on steams experiencing moderate levels of nutrient enrichment. Since the BMWP index relies heavily on family richness and less on relative abundances of sensitive taxa, the higher values for this parameter in coffee streams may also be associated to the trends observed for richness, diversity and predator abundances.

Although we describe the impact of coffee farming in terms of trends observed over the course of a year (i.e. average physicochemical values, total macroinvertebrates detected), the impacts of coffee farming may vary by season in relation to agricultural practices and weather patterns. For example, application of fertilizers in Costa Rica is recommended for the months of May, July and October, coinciding with the rainy season (ICAFE 2011). We observed a drop in the conductivity during these same months, probably due to dilution by rainfall. This pattern of fertilization during the rainy season may help prevent stream impairment locally, but promote degradation further down the stream network. The question of whether the physicochemical and bio integrity patterns observed are due to actual moderate impact of coffee agriculture on streams or the effectiveness of high elevation streams in exporting pollutants downstream should be a priority for future studies. Studies in receiving water bodies would help address this question. In fact, the Pirris watershed presents the perfect context to do so in the near future, as the main stem of the river, downstream of our sampling sites, was recently dammed, allowing the opportunity of quantifying long term changes in water chemistry and biotic indicators like algae, without the confounding impacts of other land uses.

CONCLUSION

Streams within the high elevation, high intensity coffee growing region of the Pirris watershed, Costa Rica, present some evidence of degradation, notably an increase proportion of certain tolerant taxa (Simuliidae and Hydropsychidae), a decreased proportion of Shredders, and increases in pH, conductivity, and turbidity relative to a forested reference site. In spite of this, coffee streams fall within recommended physicochemical and bio-integrity criteria for aquatic ecosystem conservation, and support high levels of diversity and pollution sensitive taxa. These latter findings partially support the potential role of coffee agroforestry systems to provide ecosystem services (Perfecto et al. 1996, Jha et al. 2014). Future studies must evaluate whether the levels of stream integrity described in this study reflect a low to moderate effect of coffee farming on streams, or the high effectiveness of streams within high elevations to export pollutants downstream due to their steep gradients and rainfall patterns.

Based on our findings on conductivity levels and macroinvertebrate assemblages, we recommend that moderating the application of agrochemicals and reforesting riparian vegetation with native trees should be a priority for promoting stream ecosystem conservation within coffee farms of the Pirris watershed. Incorporating these practices as part of certification programs or payment for ecosystem services schemes may help promote river network conservation by lowering the impact of high elevation coffee farming.

REFERENCES

Ardón, M., & Pringle, C. M. (2008). Do secondary compounds inhibit microbial-and insect-mediated leaf breakdown in a tropical rainforest stream, Costa Rica?. *Oecologia*, 155(2), 311-323.

Ardón, M., Pringle, C. M., & Eggert, S. L. (2009). Does leaf chemistry differentially affect breakdown in tropical vs temperate streams? Importance of standardized analytical techniques to measure leaf chemistry. *Journal of the North American Benthological Society*, 28(2), 440-453.

Avelino, J., Zelaya, H., Merlo, A., Pineda, A., Ordoñez, M., & Savary, S. (2006). The intensity of a coffee rust epidemic is dependent on production situations. *Ecological modelling*, 197(3), 431-447.

Barbour, M. T., Stribling, J. B., & Karr, J. R. (1995). Multimetric approach for establishing biocriteria and measuring biological condition. Biological assessment and criteria: Tools for water resource planning and decision making, 63-77.

Bunn, C., Läderach, P., Rivera, O. O., & Kirschke, D. (2015). A bitter cup: climate change profile of global production of Arabica and Robusta coffee. *Climatic Change*. 129: 89-101.

Bradley D.C. and S.J. Ormerod. (2002). Long term effects of catchment liming on invertebrates in upland streams. *Freshwater Biology*. 47: 161-171.

Castro-Tanzi, S., Dietsch, T., Urena, N., Vindas, L., & Chandler, M. (2012). Analysis of management and site factors to improve the sustainability of smallholder coffee production in Tarrazú, Costa Rica. *Agriculture, Ecosystems & Environment*, 155, 172-181.

Chang, F. H., Lawrence, J. E., Rios-Touma, B., & Resh, V. H. (2014). Tolerance values of benthic macroinvertebrates for stream biomonitoring: assessment of assumptions underlying scoring systems worldwide. *Environmental monitoring and assessment,* 186(4), 2135-2149.

Chará-Serna, A. M., Chará, J. D., Zúñiga, M. D. C., Pedraza, G. X., & Giraldo, L. P. (2010). Clasificación trófica de insectos acuáticos en ocho quebradas protegidas de la ecorregión cafetera colombiana. *Universitas Scientiarum*, 15(1), 27-36.

Clay, J. (2004). Coffee. In: Clay, J. (Ed.), World Agriculture and the

Environment. Island Press, Washington, p. 570.

Colwell, R. K. (2013). EstimateS: Statistical estimation of species richness and shared species from samples. http://viceroy.eeb.uconn.edu/estimates/ Accessed 12/29/2014.

Cross, W. F., Wallace, J. B., Rosemond, A. D., & Eggert, S. L. (2006). Whole-system nutrient enrichment increases secondary production in a detritus-based ecosystem. *Ecology*, 87(6), 1556-1565.

Galindo, L. Constantino, L., Benavides, P., Montoya, E. & Rodriguez, N. (2014). Evaluación de macroinvertebrados acuáticos y calidad de agua en quebradas de fincas cafeteras de Cundinamarca y Santander Colombia. http://biblioteca.cenicafe.org/bitstream/10778/514/1/arc063%281%2970-92.pdf. Accessed 04/10/2015.

Donald PF. (2004). Biodiversity impacts of some agricultural commodity production systems. *Conservation Biology*. 18: 17–38.

[FAO] Food and Agriculture Organization of the United Nations. (2014). FAOSTAT. FAO. http://faostat.fao.org/site/567/. Accessed 02/28/2014.

Fernández, L., & Springer, M. (2008). El efecto del beneficiado del café sobre los insectos acuáticos en tres ríos del Valle Central (Alajuela) de Costa Rica.Rev. Biol.

Trop, 56(4), 237-256.

Fischer, E. F., & Victor, B. (2014). High-End Coffee and Smallholding Growers in Guatemala. Latin American Research Review, 49(1), 155-177.

Gerritsen, J. (1995). Additive biological indices for resource management. *Journal of the North American Benthological Society*. 14:451-457.

Giraldo, L. P., Chará, J., del Carmen Zuñiga, M., Chará-Sema, A. M., & Pedraza, G. (2014). Impacto del uso del suelo agropecuario sobre macroinvertebrados acuáticos en pequeñas quebradas de la cuenca del río La Vieja (Valle del Cauca, Colombia). Revista de Biología Tropical, 62, 203-219.

Guerrero-Bolano, F., Manjarrés-Hernández, A., & NÚÑEZ-PADILLA, N. O. R. B. E. L. I. S. (2003). Los macroinvertebrados bentónicos de Pozo Azul (cuenca del Rio Gaira, Colombia) y su relación con la calidad del agua. Acta Biológica Colombiana, 8(2), 44-55.

Hammer, Ø., Harper, D. A. T., & Ryan, P. D. (2001). PAST-Palaeontological statistics. www. uv. es/~ pardomv/pe/2001_1/past/pastprog/past. pdf, acessado em, 25(07), 2009.

Hawkes, H. A. (1998). Origin and development of the biological monitoring working party score system. Water Research, 32(3), 964-968.

Hughes, Robert M., Alan T. Herlihy, and Philip R. Kaufmann. "An Evaluation of Qualitative Indexes of Physical Habitat Applied to Agricultural Streams in Ten US States1." (2010): 792-806.

Hilsenhoff, W. L. (1988). Rapid field assessment of organic pollution with a family-level biotic index. *Journal of the North American Benthological Society*, 65-68.

(ICAFE) Instituto del Café de Costa Rica. (2011). Guía Técnica para el Cultivo del Café. 1a ed. Heredia Costa Rica. 2011: ICAFE-CICAFE. 72 p. ISBN 978-9977-55-041-4.

(ICAFE) Instituto del Café de Costa Rica. (2012). Regiones Cafetaleras: Tarrazu. http://www.icafe.go.cr/nuestro_cafe/regiones_cafetaleras/tarrazu.html Accessed 12/29/2014.

(IMN) Instituto Meteorológico Nacional. (2015). Datos climáticos: San José. http://www.imn.ac.cr/IMN/MainAdmin.aspx?__EVENTTARGET=ClimaCiudad&CIUDAD=7. Accessed 03/01/2015.

Jha, S., Bacon, C. M., Philpott, S. M., Méndez, V. E., Läderach, P., & Rice, R. A. (2014). Shade coffee: update on a disappearing refuge for biodiversity. *BioScience*, 64(5), 416-428.

Justus, B. G., Petersen, J. C., Femmer, S. R., Davis, J. V., & Wallace, J. E. (2010). A comparison of algal, macroinvertebrate, and fish assemblage indices for assessing low-level nutrient enrichment in wadeable Ozark streams. *Ecological Indicators*, 10(3), 627-638

Karr, J. R., & Chu, E. W. (1998). Restoring life in running waters: better biological monitoring. Island Press.

Mafla-Herrera, M. (2005). Guía para evaluaciones ecológicas rápidas con indicadores biológicos en ríos de tamaño mediano Talamanca-Costa Rica. Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) Turrialba, Costa Rica.

Martínez, M. L., Pérez-Maqueo, O., Vázquez, G., Castillo-Campos, G., García-Franco, J., Mehltreter, K., & Landgrave, R. (2009). Effects of land use change on biodiversity and ecosystem services in tropical montane cloud forests of Mexico. *Forest Ecology and Management*, 258(9), 1856-1863.

Medina Fernández, B. Y., & CATIE, Turrialba (Costa Rica). (2004). Externalidades hídricas del sistema agroforestal café con sombra, en la subcuenca del río Guacalate, Guatemala. http://orton.catie.ac.cr/REPDOC/A0229E/A0229E.PDF. Accessed. 04/10/2015.

Merritt, R. W., & Cummins, K. W. (Eds.). (1996). An introduction to the aquatic insects of North America. Kendall Hunt.

Meylan, L., Merot, A., Gary, C., & Rapidel, B. (2013). Combining a typology and a conceptual model of cropping system to explore the diversity of relationships between ecosystem services: The case of erosion control in coffee-based agroforestry systems in Costa Rica. *Agricultural Systems*, 118, 52-64.

(MINAE) Ministerio de Ambiente y Energia de Costa Rica. (2007). Reglamento para la Evaluación y Clasificación de la Calidad de Cuerpos de Agua Superficiales. Nº 33903-MINAE-S. http://www.cimar.ucr.ac.cr/PDFS/Reglamento_Evaluacion_y_Clasificacion_Calidad_Agua_Superficial.pdf. Accessed 02/28/2015.

Moguel, P., & Toledo, V. M. (1999). Biodiversity conservation in traditional coffee systems of Mexico. *Conservation Biology*, 13(1), 11-21.

Ndaruga, A. M., Ndiritu, G. G., Gichuki, N. N., & Wamicha, W. N. (2004). Impact of water quality on macroinvertebrate assemblages along a tropical stream in Kenya. *African Journal of Ecology*, 42(3), 208-216.

Ordaz, A. L., Martín, R., & Ortaz, M. (2010). Macroinvertebrados acuáticos del

Ramal de Calderas, Andes de Venezuela.In: Evaluación rápida de la biodiversidad y aspectos socioecosistémicos del Ramal de Calderas: Andes de Venezuela. Conservation International, Center for Applied Diversity Science, 2010.

Perfecto I, Rice RA, Greenberg R, Van der Voort ME. (1996). Shade coffee: A disappearing refuge for biodiversity. *BioScience* 46: 598–608.

Rahayu S, Suryadi I, Verbist B, Dedecker A, Mouton A and van Noordwijk M. 2009. Water quality biomonitoring using macroinvertebrates in Way Besai, Sumberjaya, West Lampung. In: Takizawa S, Kurisu F and Satoh H,(eds). Proceeding Southeast Asian Water Environment. . Norwich, UK. Page Bros Ltd. http://regions/southeast_asia/publicationsdo=view_pub_detail&pub_no=PP0284-10-10.

Rahn, E., Läderach, P., Baca, M., Cressy, C., Schroth, G., Malin, D., ... & Shriver, J. (2014). Climate change adaptation, mitigation and livelihood benefits in coffee production: where are the synergies?. *Mitigation and Adaptation Strategies for Global Change*, 19(8), 1119-1137.

Ramírez, A., & Gutiérrez-Fonseca, P. E. (2014). Functional feeding groups of aquatic insect families in Latin America: a critical analysis and review of existing literature. *Revista de Biologia Tropical*, 62, 155-167.

Renderos Durán, R. V. (2001). The effect of coffee-eucalyptus deglupta agroforestry system over water contamination with nitrates in micro-watershed from the south zone of Costa Rica. http://www.sidalc.net/cgi-bin/wxis.exe/?IsisScript=orton.xis&method=post&formato=2&cantidad=1&expresion=mfn=049053. Accessed. 04/10/2015.

Reynoldson, T. B., Bailey, R. C., Day, K. E., & Norris, R. H. (1995). Biological guidelines for freshwater sediment based on BEnthic Assessment of SedimenT (the BEAST) using a multivariate approach for predicting biological state. *Australian journal of ecology*, 20(1), 198-219.

Reynoldson, T. B., Norris, R. H., Resh, V. H., Day, K. E., & Rosenberg, D. M. (1997). The reference condition: a comparison of multimetric and multivariate approaches to assess water-quality impairment using benthic macroinvertebrates. *Journal of the North American Benthological Society*, 833-852.

Rowe, M., Essig, D., & Jessup, B. (2003). Guide to selection of sediment targets for use in Idaho TMDLs. Idaho Department of Environmental Quality, Boise. http://water.epa.gov/scitech/swguidance/standards/criteria/aqlife/sediment/upload/2004_08_17_criteria_sediment_appendix5.pdf. Accessed 02/28/2015.

Rueda, X., Thomas, N. E., & Lambin, E. F. (2014). Eco-certification and coffee cultivation enhance tree cover and forest connectivity in the Colombian coffee landscapes. Regional *Environmental Change*, 1-9.

Sagastizado Méndez, M. E., & CATIE, Turrialba (Costa Rica). (2001). Impacto del uso de la tierra sobre la calidad del agua en la cuenca del Río Talnique, El Salvador. Land use impact on the water quality in the watershed of Rio Talnique, El Salvador.

Shields Jr, F. D., Knight, S. S., & Cooper, C. M. (1994). Effects of channel incision on base flow stream habitats and fishes. *Environmental Management*,18(1), 43-57.
Springer, M., Ramírez A. & P. Hanson (eds.). Macroinvertebrados de agua dulce de Costa Rica I. Rev. Biol. Trop. 58 (Suppl. 4): 3-37.

Springer, M., Ramírez A. & P. Hanson (eds.). 2010. Macroinvertebrados de agua dulce de Costa Rica I. Rev. Biol. Trop. 58 (Suppl. 4): 3-37.

Starbucks Coffee Company. (2014). Generic scorecard (version 3.3). http://www.scsglobalservices.com/files/cafe_scr_genericv3.3_111814.pdf. Accessed 04/10/2015.

Sustainable Agriculture Network (SAN). (2010). Sustainable Agriculture Standard. http://san.ag/web/our-standard/our-sustainability-principles/ Accessed 01/04/15.

U.S.EPA (Environmental Protection Agency). (2010). A Field based Aquatic Life Benchmark for Conductivity in Central Appalachian Streams. Office of Research and

Development, National Center for Environmental Assessment, Washington, DC. EPA/600/R10/023A.

US EPA (Environmental Protection Agency). (2012a). Turbidity: What is Turbidity, why is it important? http://water.epa.gov/type/rsl/monitoring/vms55.cfm. Accessed 02/28/2015.

US EPA (Environmental Protection Agency). (2012b). Conductivity: What is Conductivity, why is it important? http://water.epa.gov/type/rsl/monitoring/vms59.cfm. Accessed 02/28/2015.Accessed 04/10/2015.

U.S. Department of Agriculture- Natural Resource Conservation Service (USDA-NRCS). 1993. Soil survey manual. Chapter 3: Examination and description of soils. Soil Conservation Service. U.S. Department of Agriculture Handbook 18.

Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R., & Cushing, C. E. (1980). The river continuum concept. *Canadian journal of fisheries and aquatic sciences*, 37(1), 130-137.

Vázquez, G., Aké-Castillo, J. A., & Favila, M. E. (2011). Algal assemblages and their relationship with water quality in tropical Mexican streams with different land uses. *Hydrobiologia*, 667(1), 173-189.

Walshe, B. M. (1948). The oxygen requirements and thermal resistance of chironomid larvae from flowing and from still waters. *Journal of Experimental Biology*, 25(1), 35-44.

Wintgens, J. N. (2009). Coffee: growing, processing, sustainable production. A guidebook for growers, processors, traders and researchers. Wiley-Vch.

Wolman, M. G. (1954). A method of sampling coarse river-bed material. EOS, *Transactions American Geophysical Union*, 35(6), 951-956.

Zeltzer ND. 2008. Foreign-economic-retirement migration: Promises and potential, barriers and burdens. Elder Law Journal 16: 211–241.

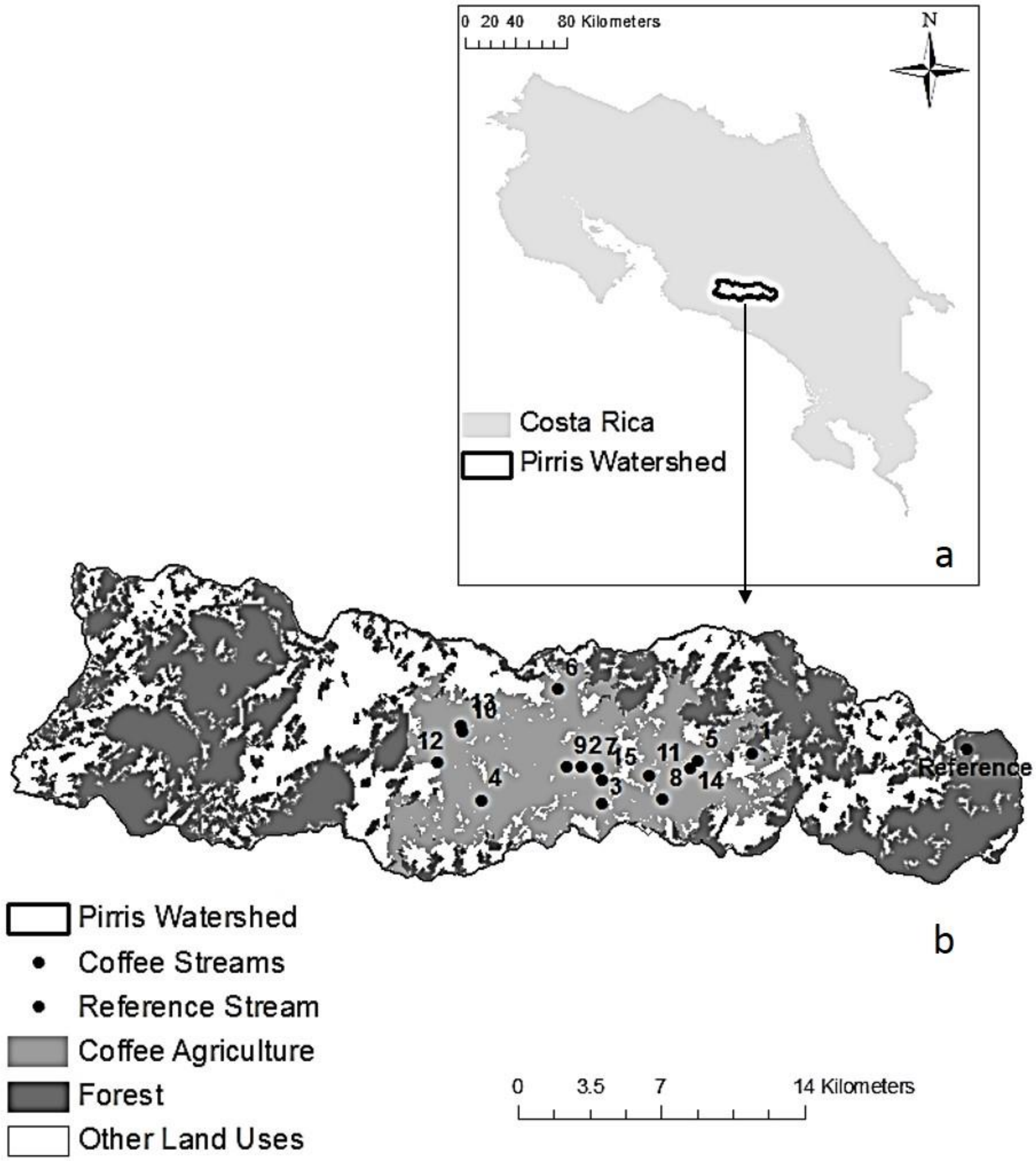

FIGURE 2.1. Location of the Pirris watershed, in the Central Pacific Region of Costa Rica (a), and streams assessed for this study (b).

TABLE 2.1. List of studies evaluating the impact of coffee agriculture on stream ecosystems[1].

Previous Studies		Components of Study					Findings about the Condition of Coffee Streams		
Citation	Location	Elevation (masl)	Replicates	References	Land Use Analysis	Description of Coffee Farm	General	Relative to Forest	Relative to Other Land Use
Sagastizado-Mendez, 2001	Libertad/ Sonsonante, El Salvador	1100-1350	1	0	NO	Rustic Shade	Excellent	?	Excellent
Renderos-Duran, 2001	Perez Zeledon, Costa Rica	700	2	1	NO	Shade Monoculture	?	Poor	?
Gerrero-Bolano et al., 2003	Magdalena, Colombia	750	1	0	NO	?	Excellent	?	?
Medina-Fernandez, 2004	Chimaltenango, Guatemala	1000	7	7	NO	Shade Monoculture	Moderate	Poor	Good
Rahayu et al., 2009	Lampung Province, Indonesia	987	?	?	NO	?	?	Good	Good
Martinez el al, 2009	Veracruz, Mexico	1117-1327	3	2	YES	?	Moderate	Poor	Poor
Ordaz et al., 2010	Ramal Calderas, Venezuela	<1200	3	0	NO	?	?	?	Poor
Vasquez, et al. 2011	Veracruz, Mexico	1117-1327	3	2	YES	?	Moderate	Poor.	Poor
Galindo et al., 2012	Santander/Cundinamarca, Colombia	1410	108	0	NO	?	Moderate	?	?
Giraldo et al., 2014	Valle del Cauca, Colombia	1534	8	7	NO	?	Moderate	Good	Excellent

1. The list was compiled by searching in Google Scholar for publications that included “coffee” in their title, and the following keywords: “streams,” “water quality,” “physicochemistry,” “macroinvertebrates,” “aquatic,” and “watershed.” Studies that focused on coffee processing effluents or had streams in coffee growing regions, but that focused on sub-watersheds dominated by other land uses such as pastures were discarded from the list.

Table 2.2. Characteristics of streams draining coffee plantations "coffee streams" (N=15) and a forested reference stream in the Pirris Watershed. Shaded rows highlight coffee streams (N=6) that were selected for comparison to the reference site because of similarity in terms of Life Zone and Stream Order.

Study Sites	Geomorphology				Land Use Percentages			
	Order	Area (ha)	Gradient (%)^	Life Zone*	Coffee	Forest	Urban	Other
Reference Stream	3	38.7	39.5	LMVH	0.0	100.0	0.0	0.0
Coffee Streams								
1	3	35.6	4.5	LMH	57.8	26.9	1.0	14.2
2	3	50.7	26.3	LMVH	81.5	7.7	3.0	7.8
3	3	54.9	6.3	PMVH	70.6	11.6	3.1	14.8
4	3	59.7	19.2	LMVH	81.7	4.2	4.2	9.9
5	3	64.3	27.8	LMVH	69.9	9.0	1.2	19.9
6	3	67.1	17.0	LMH	47.4	24.9	4.8	23.0
7	3	74.8	8.7	LMVH	79.0	8.9	3.1	9.0
8	3	79.0	6.2	LMVH	86.5	2.1	2.2	9.2
9	3	98.0	18.3	LMVH	76.3	10.9	3.4	9.4
10	3	140.3	33.2	LMH	68.5	11.3	3.7	16.5
11	4	116.4	25.7	PMVH	80.9	0.4	3.2	15.6
12	4	160.2	16.5	LMVH	57.7	12.3	4.0	26.0
13	4	231.3	12.0	LMVH	54.5	9.0	5.6	31.0
14	4	328.6	18.3	LMVH	59.8	23.3	2.1	14.8
15	4	505.4	17.0	LMVH	57.7	17.2	4.4	20.7

^ % Gradient measured as percent slope across the sampling site.

* Holdridge Life Zones: LMVH (Lower Montane Very Humid), LMH (Lower Montane Humid), PMVH (Pre-Montane Very Humid).

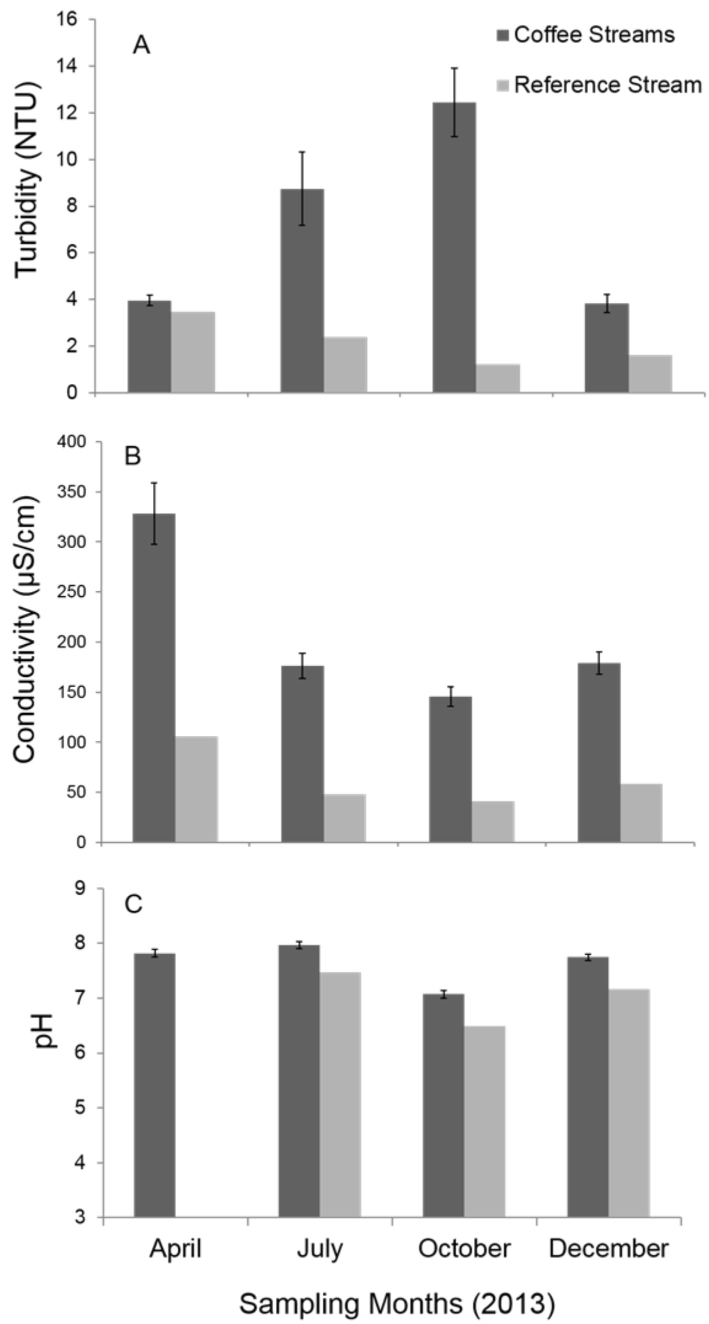

FIGURE 2.2. Stream physicochemistry trends during 2013 for the coffee streams (N=15) and the reference site (N=1). Values are presented as Means (±SE) for (A) Turbidity (NTU), (B) Conductivity (µS/cm) and (C) pH for the coffee streams, and absolute values of the same parameters for the reference stream. There was no pH value recorded for the reference stream in the month of April due to equipment failure.

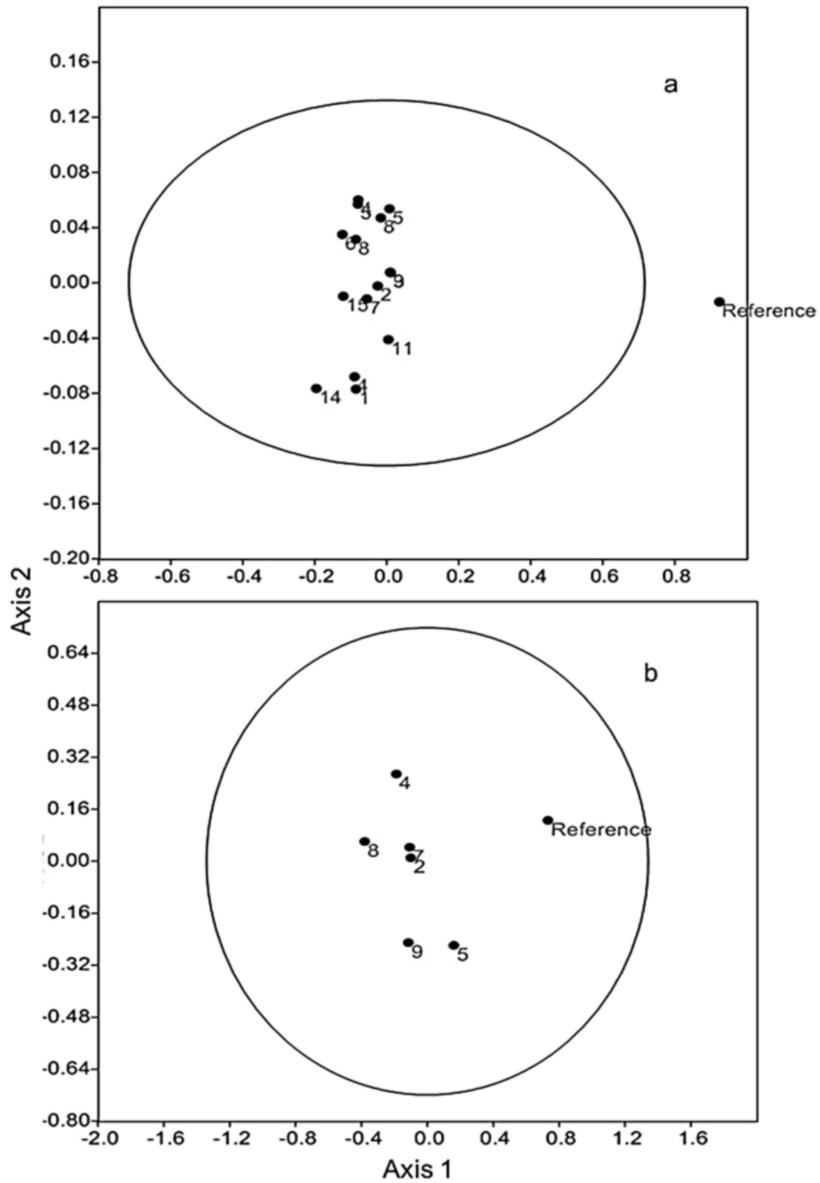

FIGURE 2.3. Non Metric Multidimensional Scaling (NMDS) plots showing (a) macroinvertebrate assemblages in coffee streams (N=15) and the reference site, and (b) macroinvertebrate assemblages of focal coffee streams (N=6) and the reference site (N=1). Sites that fall within the 95% confidence ellipses (enclosed circles) are not significantly different from each other in terms of macroinvertebrate assemblages. Panel b provides support for comparing our focal coffee streams with the reference stream due to greater similarity in biological assemblages.

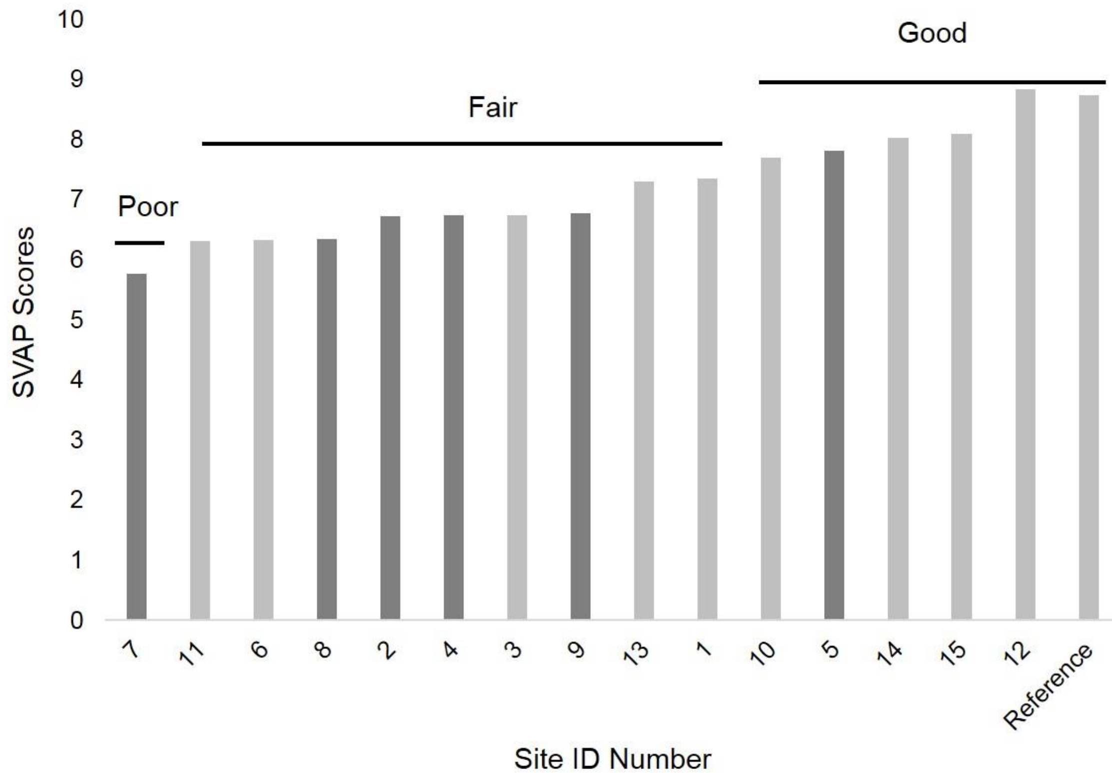

FIGURE 2.3. Stream Visual Assessment Protocol (SVAP) mean scores for coffee streams, and a forested reference site in the Pirris Watershed, Costa Rica. SVAP categories according to scores (Poor, Fair, and Good) are included on top of the data bars. Shaded bars reflect data from the focal coffee streams (N=6).

TABLE 2.3. Using the Target Condition Approach, this table indicates physicochemical and bio-integrity parameters of coffee streams (N=15) in the Pirris Watershed, Costa Rica, compared to stream conservation target values.

Monitored Parameters	Target Values	Observed Values in Coffee Streams				% Sites Within Target Range
		Mean	SD	Min	Max	
Turbidity (NTU)	<25[a]	7.56	3.38	3.29	14.75	100
Conductivity (µS/cm)	<300[b]	192.76	46.67	133.00	288.83	73
pH	6.5-8.5[a]	7.63	0.21	7.27	7.93	100
%Fines	<20[c]	17.60	4.40	9.00	24.00	73
FBI*	<5[d]	4.26	0.49	3.40	5.20	93
BMWP^	>100[a]	110.94	12.85	86.00	132.00	86

a.MINAE 2007; b. EPA 2011; c. Rowe et al. 2003; d. Hilssenhoff 1987.

* FBI: Hilssenhoff's Family Biotic Index

^ BMWP: Biological Monitoring Working Party Group

TABLE 2.4. Using the Reference Comparison Approach, physicochemical and bio-integrity parameters are compared for focal coffee streams (N=6) and the forested reference site, all representing 3rd order streams within the Lower Montane Very Humid Life Zone. Response Direction columns show predicted response to stress and observed response of coffee streams relative to the forested reference site.

METRIC	Reference Stream		Focal Coffee Streams				Response Direction Relative to Reference		
PHYSICOCHEMICAL	Mean	SD	Mean	SD	Min	Max	Predicted	Observed	% Sites Impaired
Turbidity (NTU)	2.17	0.99	6.52	1.49	4.67	8.40	+	+	100
Conductivity(μS/cm)	63.25	29.38	209.98	44.82	165.17	288.83	+	+	100
pH	7.04	0.50	7.67	0.17	7.41	7.89	+	+	100
% Fine Substrate	15.00	4.95	16.67	4.68	9.00	22.00	+	+	83
BIOLOGICAL									
Richness	29.00	N/A	17.50	0.84	16.00	18.00	-	+	0
Diversity	0.74	N/A	0.85	0.04	0.78	0.89	-	+	0
% dominance	0.30	N/A	0.15	0.04	0.11	0.22	+	-	0
% Predators	6.00	N/A	16.69	4.39	11.52	23.69	-	+	0
% Shredders	32.00	N/A	7.43	5.24	2.60	15.00	-	-	100
%Simuliidae	8.00	N/A	16.35	11.13	4.67	36.46	+	+	83
Baetidae/ Ephemeroptera	95.00	N/A	52.74	18.20	25.40	77.08	+	-	0
Hydropsychidae/ Trichoptera	39.00	N/A	63.45	29.06	11.48	87.37	+	+	83
%EPT*	46.00	N/A	53.80	8.58	40.33	63.53	-	+	16
FBI	4.00	N/A	4.20	0.53	3.36	4.79	+	+	83

*%EPT: % Ephemeroptera, Plecoptera andTrichoptera taxa relative to other taxa
^ FBI: Hilssenhoff's Family Biotic Index.

TABLE 2.5. Macroinvertebrate abundance in focal coffee streams (N=6) and a forested reference stream. Functional Feeding Group (FFG) categories are indicated for each taxa, where: Filterers=Ft, Collector Gatherers=CG, Predators=Pr, Shredder-Detritivores=Sh-Dt, Shredder on life plant tissue=Sh-HB, and piercers of life plant tissue=Pc-Hb.

Taxa	FFG	# of sites were taxon was detected	Focal Coffee Streams Abundance Mean	Focal Coffee Streams Abundance SD	Reference Stream Abundance
Amphipoda					
Hyallelidae	Cg	3	0.67	0.82	338
Blattodea					
Blaberiidae	?	2	3.17	5.15	2
Coleoptera					
Dystiscidae		4	0.83	0.75	4
Elmidae	Cg	6	24.50	13.49	1
Hydrophilidae	Pr	2	0.67	1.21	36
Psephenidae	Sc	6	22.33	36.64	
Ptilodactylidae	Sh-Dt	6	51.17	42.18	0
Diptera					
Blephaceridae	Sc	1	2.17	5.31	37
Chironomidae	Cg	6	31.67	33.67	74
Dixidae		1	0.33	0.82	0
Simuliidae	Ft	6	186.67	1.63	16
Stratyiiomidae	Cg	3	1.33	0.82	0
Tipulidae	Sh-Dt	3	15.17	111.71	0
Empididae	Pr	1	0.67	1.75	0
Psychodidae	Cg	1	0.33	7.68	0
Decapoda					
Paleomonidae	Cg	2	0.50	0.84	0
Pseudothelphusidae	Cg	4	11.00	24.05	0
Diplopoda		4	2.17	2.14	0
Ephemeroptera					
Baetidae	Cg	6	192.17	109.87	37
Leptohyphidae	Cg	6	105.00	94.84	0
Leptophlebiidae	Cg	6	46.17	31.82	2
Gastropoda					
Hydrobiidae	Sc	2	2.17	4.83	0
Physidae	Sc	1	2.17	5.31	0
Hemiptera					

Belostomatidae	Pr	4	25.50	32.28	0
Notonectidae	Pr	2	1.67	2.88	0
Veliidae	Pr	6	27.83	16.70	0
Hirudinea	Pr	5	20.50	30.45	19
Isopoda		3	1.83	2.79	2
Lepidoptera					
Noctuidae	Sh-Hb	1	0.33	0.82	0
Pyralidae	Sh-Hb	6	5.83	1.72	0
Megaloptera					
Corydalidae	Pr	4	13.00	28.47	0
Odonata					
Calopterygidae	Pr	6	44.00	33.66	0
Coenagrionidae	Pr	5	12.67	11.99	8
Libellulidae	Pr	6	34.33	11.98	0
Oligochaeta		6	12.67	11.93	0
Plecoptera					
Perlidae	Pr	3	4.50	9.12	31
Trichoptera					
Calamoceratidae	Sh-Dt	3	8.33	15.16	14
Glossosomatidae	Sc	5	15.17	14.63	0
Helycopsichidae	Sc	6	24.67	28.05	9
Hydrobiosidae	Pr	6	22.17	6.77	9
Hydropsychidae	Ft	6	172.00	102.09	35
Hydroptilidae	Pc-Hb	5	13.50	28.20	0
Lepidostomatidae	Sh-Dt	5	2.83	4.12	252
Leptoceridae	Cg	4	4.17	6.46	64
Odontoceridae	Sh-Dt	1	1.00	2.45	0
Philopotamidae	Ft	3	1.00	1.10	0
Polycentropodidae	Ft	6	3.33	3.14	6

TABLE 2.6. Correlation coefficients (r_s) between physicochemical and biological response variables and the SVAP scores across coffee streams (N=15) and in a forested reference site in the Pirris watershed, Costa Rica. *P ≤0.05.

Response Variables	Correlation Coefficients	
PHYSICOCHEMICAL	r_s	p
Turbidity	-0.17	0.52
Conductivity	-0.12	0.66
pH	0.14	0.57
%Fine Substrates	-0.10	0.75
BIOLOGICAL		
Richness	-0.17	0.52
Diversity	0.05	0.86
% dominance	-0.04	0.86
% Predators	0.15	0.91
%Shredders	0.50	*0.05
%Simuliidae	0.05	0.86
Baetidae/Ephemeroptera	0.36	0.17
Hydropsychidae/Trichoptera	-0.16	0.56
%EPT	0.04	0.89
FBI	-0.29	0.27
BMWP	-0.25	0.35

APPENDIX 2.1. List of macroinvertebrate taxa observed in coffee streams (N=15)

Taxon	FFG	Mean	SD	Total	% of total Sample
AMPHIPODA					
Hyallelidae	CG	1.7	5.4	25	0.1
BLATTODEA					
Blaberiidae	Unk.	1.3	3.5	20	0.1
COLEOPTERA					
Psephenidae	Sc	20.1	30.4	302	1.6
Staphylinidae	Pr	0.9	1.4	13	0.1
Ptilodactylidae	Sh-Dt	38.7	33.9	580	3
Hydrophilidae	Pr	0.5	1.1	8	0
Elmidae	CG	29.4	23.4	441	2.3
Gyrinidae	Pr	2.6	5.4	39	0.2
Helophoridae	Sh-Dt	0.4	1.5	6	0
COLLEMBOLA	CG	0.3	0.5	4	0
DIPLOPODA	Sh-Dt	1.4	2.1	21	0.1
DIPTERA					
Culicidae	Ft	0.3	1.3	5	0
Dixidae	CG	0.1	0.5	2	0
Dolichopodidae	Pr	0.1	0.3	1	0
Dystiscidae	Pr	1.2	1.9	18	0.1
Empididae	Pr	0.7	1.2	11	0.1
Blephaceridae	Sc	1	3.3	15	0.1
Tipulidae	Sh-Dt	11.9	9.9	179	0.9
Simuliidae	Ft	235.9	192.5	3539	18.3
Stratyiomidae	CG	0.7	1.2	10	0.1
Ceratopoganidae	Pr	1.5	5.4	22	0.1
Chironomidae	CG	30.5	22.9	458	2.4
Psychodidae	CG	1.5	4.6	23	0.1
DECAPODA					
Paleomonidae	CG	2.2	7.4	113	0.6
Pseudothelphusidae	CG	5.5	15.2	3	0
EPHEMEROPTERA					
Baetidae	CG	195.9	116.6	2939	15.2
Leptohyphidae	CG	174.7	162	2620	13.6
Leptophlebiidae	CG	74.8	95.2	1122	5.8
GASTROPODA					
Hydrobiidae	Sc	1.3	3.2	19	0.1
Sphaeridae	Ft	1	2.1	15	0.1
Thiaridae	Sc	0.4	1.5	6	0.0
HEMIPTERA					
Veliidae	Pr	20.3	16.3	304	1.6

Guerridae	Pr	0.2	0.4	3	0
Notonectidae	Pr	0.7	1.9	10	0.1
Belostomatidae	Pr	17.5	21.9	263	1.4
HIRUDINEA	Pr	18.6	23.6	279	1.4
ISOPODA	Sh-Dt; Pr	4.9	14.8	73	0.4
LEPIDOPTERA					
Pyralidae	Sh-HB	7.3	5.4	109	0.6
Noctuidae	Sh-HB	0.2	0.6	3	0
MEGALOPTERA					
Corydalidae	Pr	6.6	18.3	99	0.5
ODONATA					
Coenagrionidae	Pr	12.3	13	184	1
Calopterygidae	Pr	43.5	34	652	3.4
Libellulidae	Pr	37.0	22.6	565	2.9
OLIGOCHAETA	Pr	16.1	13.8	241	1.2
PLECOPTERA					
Perlidae	Pr	4.9	8.4	73	0.4
TRICHOPTERA					
Calamoceratidae	Sh-Dt	7.1	12.8	106	0.5
Glossosomatidae	Sc	27.8	40.1	417	2.2
Philopotamidae	Ft	1.7	4.3	25	0.1
Hydroptilidae	Pc-Hb	11.2	19.2	168	0.9
Hydropsychidae	Ft	137.2	86.2	2058	10.6
Limnephilidae	Sh-Dt	0.3	0.7	4	0
Polycentropodidae	Ft	3.3	3.5	50	0.3
Hydrobiosidae	Pr	33.3	28.8	499	2.6
Helycopsichidae	Sc	24.1	25.3	361	1.9
Lepidostomatidae	Sh-Dt	2.4	3.6	36	0.2
Leptoceridae	CG	5.0	6.4	75	0.4
Odontoceridae	Sh-Dt	1.0	2.3	15	0.1
TROMBIDIFORMES					
Hydracarina	Pr	2.0	7.5	30	0.2

APPENDIX 2.2. Scores for the individual elements of the SVAP for 15 coffee streams and a reference site in the Pirris watershed, Costa Rica.

SVAP Elements	Sites															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Reference
Bank Stability	4.7	5.0	5.5	5.8	5.8	6.0	2.0	8.3	8.3	4.8	8.7	10.0	9.0	9.8	7.5	9.7
Barriers to Movement	7.3	5.7	8.0	9.5	6.0	6.0	4.7	7.3	3.7	7.5	8.0	7.5	7.8	6.5	8.8	5.0
Canopy Cover	6.7	5.7	3.8	3.0	8.8	4.8	2.0	4.3	1.0	3.8	9.0	8.5	3.8	9.8	7.3	10.0
Channel Condition	8.0	7.0	8.0	8.0	8.0	6.0	8.0	8.0	7.0	8.0	7.0	8.0	8.0	8.0	8.0	10.0
Embeddedness	5.3	6.3	5.5	6.8	6.4	5.0	3.3	4.5	5.7	3.8	6.3	8.3	4.3	4.3	7.3	7.7
Habitat Availability	9.7	7.7	8.0	6.5	8.8	7.0	6.3	8.8	8.0	5.8	8.0	8.3	8.8	8.8	9.0	7.3
Hydrological Alteration	10.0	7.0	9.8	10.0	9.3	9.8	10.0	10.0	10.0	10.0	8.0	10.0	10.0	9.5	10.0	9.3
Livestock Impact	8.3	8.3	5.0	8.0	9.0	5.3	6.3	1.0	8.7	7.3	3.3	9.0	8.8	8.3	9.3	9.3
Nutrient Enrichment	7.7	8.7	7.0	7.0	8.5	7.5	8.3	3.5	7.7	7.3	8.3	9.8	5.8	7.8	6.0	9.3
Pools	6.0	5.0	3.0	3.0	8.0	5.0	3.0	5.0	7.0	5.0	8.0	8.0	8.0	8.0	8.0	6.0
Riparian Condition	2.8	4.0	5.6	2.0	4.6	4.3	3.8	3.8	3.3	2.5	7.7	8.5	4.0	8.1	5.5	10.0
Presence of Trash	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Water Appearance	9.0	7.0	8.5	8.0	8.6	5.8	7.0	8.3	7.7	6.5	7.7	9.0	7.0	5.8	8.8	10.0
Average	7.3	6.7	6.7	6.7	7.8	6.3	5.8	6.3	6.8	6.3	7.7	8.8	7.3	8.0	8.1	8.7

CHAPTER 3

SHADE TREE COVER CRITERIA FOR NON-POINT SOURCE POLLUTION CONTROL IN THE RAINFOREST ALLIANCE COFFEE CERTIFICATION PROGRAM: A SNAPSHOT ASSESSMENT OF COSTA RICA'S TARRAZU COFFEE REGION.

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ABSTRACT

Coffee agriculture often coincides with headwater tropical streams. Therefore, non-point source pollution management in this context is not only important locally, but also for regions downstream. Sustainability certification programs, such as the Rainforest Alliance (RA), provide management guidelines for non-point source pollution control in coffee, including the reforestation of farms with shade trees. In the case of RA, the certification recommends, at a minimum, 40% shade tree cover. The purpose of this research was to assess the effectiveness of this practice in Tarrazú, a high elevation coffee growing region in Costa Rica. We monitored indicators of non-point source pollution on 10 sub-watersheds within Tarrazú, divided in two groups: High Shade Tree Cover (N=5) or sites that met the 40% minimum, and Low Shade Tree Cover (N=5) or sites with <40% cover. We monitored groups during the dry (April & December), transition (July), and peak (October) rainfall seasons of 2013, and compared responses between groups using t-tests. We found support for the effectiveness of shade tree cover at controlling non-point source pollution to streams. The High Shade Tree Cover group had significantly lower annual turbidity averages (p=0.0429) and lower turbidity during the transition season (p=0.0044). The High Shade Tree Cover group also had lower conductivity values during the transition period (p=0.0504). We analyzed our groups based on the percentage of coffee area certified by the Rainforest Alliance, and found a trend for higher area certified on sub-watersheds within the High Shade Tree Cover category. Together these results support the role that sustainability certifications may play in promoting watershed conservation. In particular, our study provides evidence of the benefits of the RA

shade tree cover criteria for controlling watershed erosion within high elevation tropical agro-ecosystems, especially if implemented at the watershed scale.

INTRODUCTION

Coffee is among the most valuable commodities in world trade (Taugourdeau 2014, FAO 2011) and its global production has steadily increased over the last 50 years (ICO 2014). The demand for coffee drives significant land use transformation in tropical nations, while the majority of the world's consumption occurs in the United States of America and the European Union (ICO 2014). Coffee markets, therefore, exemplify the global environmental footprint of consumer culture in industrialized countries.

An important and understudied environmental issue associated with coffee farming is the management of non-point source pollution to streams. Sources of pollutants in coffee farms include agrochemical inputs, primarily nitrogen based fertilizers and lime (Castro-Tanzi et al.. 2012), as well as sediment from erodible dirt roads (Verbist et al. 2010). Managing non-point source pollution from these sources is crucial, as coffee farms are typically situated at the headwaters of tropical watersheds, and their impact may extend to the entire river network, even reaching coastal environments (Robinson and Mansingh 1997, Freeman et al. 2007). Moreover, the high slopes and heavy rainfall that characterize coffee growing landscapes are risk factors for pollutant export to waterways (Ali et al. 2012).

Awareness of the environmental and social threats associated with expanding markets for tropical agricultural goods, such as coffee, led to the creation of sustainability certification programs in the late 1980s. Certification programs outline environmental and social justice criteria, and provide economic incentives to producers that comply with such standards (Perfecto et al.. 2005, Blackman and Naranjo 2010, Blackman 2011). Among the oldest certifiers is the Rainforest Alliance™ (RA), which certifies close to

3.3% of the coffee produced globally (RA 2012). We focus on RA because this study emerged in part from a collaborative effort to evaluate the organization´s water quality conservation efforts (See Chapter 1).

For the purpose of non-point source pollution control in coffee, RA guidelines include the conservation of riparian buffers at widths that vary from 5m to 20m depending on slope and intensity of agrochemical use (SAN 2010), as well as the reforestation of coffee farms with shade trees at a minimum of 40% cover (SAN 2010). While several other certifications have similar shade tree cover and buffer guidelines, the only other certification program with equally strict criteria for these practices as RA is the Smithsonian Migratory Bird Institute's Bird Friendly Certification (SAN 2010, SMBC 2002).

This study evaluates the effectiveness of one of these requirements, the preservation of shade tree cover at a 40% minimum. Shade trees have been shown to help reduce contamination of underground water sources with agrochemicals (Babbar and Zak 1995) and in some cases, may be nearly as effective as native forest at reducing surface runoff by increasing soil organic matter and infiltration (Bermudez 1980, Young 1989, Harriah et al. 2006, Verbist et al. 2010). A question that has not been addressed by previous studies is how much shade tree cover would be required to reap these benefits at the landscape scale. Our study seeks to fill this information gap by evaluating the effectiveness of the levels required by RA, which have been established without empirical evidence of their role in non-point source pollution management.

To address this objective, we present a snapshot assessment of water quality indicators of non-point source pollution (turbidity and conductivity) in streams across

Tarrazú, a high intensity coffee-growing region in Costa Rica, which has a predominance of high elevation coffee (i.e. >1350masl, classified as Strictly Hard Bean) (Castro-Tanzi et al. 2012). Currently, there is an increased demand for high elevation coffee from premium origins, such as Tarrazu, due to the emergence of specialty coffee markets (Laderach et al. 2011, Rueda and Lambin 2013). Furthermore, high elevation coffee many provide a more reliable supply in the future due to the lower incidence of coffee pests, which thrive at lower elevations (Avelino et al. 2006), and potentially higher resilience to climate change (Rhan et al. 2014).

We compared turbidity and conductivity values in 10 sub-watersheds within Tarrazu (5 High Shade Tree cover, i.e. close to or greater than 40%) and 5 with Low Shade Tree Cover (i.e lower than 40%)) for a period of one year. With this information we hoped to answer whether a 40% shade tree cover level significantly impacts non-point source pollution in coffee agroforestry systems. We also asked whether the RA certification program was effective at implementing reforestation practices within coffee agroforestry landscapes by examining percentages of certified coffee in these 10 sub-watersheds. Our goal was to provide empirical data to elucidate the role of the RA sustainable coffee certification at promoting water quality conservation in tropical highland agro-ecosystems.

METHODS

Study Site

Our research was conducted in Costa Rica, which is home to RA's largest office outside of the US and to UGA affiliated research institutions that provided logistical support. Within Costa Rica, we selected the Tarrazú region (Figure 3.1a), which is the only high elevation coffee region in the country participating in the RA certification program.

The Tarrazú region is part of the headwaters of the Pirris Watershed, in the central Pacific region of Costa Rica (Figures 3.1a and 3.1b). Topography, climate and production intensity make Tarrazú an ideal context for addressing non-point source pollution management. The region is located at the higher end of the elevation (1200-1900 masl), rainfall and productivity gradient that characterizes coffee farming (Mitchell 1988), which means that these are areas of high vulnerability to water quality degradation, and thus in greatest need for effective watershed management. Coffee in Tarrazú is often grown on gradients as steep as 60% (Castro-Tanzi et al. 2012), rainfall averages 2,400 mm/yr, which is high for coffee producing regions (ICAFE 2012) and soils are ultisols of alluvial origin (ICAFE 2012), which are highly erodible, prone to cation loss, and acidic (USDA-NRCS 2014).

Land use in Tarrazú consists mainly of coffee plantations (Soto-Montoya and Ortiz-Malavasi 2008), with coffee production averaging nearly 36,000,000 kilos per year (ICAFE 2012). Farms usually exhibit a shade monoculture pattern, or coffee in association with one or two upperstory shade tree species. The two most common shade trees in Tarrazú are *Erythrina* spp., a nitrogen-fixing legume, and *Musa* spp. (i.e. banana plants) (Castro-Tanzi et al. 2012). This intensive configuration of coffee plantations is characteristic of highly productive coffee enterprises, and is a step away from full sun coffee (Moguel and Toledo 1999). The most commonly applied agrochemicals are nitrogen based fertilizers, applied at an average of 212 kg/ha/y (±SD50) and lime, which is applied at an average of 658 kg/ha/y (±SD445) (Castro-Tanzi et al. 2012).

Most of the coffee farms in Tarrazú belong to one of three cooperatives: Coope Dota, Coope Tarrazú, and Coope Llano Bonito. The former two currently participate in the RA certification program (Figure 3.1a), while the latter was part of the RA certification program until 2004. Although the RA program is implemented at the farm scale, our study was designed at the sub-watershed level, because our main goal was to study the effectiveness of shade tree cover at non-point source pollution management, which is driven by factors that occur at large spatial scales. Our study sites, therefore, consist of sub-watersheds within the Pirris Watershed (Figure 3.1b), which include both RA certified and uncertified farms.

We conducted a purposeful site selection process, using GIS and remote sensing to pre-identify sub-watersheds with similar land use and hydrological characteristics to isolate shade tree cover as the most significant landscape variation between our sampling units. Sites were 3rd to 5th order streams, with similar reach gradients and permanent water flow. Sites were also selected to have coffee as the dominant land use and less than 10% urban+exposed soil at the watershed scale (determined using aerial image analysis as detailed in the Landscape Analysis section below). All sites have sub-watershed slopes above 30% (determined using Digital Elevation Model, 10m resolution), which is considered steep topography for agricultural applications (USDA-NRCS 1993). This buttressed our findings by maximizing topographical and land use similarities between watersheds, but it also limited the number of candidate streams (N~40). Of the 40 potential sites, which we were only able to conduct repeated sampling at 10 sites due to accessibility issues and time limitations

Landscape analysis

We classified land cover using two adjacent multispectral, 2-meter resolution images from the Tarrazú coffee region, pansharpened with corresponding Panchromatic, sub-meter resolution images. All images were captured with the Worldview-2 Satellite and corrected using the SRTM 900m DEM. The first image was captured on January 31, 2012 at a 49° angle, the second on February 27 2012 at an angle of 41°. Images were analyzed independently (not mosaicked) in order to account for accuracy issues related to dates and angle views of the individual datasets.

Land cover classes included: 1) Sun Coffee (i.e. conventional un-shaded coffee), 2) Shade Tree Cover (i.e. upperstory tree cover in coffee farms), 3) Forest, 4), Urban, 5) Pastures and 6) Exposed Soil (Table 3.1). We first delimited forest patches by hand and erased them from the image to avoid classification confusion with the Shade Tree Cover category. Once forests were eliminated, we increased image contrast to 50% and set brightness to 16%, which allowed us to better differentiate between the darker greens associated with coffee plants and the brighter tones associated with the over-story shade trees (*Erythrina* sp. and *Musa* sp.). After enhancing vegetation contrast, we conducted a Maximum Likelihood supervised classification in ArcGIS (ver. 10.0). Accuracy was estimated using a confusion matrix approach (Campbell 1996) and was estimated as 79.4% and 94.4% for image 1 and 2 respectively. Kappa coefficient was estimated at 74.6% for image 1 and 92.9% for image 2. For the Shade Tree Cover class, accuracy, Image 1 was 98% accurate and Image 2 was 100% accurate. We calculated watershed scale percentages of all 6 land-cover classes across the entire upstream drainage area of our sampling units. Additionally, we calculated percentage of forest in the 5m and 20m buffer zones, upstream of the sampling points to account for its potential confounding influence on non-point source pollution control.

The 10 sites were ranked by shade tree cover and divided into two groups. Percent cover in top five sites ranged from 36-60%, approximating or exceeding the RA 40% minimum guideline, while the lower 5 had 18-31% cover (Table 3.1). These two groups were used to compare the effects of the RA-recommended cover levels.

Aside from our land use assessment, we also assessed the percentage of coffee area certified by RA on the upstream drainage basins of our study streams. For this we used a GIS layer from the Costa Rica Coffee Institute (ICAFE), showing coffee farms across Costa Rica for the year 2012, delimited by property limits and identified by farm owner. We consulted with representatives from local coffee cooperatives (Coope Dota and Coope Tarrazu) to identify farm owners participating in the RA certification program. We then calculated the proportion of RA certified coffee over total coffee agricultural area in each sub-watershed.

Stream Assessment

We sampled sites four times during 2013 following the historical rainfall patterns of the study region (IMN 2014, Figure 3.2b). Our four sampling events were: 1) April (dry season), July (transition period), October (peak rainy season) and December (return to dry season) (Figure 3.1a). During each sampling event we collected data on stream discharge, and physicochemical parameters across reaches of length 12X their width (USDA-NRCS-1998). Streams were identified using land cover layers and digital elevation models in ArcGIS following the criteria described in the *Study Site* section (above), and located using site coordinates.

To characterize stream physicochemical parameters, we measured conductivity and turbidity using a YSI 6850 multi parameter probe. Turbidity was selected as an indicator of watershed erosion (EPA 2012A) and conductivity as an indicator of agrochemical pollution (EPA 2012B). We selected these two parameters because previous studies support their effectiveness at reflecting landscape level impacts of agricultural activities (Minaya et al. 2013), and assessing these parameters was more cost efficient than assessing other relevant variables (e.g. nitrogen, phosphorus).

Data Analysis

We conducted one tailed t-tests in JMP Pro 11 (SAS Institute Inc. 2013) to test the prediction that the Low Shade Tree Cover group would exhibit higher turbidity and conductivity values than the High Shade Tree cover group. We assessed this hypothesis on data from each sampling season and annual averages. Because other land use variables aside from shade tree cover also showed to be significantly different between the two test groups (i.e. Sun Coffee and Exposed Soil, Table 1), we used the Akaike Information Criterion (AICc) in an Information Theoretic approach(Burnham and Anderson 2002) to evaluate the best model for explaining variables that responded in accordance to our prediction.

Additionally, we conducted one tailed t-tests to evaluate the prediction that the High Shade Tree Cover group would have higher percentages of coffee area certified by the Rainforest Alliance than the Low Shade Tree Cover group.

RESULTS

Hydrological, Geographical, and Land Use Trends

Rainfall in 2013 followed the historical patterns (IMN 2014) of low precipitation from January to April, a transition period between May and August, a sharp rainfall spike between August and October, and a return to baseline levels between November and December (Figure 2b). Discharge varied according to rainfall, as illustrated on Figure 2a, which shows mean discharge/area ratios for all sampling sites on each sampling season.

General characteristics for each of our Shade Tree Cover groups are listed on Table 1. Average discharge ranged from 0.54 to 5.05 ft^3/s for the High Shade Tree Cover group, and from 0.43 to 5.85 ft^3/s for the Low Shade Tree cover group. Watershed slope ranged from 31.23% to 56.05% in the High Shade Tree Cover group and from 34.9% to 55.4% in the Low Shade Tree Cover group. There was no statistically significant difference in terms of these variables among the two test groups.

In terms of land use percentages (Table 3.1), we found the following ranges for the High Shade Tree Cover group: Shade Tree Cover (35.31-55.42%), Sun Coffee (12.04-34.15%), Pastures (7.70-20.24%) Urban (2.18-4.75%), Exposed Soil (0.84-2.73%), and Forest (2.09-24.90%). For the Low Shade Tree Cover group we found the following land cover ranges: Shade Tree Cover (17.82-31.69%), Sun Coffee (25.78-49.23%), Pastures (10.81-28.90%) Urban (1.23-5.56%), Exposed Soil (2.11-3.98%), and Forest (0.35-23.25%). We found statistically significant differences between groups for the variables Shade Tree Cover ($p=0.0051$), Sun Coffee ($p=0.0139$), and Exposed Soil ($p=0.0116$).

Riparian forest cover was similar between groups at both the 5m and 20m buffer scales (Table 3.1). For the High Shade Tree Cover group, forest cover in the 5m buffer ranged from 4.29% to 24.25%; in the 20m buffer, it ranged from 4.21% to 23.19%. For the Low Shade Tree cover group, forest cover in the 5m buffer ranged from 2.46% to 20.48% and from 2.48% to 18.30% in the 20m buffer.

The percentages of coffee area certified by the Rainforest Alliance ranged from 0% to 61.52% in the High Shade Tree Cover group, and from 0% to 13.82% in the Low Shade Tree Cover group.

Water Quality Trends

When we examined trends within each season, we found that in the High Shade Tree Cover group, turbidity values ranged from 2.90 to 5.23 NTU in April, from 4.40 to 11.53 NTU in July, from 6.83 to 20.30 NTU in October, and from 2.56 to 7.00 in December. In the Low Shade Tree Cover sites, turbidity values ranged from 3.13 to 5.00 NTU in April, from 4.60 to 24.70 NTU in July, from 9.10 to 24.60 NTU in October, and from 2.56 to 5.60 in December. The levels of turbidity were lower in the High Shade Tree Cover group in each sampling period, but only statistically significant in July ($p=0.0044$), (Figure 3.3a). When we averaged across sampling months, average annual turbidity was 6.05 (±2.79) NTU for the High Shade Tree cover group, and 14.75 (±5.69) NTU for the Low Shade Tree cover group, and the difference was statistically significant.($p=0.0420$; Figure 3.4a).

The High Shade Tree Cover sites had conductivity values ranging from 233.33 to 493.66 µS/cm in April, from 89.00 to 227.00 µS/cm in July, from 85.66 to 207.00 µS/cm in October, from 109 to 227.67 µS/cm in December, and averaged 288.83 (±133) µS/cm for the sampling year. In the Low Shade Tree Cover group conductivity was between 285.66 to 442.00 µS/cm in April, from 151.00 to 236.00 µS/cm in July, from 129 to 193.66 µS/cm in October, from 154.66 to 216.00 µS/cm in December. While conductivity tended to be lower in the High Shade Tree group, the difference was only statistically significant during July (p=0.05). Averaging across sampling months, annual Conductivity averaged 288.83 (±133) µS/cm for the sampling year in the High Shade Tree cover group, and 271.91 (±180) µS/cm for the Low Shade Tree Cover group during 2013. The difference was not statistically significant (p=0.13).

The percentage of coffee agricultural area certified by the Rainforest Alliance was higher in the High Shade Tree Cover category, but despite quite large mean differences, this trend was not significant (p=0.08, Figure 3.4).

Comparison of Land Use Variables' Effects on Turbidity and Conductivity.

We found that % sun coffee, and % exposed soil differed between our High Shade Cover and Low Shade Cover groups (Table 3.1). We compared the goodness-of-fit between models that used % shade tree cover, % sun coffee, or % exposed soil in explaining variability in turbidity and conductivity. Shade Tree Cover was the best model explaining turbidity trends in the transition season of July (AIC_cw=0.72) and through the year (AIC_cw=0.73) (Table 3.2). The best model for explaining conductivity levels in July was the percentage of Sun Coffee (0.43), but the model with Shade Tree Cover had similar support (AIC_cw=0.35) (Table 3.2).

DISCUSSION

This study evaluated the effectiveness of the Rainforest Alliance's (RA) certification guideline of 40% minimum shade tree cover at controlling turbidity and conductivity, two indicators of non-point source pollution, in coffee agroforestry systems. We provide the first account of a correlation between these variables and different levels of shade tree cover at the sub-watershed scale. Our study showed that sub-watersheds with High Shade Tree Cover or sites that are near or exceed RA's 40% minimum, had lower stream turbidity on an annual basis and lower turbidity and conductivity during the transition period from dry to rainy season (July). We also found that sub-watersheds that comply with RA's shade tree cover criteria tended to have higher percentages of RA certified farms, though the trend was not significant at the α=0.05 level. These results showed the potential of shade reforestation within coffee farms to impact non-point source pollution control at the sub-watershed scale, and of the RA certification program at promoting the implementation of this practice.

The role of shade trees in non-point source pollution control

The strongest within-month effects of Shade Tree Cover on turbidity were seen in July. It is not surprising that the mitigation of non-point source pollution from shade tree cover was more evident during the July sampling event. The transition from dry to rainy season (in this case represented by our July sample) is a period when loose detached soil is washed into the streams at a higher rate (Ziegler et al. 2000). For turbidity, as the rainy season progresses, higher discharge within the stream could cause greater rates of bank erosion, leading to turbidity increases unrelated to non-point source pollution from land use practices. Since discharge can vary in terms of factors such as watershed area and slope, and these two variables were on average similar between groups, we would expect that these factors would affect all sites equally, confounding the influence of shade tree cover. During the dry season (April and December), we saw low turbidity levels on both groups, likely due to stable discharge and low runoff across sites.

Conductivity, however, was higher during the month of April, which represents the baseline conditions and the end of the dry season. This trend could be explained by a greater proportion of groundwater inputs during this period, lack of dilution and heightened evaporation (Carusso 2002). With the onset of the rainy season, conductivity experienced dilution by precipitation and stream flow. The fact that during the transition period conductivity was significantly lower for the High Shade Tree Cover group implies a faster rate of dilution at these sites, maybe due to lower agrochemical inputs from runoff. According to our AICc analysis, Shade Tree Cover and Sun Coffee percentages are equally likely to be driving this pattern. Either higher levels of exposed Sun Coffee lead to greater agrochemical inputs, and/or lower shade tree cover promotes less on-site agrochemical retention. These propositions are not mutually exclusive, and while the latter corresponds to our predictions for this study, the former corresponds to predictions by other authors suggesting greater rates of agrochemical application in Full Sun coffee vs Shade Coffee (Moguel and Toledo 1999). The relative importance of shade tree cover vs percentage of sun coffee in driving agrochemical trends and the mechanisms behind these trends could form the basis of studies in the future.

In terms of the implications of these results for aquatic ecosystem conservation, previous research has suggested that aquatic biota show sensitivity to turbidity levels as low as 10 NTU (DEQ 2014). The High Shade Tree cover sites maintained turbidity levels below 10 NTU through the year, except for one site that surpassed this value during July (transition season , 11 NTU), and two sites that surpassed it in October (peak rain, 10.1 and 20.3 NTU). In contrast, three of the Low Shade Tree cover sites surpassed this level in July (24.7, 12.7 and 20.5 NTU) and four during October (24.3, 17.4, 11.9 and 14.5 NTU). This suggests that coffee agricultural sub-watersheds complying with the RA shade tree cover guidelines promote aquatic ecosystem conditions that favor optimal biological health during a greater part of the year.

For conductivity, it has been suggested that values under 300 µS/cm are considered safe for preservation of freshwater fauna (USEPA 2010) in streams that are naturally low in solutes (which we assume should be the case in our study system). Both groups had average values that surpassed this level during April, while both maintained relatively low conductivity levels during the rest of the year. This suggests that the impact of agrochemical pollution is best detected before the onset of the rainy season, and that the RA practice of preserving 40% shade tree cover may not be enough to mitigate this issue, as we discuss below.

Agrochemical indicators across the Tarrazú region

The difference between Shade Tree Cover groups and conductivity, our indicator of agrochemical pollution, was less supported than the differences between the groups in terms of turbidity. This was especially evident during the dry season, when both groups exhibited average conductivity values that surpass recommended levels. A possible explanation is that conductivity may be influenced by unaccounted for differences in agrochemical application intensity across the study sites. Turbidity, an indicator of erosion, may vary more uniformly, as sites share similar rainfall and soil properties. On the other hand, the potential benefits of shade tree cover to regulate agrochemical exports to streams may have been confounded by unobserved farm-level agrochemical practices. For instance, previous studies show that across the Tarrazú coffee region, nitrogen application varies from 113 to 374 kh/ha (mean 212 (±50)) and lime application varies from 0 to 2048 kg/ha (mean 658 (±445)) (Castro-Tanzi et al. 2012).

Since our High and Low Shade Tree Cover groups differed in terms of proportion of RA certified farms, the fact that we observed similar levels of conductivity in both groups suggests that although RA may have been effective at implementing shade tree cover reforestation (SAN criterion 2.8, see Chapter I), it may have limited impact in the application of plans for agrochemical reduction (SAN criterion 9.2, see Chapter 1) Further studies are needed to evaluate this trend further.

Contribution to current knowledge

Our work builds on previous studies, which have reported the role of shade trees in providing landscape level hydrological services. For example, Gomez-Delgado et al. (2011) found low rates of runoff and stream sediment load associated with an agro-forestry system of 12.5 shade trees per hectare of coffee, draining gentle slopes (11%) on a single large estate. Our study confirms these findings with streams draining steeper landscapes (mean slope of 43.3- 44.4%), which tend to be more vulnerable to runoff and erosion (Turkelboom et al. 1997, Fox and Bryan 1999, Verbist et al. 2010). We also extend the perspective of previous studies that compare water quality from shaded and un-shaded coffee plantations. For example, Babbar and Zak (1994) found support for the role of shade trees at water quality conservation by comparing shaded coffee plots (200-250 stems of shade trees per hectare) with un-shaded plantations. Their work, however, did not compare different levels of shade tree cover, as we did in our study. Furthermore, we contribute by addressing these issues using remote sensing, which is an approach that could be more feasibly implemented for large-scale assessments of compliance with shade tree cover guidelines, than the stems/per hectare approach used by previous authors (Babbar and Zak 1994, Verbist et al. 2010, Gomez-Delgado et al. 2011). Recent studies have used remote sensing to assess the role of coffee agroforestry systems in providing hydrological services (Taugourdeau et al. 2014), but our study is the first to show the distinct role of shade trees in non-point source management within steep topographies and among sub-watersheds.

The role of the Rainforest Alliance certification on non-point source pollution control

Our data suggest that the benefits of shade trees for erosion control are better achieved by having ~40% or more shade tree cover at the watershed scale. This provides empirical support for the RA certification requirements. Our study also shows that sub-watersheds with high percentage of shade tree cover have a higher proportion of RA certified farms. Although this trend was not significant, it suggests that this program may influence landscape level coffee agroforestry management, which we were not able to support statistically due to our low sample size. Additionally, our study did not test whether the higher shade tree cover is a consequence of the RA requirements, or if having higher shade tree cover led to the inclusion of these farms in the certification program. We suggest that follow-up studies should focus on evaluating the same farms before and after becoming RA certified to confirm the positive impact of the RA program on shade tree cover reforestation. A previous study followed this “before and after” approach and found that the RA certification in fact was associated with measurable increases in shade tree cover above 40% in high intensity coffee growing regions in Colombia (Rueda et al. 2014). Our study provides some support for Rueda et al.’s (2014) findings but more studies are needed to verify the implications of our results in Costa Rica.

We found some potential limitations of the RA program regarding the implementation of agrochemical management practices (as we suggested earlier) and riparian buffer guidelines (SAN criterion 2.4, See Chapter 1). Our sub-watersheds all averaged around 12-14% forest cover in the 20m riparian buffer, and about 14-15% in the 5m buffer zone, regardless of the proportion of farms that were certified. This level of riparian forest degradation could have consequences for the condition of aquatic ecosystems draining coffee farms. For example, parallel studies conducted in the Tarrazu coffee region (See Chapter 2), found that one of the most notable changes in stream bio-integrity was a reduction in shredder taxa, which could be associated with a loss of high quality leaf litter from native riparian trees. The RA program has a requirement for riparian buffer preservation, but from our observations, this is not a widespread practice in coffee agroforestry systems in Costa Rica.

Finally, although our study was conducted at the sub-watershed scale, the RA certification is applied at the farm scale. The benefits of preserving RA’s 40% minimum would have more impact if the program could reach this target at the landscape level. Expanding shade tree requirements to the sub-watershed scale may be more feasible though partnerships between certification programs and other conservation initiatives. For example a pilot program sponsored by the Costa Rica National Forestry Fund (FONAFIO) and the Costa Rica Coffee Institute (ICAFE) encourages shade coffee by paying ~ $1 per upperstory shade tree planted (Virginio-Filho and Abarca Monge 2008). Partnerships with such programs may allow RA to scale up their efforts to ensure ecologically meaningful water quality outcomes. This echoes Tscharntke et al.'s (2014) proposition that certification programs need to establish connections with broader ecosystem protection initiatives in order to achieve landscape level impact and more effectively advance conservation goals.

CONCLUSION

Elucidating strategies for watershed management in high elevation coffee allows for more targeted efforts in an increasingly important agricultural sector. This study provides a stepping-stone towards this goal by supporting the role of shade trees in non-point source pollution control at a minimum of ~40% shade tree cover. This level of shade tree cover corresponds to guidelines included in the Rainforest Alliance and Smithsonian Bird Friendly certification. Therefore, our study provides empirical evidence to support the guidelines used in these programs for tropical highland water quality management. Future studies should aim to corroborate our findings with more frequent analysis of stream physicochemical patterns through the year, the inclusion of additional non-point source pollution indicators, such as heavy metals, nitrogen and phosphorus, and more detailed quantification of sediment exports from sites above and below 40% shade tree cover.

References

Allan, J. D. (2004). Landscapes and riverscapes: the influence of land use on stream ecosystems. *Annual Review of Ecology, Evolution, and Systematics*, 257-284.

Ali, M., Sterk, G., Seeger, M., Boersema, M. P., & Peters, P. (2011). Effect of hydraulic parameters on sediment transport capacity in overland flow over erodible beds. *Hydrology and Earth System Sciences Discussions*, *8*(4), 6939-6965.

Avelino, J., Zelaya, H., Merlo, A., Pineda, A., Ordoñez, M., & Savary, S. (2006). The intensity of a coffee rust epidemic is dependent on production situations. *Ecological modelling*, *197*(3), 431-447.

Bradley D.C. and S.J. Ormerod. 2002. Long term effects of catchment liming on invertebrates in upland streams. *Freshwater Biology*. 47: 161-171

Burnham, K. P.; Anderson, D. R. (2002), *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach* (2nd ed.), Springer-Verlag, ISBN 0-387-95364-7.

Caruso, B. S. (2002). Temporal and spatial patterns of extreme low flows and effects on stream ecosystems in Otago, New Zealand. *Journal of Hydrology*,*257*(1), 115-133.

Chang, F. H., Lawrence, J. E., Rios-Touma, B., & Resh, V. H. (2014). Tolerance values of benthic macroinvertebrates for stream biomonitoring: assessment of assumptions underlying scoring systems worldwide. *Environmental monitoring and assessment*, *186*(4), 2135-2149.

Colwell, R. K. 2013. EstimateS: Statistical estimation of species richness and shared species from samples. http://viceroy.eeb.uconn.edu/estimates/ Accessed 12/29/2014.

R. B. Davies. Hypothesis testing when a nuisance parameter is present only under the alternative. *Biometrika*, 74:33–43, 1987.

(DEQ) Department of Environmental Quality (Oregon). 2014. Turbidity technical review:
Summary of sources, effects, and issues related to revising the
Statewide Water Quality Standard for Turbidity.
http://www.deq.state.or.us/wq/standards/docs/Turbidity/TurbidityTechRev.pdf. Accessed 03/10/2015.

FAO, 2011. FAOSTAT Agriculture Data. http://faostat.fao.or

Moguel, P. and V.Toledo, 1999. Biodiversity conservation in traditional coffee systems of Mexico. *Conservation Biol*ogy. 13, 1–12.

Ferreira, W. R., Ligeiro, R., Macedo, D. R., Hughes, R. M., Kaufmann, P. R., Oliveira, L. G., & Callisto, M. (2014). Importance of environmental factors for the richness and distribution of benthic macroinvertebrates in tropical headwater streams. Freshwater Science, 33(3), 860-871. doi:10.1086/676951

Fisher, D. W., Gambell, A. W., Likens, G. E., & Bormann, F. H. (1968). Atmospheric contributions to water quality of streams in the Hubbard Brook Experimental Forest, New Hampshire. *Water Resources Research*, *4*(5), 1115-1126.

Fondo Nacional de Financiamiento Forestal (FONAFIFO). 2014. Montos Asignados al Pago de los Servicios Ambientales por Modalidad. http://www.fonafifo.go.cr/psa/estadisticas_psa.html. Last accessed 10/31/2014.

Giraldo, L. P., Chará, J., del Carmen Zuñiga, M., Chará-Sema, A. M., & Pedraza, G. (2014). Impacto del uso del suelo agropecuario sobre macroinvertebrados acuáticos en pequeñas quebradas de la cuenca del río La Vieja (Valle del Cauca, Colombia). *Revista de Biología Tropical*, *62*, 203-219.

Hilsenhoff, W. L. (1988). Rapid field assessment of organic pollution with a family-level biotic index. *Journal of the North American Benthological Society*, 65-68.

Instituto del Café de Costa Rica. 2012. Region Cafetalera de Tarrazu. http://www.icafe.go.cr/nuestro_cafe/regiones_cafetaleras/tarrazu.html Accessed 12/29/204

International Coffee Organization (ICO). 2014. World coffee trade (1963 – 2013): A review of the markets, challenges and opportunities facing the sector. ICC 111-5 Rev. 1. http://www.ico.org/news/icc-111-5-r1e-world-coffee-outlook.pdf . Accessed 12/3/2014.

Jha, S., Bacon, C. M., Philpott, S. M., Méndez, V. E., Läderach, P., & Rice, R. A. (2014). Shade Coffee: Update on a Disappearing Refuge for Biodiversity. *BioScience*, *64*(5), 416-428.

Karr, J. R., & Chu, E. W. (1998). *Restoring life in running waters: better biological monitoring*. Island Press.

Laderach, P., Lundy, M., Jarvis, A., Ramirez, J., Portilla, E. P., Schepp, K., & Eitzinger, A. (2011). *Predicted impact of climate change on coffee supply chains* (pp. 703-723). Springer Berlin Heidelberg.

Melo, A. S., & Froehlich, C. G. (2001). Macroinvertebrates in neotropical streams: richness patterns along a catchment and assemblage structure between 2 seasons. *Journal of the North American Benthological Society*, *20*(1), 1-16.

Merritt, R. W., & Cummins, K. W. (Eds.). (1996). *An introduction to the aquatic insects of North America*. Kendall Hunt.

Meyer, J. L., & Likens, G. E. (1979). Transport and transformation of phosphorus in a forest stream ecosystem. *Ecology*, 1255-1269.

Meylan, L. (2012). Design of cropping systems combining production and ecosystem services: developing a methodology combining numerical modeling and participation of farmers: application to coffee-based agroforestry in Costa Rica (Doctoral dissertation, PhD thesis, Montpellier Supagro, France).

(MINAE) Ministerio de Ambiente y Energia de Costa Rica. 2007. Reglamento para la Evaluación y Clasificación de la Calidad de Cuerpos de Agua Superficiales. Nº 33903-MINAE-S. http://www.cimar.ucr.ac.cr/PDFS/Reglamento_Evaluacion_y_Clasificacion_Calidad_Agua_Superficial.pdf. Accessed 02/28/2015.

Minaya, V., McClain, M. E., Moog, O., Omengo, F., & Singer, G. A. (2013). Scale-dependent effects of rural activities on benthic macroinvertebrates and physico-chemical characteristics in headwater streams of the Mara River, Kenya. Ecological Indicators, 32, 116-122.

Mitchell, H. W. 1988. Cultivation and Harvesting of the Arabica Coffee Tree. Coffee: Agronomy. Ed. R.J. Clarke. New York: Elsevier Applied Science.

Moguel, P., & Toledo, V. M. (1999). Biodiversity conservation in traditional coffee systems of Mexico. *Conservation Biology*, *13*(1), 11-21.

Muschler, R.G. 2004. Shade management and its effect on coffee growth and quality. In: *Coffee: growing, processing, sustainable production. A guidebook for growers, processors, traders and researchers*. Wintgens, J. N. (ed). Wiley-Vch.

Muggeo, V. M. (2008). Segmented: an R package to fit regression models with broken-line relationships. *R news*, *8*(1), 20-25.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., ... & Blair, R. (1995). Environmental and economic costs of soil erosion and conservation benefits. *SCIENCE-NEW YORK THEN WASHINGTON-*, 1117-1117.

Rainforest Alliance (RA). 2012. The Rainforest Alliance demonstrates significant growth in 2011. Rainforest.alliance.org. Accessed 01/22/2015.

Rahn, E., Läderach, P., Baca, M., Cressy, C., Schroth, G., Malin, D., ... & Shriver, J. (2014). Climate change adaptation, mitigation and livelihood benefits in coffee production: where are the synergies?. Mitigation and Adaptation Strategies for Global Change, 19(8), 1119-1137.

Rueda, X., & Lambin, E. F. (2013). Linking globalization to local land uses: How eco-consumers and gourmands are changing the Colombian coffee landscapes. *World Development*, *41*, 286-301.

Rueda, X., Thomas, N. E., & Lambin, E. F. (2014). Eco-certification and coffee cultivation enhance tree cover and forest connectivity in the Colombian coffee landscapes. *Regional Environmental Change*, 1-9.

SAS Institute Inc. 2013. JMP® 11 Graph Builder for iPad. Cary, NC: SAS Institute Inc.

Smithsonian Migratory Bird Center (SMBC). 2002. Norms for production, processing and marketing of "Bird Friendly®" Coffee. http://nationalzoo.si.edu/scbi/migratorybirds/coffee/Norms-English_1.pdf. Accessed 01/04/2015.

Soto-Montoya, C and Ortiz-Malavasi, E. 2008. Atlas digital de Costa Rica. InstitutoTecnológico de Costa Rica. Vice rectoría de investigación y extensión. Escuela de Ingeniería Forestal.

Sustainable Agriculture Network (SAN). 2010. Sustainable Agriculture Standard. http://san.ag/web/our-standard/our-sustainability-principles/ Accessed 01/04/15.

Taugourdeau, S., le Maire, G., Avelino, J., Jones, J. R., Ramirez, L. G., Jara Quesada, M., ... & Roupsard, O. (2014). Leaf area index as an indicator of ecosystem services and management practices: An application for coffee agroforestry. *Agriculture, Ecosystems & Environment*, *192*, 19-37.

Townsend, C. R., Scarsbrook, M. R., & Dolédec, S. (1997). Quantifying disturbance in streams: alternative measures of disturbance in relation to macroinvertebrate species traits and species richness. *Journal of the North American Benthological Society*, 531-544.

Tscharntke, T., Milder, J. C., Schroth, G., Clough, Y., DeClerck, F., Waldron, A., Rice, R. and Ghazoul, J. (2014), Conserving biodiversity through certification of tropical agroforestry crops at local and landscape scales. Conservation Letters.
doi: 10.1111/conl.12110

US Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS). 2014. Ultisols.

http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_051839.pdf Accessed 12/29/2014.

U.S. Department of Agriculture- Natural Resource Conservation Service (USDA-NRCS). 1993. Soil survey manual. Chapter 3: Examination and description of soils. Soil Conservation Service. U.S. Department of Agriculture Handbook 18.

US Environmental Protection Agency (USEPA). 2002. National Recommended Water Quality Criteria. EPA-822-R-02-047. http://water.epa.gov/scitech/swguidance/standards/upload/2008_04_29_criteria_wqctable_nrwqc-2002.pdf Accessed 12/29/2014

U.S.EPA (Environmental Protection Agency). 2010. A Field based Aquatic Life Benchmark for Conductivity in Central Appalachian Streams. Office of Research and Development, National Center for Environmental Assessment, Washington, DC. EPA/600/R10/023A.

Virginio-Filho, E. and S. Abarca-Monge. 2008. Cafetales para servicios ecosistémicos, con énfasis en el potencial de sumideros de carbono: El caso de cooperativas cafetaleras afiliadas a COOCAFE Costa Rica. http://www.coocafe.com/cafeforestal/docs/cafe-servicios-ecosist-co2.pdf. Accessed 04/18/2015.

Wintgens, J. N. (2009). *Coffee: growing, processing, sustainable production. A guidebook for growers, processors, traders and researchers*. Wiley-Vch.

Ziegler, A. D., Sutherland, R. A., & Giambelluca, T. W. (2000). Runoff generation and sediment production on unpaved roads, footpaths and agricultural land surfaces in northern Thailand. *Earth Surface Processes and Landforms, 25*(5), 519-534.

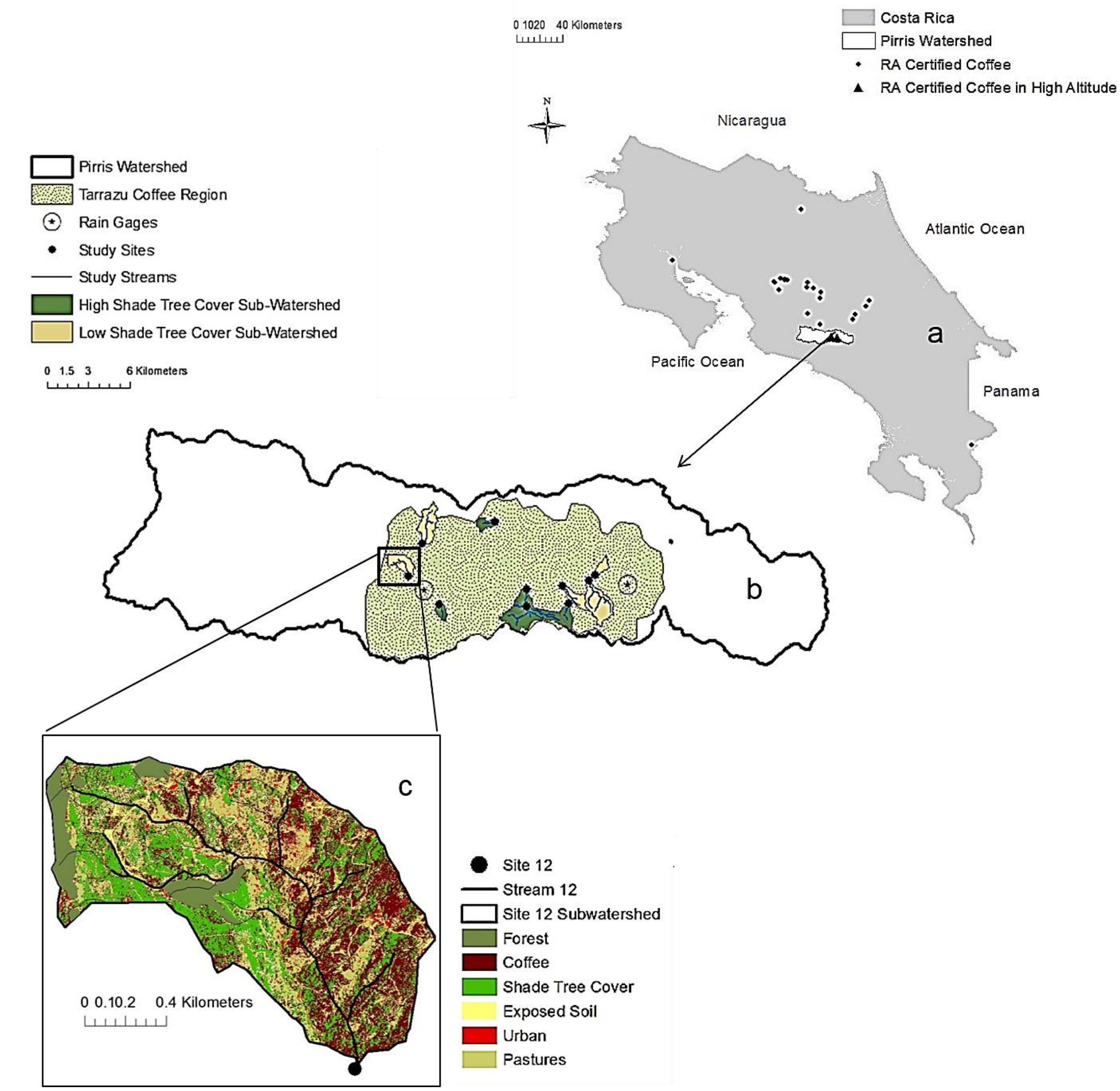

FIGURE 3.1. Study context: a) Coffee enterprises in Costa Rica that are certified by the Rainforest Alliance (RA), high elevation (>1350 masl) coffee regions are identified with a triangle, the Pirris Watershed Central Pacific, Costa Rica contains the only two RA certified coffee enterprises in a high elevation region of the Country; b) Location of the Tarrazú region, illustrating the location of our study sites (N=10) and rain-gages (N=2); c) Example of study site within Tarrazú above which we characterized the sub-watershed in terms of % forest, sun coffee, shade tree cover, exposed soil, urban areas and pastures.

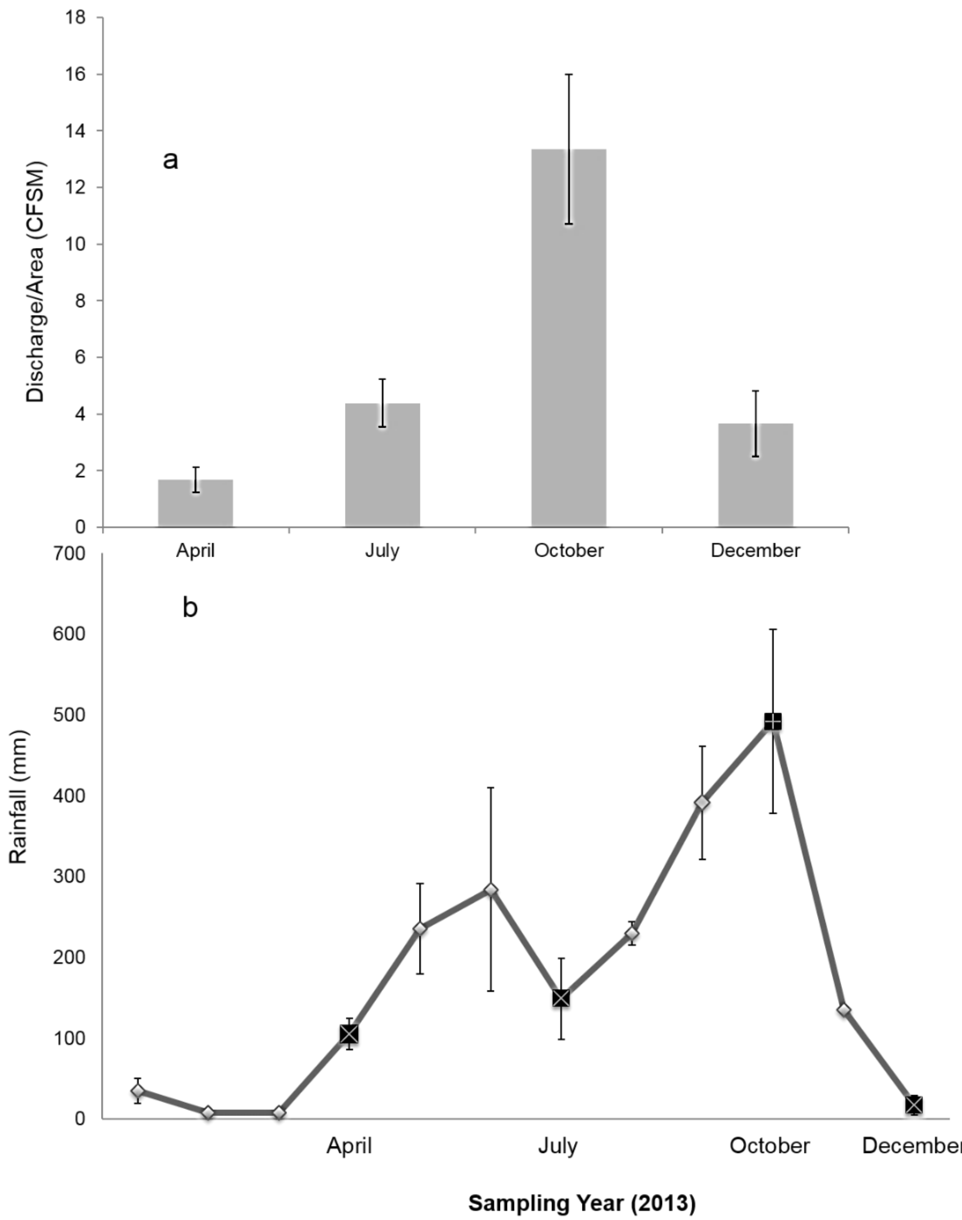

FIGURE 3.2. General hydrological dynamics of study sites (N=10) during the study year of 2013: a) Mean (±SE) discharge over sub-watershed area (cfsm); b) Mean (±SE) monthly rainfall from local gages (N=2), points highlighted in black represent our sampling events during the; dry season (December), transition season (July), peak season (October).

TABLE 3.1. Descriptive data for the upstream sub-watersheds of our study sites by shade tree cover category: High (~ 40% or more shade tree cover, N=5), and Low (<40% shade tree cover, N=5). P values represent results from t-tests conducted to evaluate differences between groups in terms of hydrological and land use variables, as well as the percentage of coffee agricultural area certified by the Rainforest Alliance. * p<0.05; **p<0.01

	SHADE TREE COVER CATEGORY				
DESCRIPTIVE VARIABLES	High		Low		T Test
Hydrology	Mean	SD	Mean	SD	P
Discharge (ft3/s)	3.45	3.04	3.04	2.46	0.7786
Area (km2)	1.53	1.97	1.80	1.03	0.7751
Slope	41.15	9.47	44.40	7.67	0.4863
Sub-watershed Land Use (%)					
Shade Tree Cover	44.40	8.46	27.01	5.31	**0.0051
Sun Coffee	24.37	8.71	37.54	9.76	**0.0139
Forest	11.99	9.37	10.77	8.27	0.7851
Pastures	13.61	5.51	18.34	7.80	0.1279
Urban	3.72	1.07	3.21	1.67	0.3351
Exposed Soils	1.89	0.76	3.11	0.89	**0.0116
Riparian Forest (%)					
20m Buffer Zone	14.07	7.76	12.80	6.52	0.7466
5m Buffer Zone	14.89	8.44	13.59	7.29	0.7315
RA Certification					
% Coffee Area RA Certified	30.34	30.17	7.41	6.86	0.0823

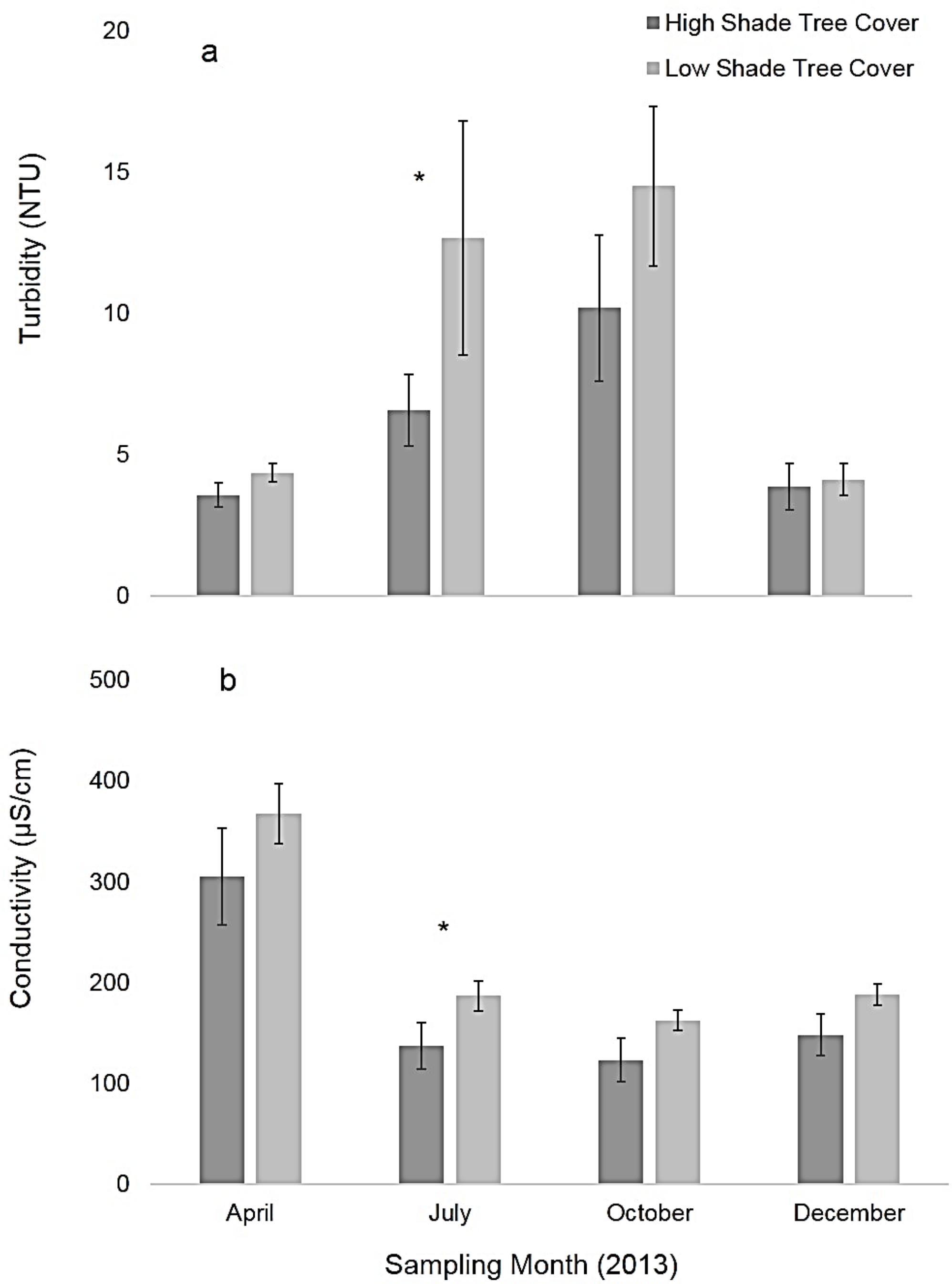

FIGURE 3.3. Means (±SE) for (a) turbidity and (b) conductivity by shade tree cover category: High Shade Tree Cover (N=5) and Low Shade Tree Cover (N=5). Results are presented per sampling month: April (baseline), July (transition), October (peak rain) and December (return to baseline). *Denotes statistical significance.

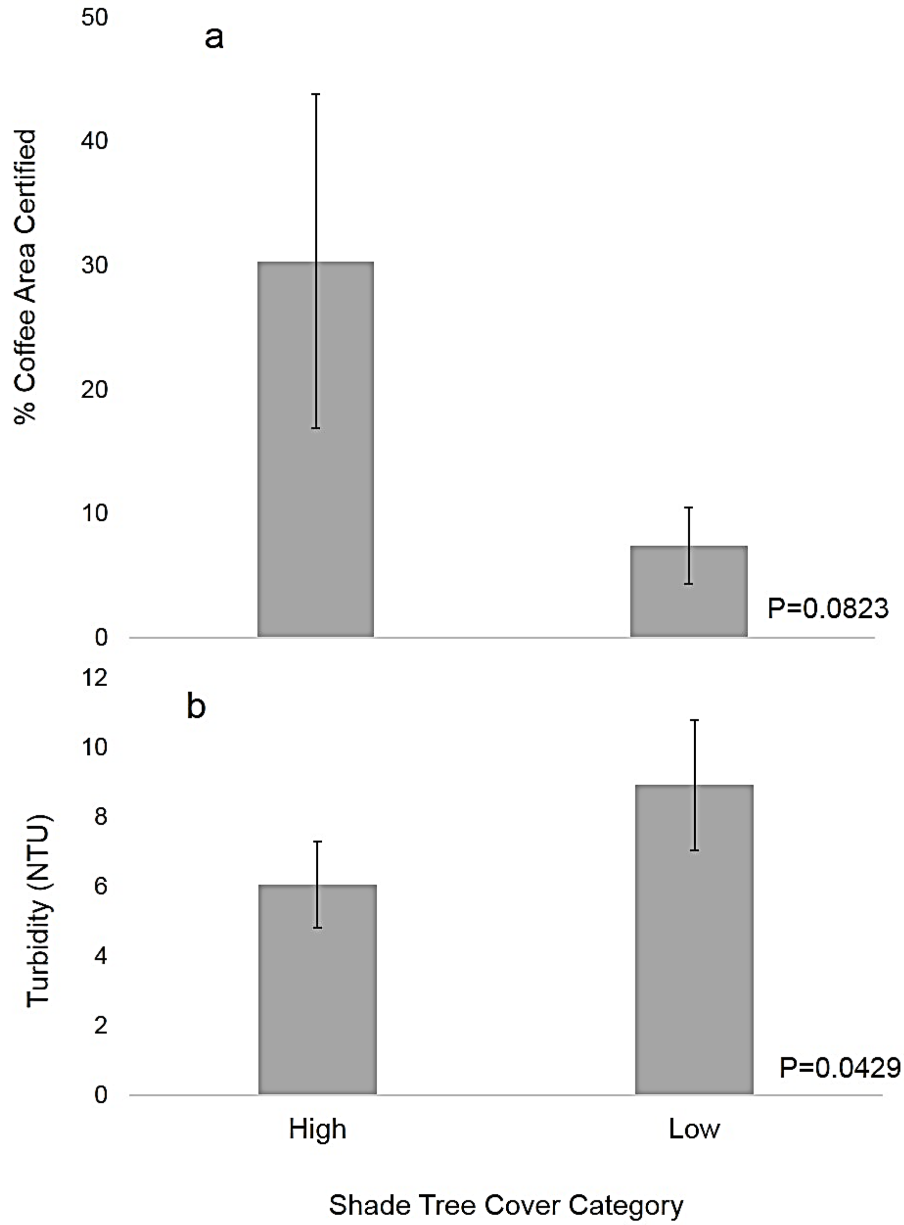

FIGURE 3.4. Means (±SE) for (a) average % of the sub-watershed's coffee growing area that is certified by the Rainforest Alliance and (b) turbidity in 2013. Comparisons are presented by shade tree cover category: High Shade Tree Cover (N=5) and Low Shade Tree Cover (N=5). P values below 0.05 are considered statistically significant. TABLE

3.2. AIC_c weights of candidate models to explain significant difference in Turbidity during the month of July and for the turbidity annual average, as well as conductivity levels in July between the two Shade Tree Cover category groups.

	AICc weights		
Candidate Models	Turbidity (July)	Turbidity (Annual Average)	Conductivity (July)
% Shade Tree Cover	0.7195	0.7338	0.3509
% Sun Coffee	0.1065	0.1081	0.4265
% Exposed Soil	0.1739	0.1581	0.2226

CHAPTER 4

BUILDING EFFECTIVE PARTNERSHIPS BETWEEN NON-GOVERNMENTAL ORGANIZATIONS AND ACADEMIA: APPLYING A COLLABORATION FRAMEWORK TO PROJECTS THAT EVALUATE SUSTAINABILITY CERTIFICATIONS

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ABSTRACT

Partnerships between non-governmental organizations (NGOs) and academics provide a unique platform for incorporating ecological research into conservation. An increasingly important type of NGO-Academia partnership involves NGOs that develop voluntary sustainability standards (e.g. the Forestry Stewardship Council) or certify compliance to such standards (e.g the Rainforest Alliance), as they must demonstrate their effectiveness to both consumers and industry. In turn, these types of partnerships provide the opportunity for ecologists to help address environmental issues with global scope in activities of economic, social, and ecological importance. In this paper, we develop a framework for building relationships between NGOs and academic institutions based on current literature on effective academic-practitioner research partnerships. Our framework consists of 1) *Problem Definition* and agreement on research strategy, 2) *Tracking Progress* towards iterative research and 3) *Moving Forward*, by fostering research networks. We used our collaborative framework to compare and contrast our (University of Georgia) partnership with the Rainforest Alliance with two other NGO-Academia partnerships that evaluated aspects of the Forest Stewardship Council and Marine Stewardship Council certification programs. Through these cases we demonstrate the utility of our NGO-Academia framework for navigating collaborative research projects, and we also gain insights about the factors that enable: 1) project initiation (e.g. prior professional relationships between partners, similar institutional philosophies), 2) progress towards goals (e.g. identifying and addressing follow up questions, involving senior level scientists in policy development) and 3) continuity (e.g. involving graduate students during research, cost sharing).

INTRODUCTION

Non-Governmental Organizations (NGOs) play a key role in conservation initiatives and environmental governance. They build bridges between science and policy when scientific uncertainties preclude development of laws for emerging environmental problems (McCormick, 1999). Building these bridges often leads NGOs to partner with scientists for evidence based conservation. Accordingly, a central component of the Ecological Society of Americas's (ESA) action plan for increasing the impact of ecological research is the "forging of global and regional partnerships" (Palmer et al. 2005). Given that developed countries are often the end consumer of natural resources from worldwide commodities chains, scientists in the US and Europe have a heightened responsibility to initiate research partnerships both locally and internationally that promote sustainability (Palmer et al. 2005, UNEP 1999).

For ecologists interested in addressing the global environmental footprint of developed nations, NGOs involved with sustainability certification (see Table 4.2) can be key partners due to their connection to commodity chains that initiate in rural areas of developing countries that may lack the infrastructure and resources for environmental oversight. Certification attempts to solve this problem by providing market incentives and technical assistance for agricultural and resource conservation practices. In spite of the proliferation of certification programs over the last two decades, there is limited evidence about their environmental effectiveness (Blackman and Rivera 2010, Milder et al. 2014).

Given their growing economic and policy importance, NGOs involved in sustainability certification are under increased pressure to provide reliable evidence of their impact. Responding to this need, the International Social and Environmental Accreditation and Labeling Alliance (ISEAL), developed the *Principles for Credible and Effective Sustainability Standards* (ISEAL 2013). NGOs that are members of ISEAL (Table 4.1) must demonstrate commitment to improving the effectiveness of their programs by rigorously measuring progress towards their conservation outcomes and integrating learning and innovation into their practices (ISEAL 2013). Complying with ISEAL's evaluative approach entails the application of science-based guidelines, which often involve collaborations with un-biased academics and researchers (Barry et al. 2012, Milder et al. 2014). Therefore, we predict that many NGO-Academia collaborative research projects will emerge in response to this growing demand for science-based impact evaluation.

Although NGOs and academics may agree on the need for research collaborations to advance conservation practice, complex challenges arise when bringing together stakeholders with potentially divergent views (Hart and Calhoun 2010, Sabatier et al.., 2005, Farnsworth 2004). Causes of tensions within these partnerships include power inequalities (e.g. funding sources, access to knowledge resources), philosophical clashes regarding the ownership and application of research outputs, and different incentive structures within academia and practice (Farnsworth 2004, Aniekwe et al. 2012).

Insights about how to overcome these challenges have been provided by members of the *Roundtable on Science and Technology for Sustainability* of the U.S. National Academies (Clark and Holliday 2006). Here we incorporate some aspects of Clark and

Holiday's (2006) ideas on how to develop effective practitioner-academic partnerships for *Linking Knowledge with Action for Sustainable Development* (Kristjanson et al. 2009), and expand them to create a collaborative framework for NGO-Academia partnerships (Figure 4.1). Our framework includes: 1) *Problem Definition,* in a collaborative and user driven (i.e. practitioner driven) manner; 2) *Tracking Progress* to evaluate if science is integrated into decision-making and if the partnership involves reciprocal learning (i.e. Clark and Holiday's *Decision Support Systems* and *Learning Orientation*); and 3) *Moving Forward* by identifying strategies to promote partnership continuity (i.e. Clark and Holliday's *Continuity* and *Flexibility*).

Our framework expands the *Problem Definition* step by using Roper's (2002) NGO-Academia collaboration typologies (step 1, Figure 4.1) to help identify a research strategy that benefits the partner with higher stakes in the project. We refine the *Tracking Progress* step using Lundy's (2003) learning alliance framework (step 2, Figure 4.1) which helps outline the process of using research outputs for policy development and iterative learning. In the *Moving Forward* step, we apply social capital concepts for elucidating aspects that promote partnership continuity (step 3, Figure 4.1, Sabatier et al. 2005, McNie 2007).

In this work we illustrate the use of this framework through a participant-observation based (Yin 2009) case study of our collaborative project, between the University of Georgia's (UGA) Odum School of Ecology and the Rainforest Alliance (RA) (Table 4.3, partnership background). We will then apply it to examine two other examples of NGO-Academia partnerships that research the effectiveness of certification programs: (1) The World Wildlife Fund/Duke University collaboration to evaluate the impacts of the Forest Stewardship Council (FSC) certification and (2) The Marine Stewardship Council (MSC)/University of Washington collaboration to evaluate the accuracy of low trophic level fish stock models.

By applying our framework to compare and contrast projects involving sustainability certifications, we seek to both document the dynamics of existing partnerships in a context that is becoming increasingly important for forging NGO-Academia collaborations (Milder et al. 2014), and test the usefulness of our framework for guiding similar projects in the future.

CASE STUDY: Collaboration between the Rainforest Alliance (RA) and the University of Georgia (UGA) for tropical stream conservation

<u>Problem Definition</u>

The RA-UGA partnership aimed "*to conduct research related to the impacts of RA's sustainability standards and best management practices on freshwater quality and biodiversity"* (RA 2009, collaboration commitment letter to UGA). UGA approached this objective by proposing to address research gaps related to RA's current certification requirements concerning freshwater management. While RA appreciated the academic desire to answer larger theory-driven questions, they made it clear that they primarily needed a reliable monitoring tool to use during audits and technical assistance initiatives.

RA's and UGA's strategies for addressing the problem differed in a manner similar to what Roper (2002) describes as *Expert Consultant* vs *Theory Development* research models (Figure 4.1). RA's interest in having UGA create a monitoring tool is characteristic of the *Expert Consultant* approach, which follows what Reid and others (2009) define as knowledge synthesis, or trading. On the other hand, UGA followed the *Theory Development* model, which seeks to generate knowledge about an under-studied topic, which is at the core of academic research.

Following RA's *Expert Consultant* strategy would have corresponded to Clark and Holiday's (2006) recommendation of working around *user-defined* problems to better link knowledge with action. In this case however, the collaboration involved using the project as a springboard for a PhD dissertation (see Table 4.3), which meant that a consulting approach would not meet the requirements for original, theory-driven, research associated with doctorate degrees (Golde and Dore 2001).

Reconciling objectives was critical in order to continue the partnership, which was important given that UGA and RA had equally important stakes in the project's success. This led to a process of negotiation to balance *Expert Consultant* with *Theory Development* aspects. First, partners agreed to undertake both aspects, but focus on one study context, which was agroforestry (cocoa/coffee interspersed with trees), because of its potential to promote ecosystem services (Gómez- Delgado et al. 2011) and its economic importance in the tropics (Kaplinsky 2004). Second, the same data collection methods were selected for each of the project's components in order to more effectively balance time and budget allocation.

For the *Expert Consultant* aspect, UGA created a water monitoring protocol to measure the impact of RA's agriculture certification program. The protocol incorporated available resources described in the literature (e.g. Hauer and Lamberti 2011, Douglas et al. 2006, Bjorkland et al. 2001, Hawkes 1998) to evaluate freshwater management at the farm, the stream and the watershed scales; hence we will refer to it as the FSW (Farm Stream and Watershed) protocol (Appendix 4.1).

The FSW protocol's watershed component recommended estimating shade tree cover within the agroforestry-farm. Although RA requires a minimum of 40% shade tree cover to comply with certification, this guideline lacked scientific support for the specific context of freshwater management (SAN 2010). UGA decided to address this research gap as part of the *Theory Development* aspect (see Chapter 3).

For *Theory Development*, we focused on comparing non-point source pollution indicators on agroforestry sub-watersheds that were above and below RA's 40% shade tree cover requirement. To measure non-point source pollution indicators, only methods included in the FSW protocol (*Expert Consultant* aspect) were applied. Reconciling methodologies presented several benefits. First, the operational costs of the collaboration were not increased, as the same tools and equipment could be applied for both aspects of the project. Second, using the FSW in the *Theory Development* aspect provided the opportunity to evaluate its feasibility.

The *Theory Development* aspect of the project took place in Tarrazu, Costa Rica, which is at the higher end of the slope and rainfall gradient in which agroforestry exists (Mitchell 1988, Soto-Montoya and Ortiz-Malavasi 2008). Since non-point source pollution problems increase with slope and rainfall, a study on steep and rainy environments would produce more generalizable management recommendations, applicable even in the most vulnerable hydrological regions.

During the course of our collaboration, RA received donor incentives to conduct freshwater research in cocoa farms in Ghana. Due to low elevation and drier conditions, RA's sites in Ghana were not ideal for evaluating optimal shade cover for the *Theory Development* project. However, the sites were suitable for testing the FSW protocol in the context of a different type of agroforestry. Moreover, extending the project to Ghana in order to accommodate donor priorities allowed UGA to get additional funds from RA donors for equipment that could be used in both study sites, while costs related to travelling were supplemented by UGA through several graduate student grants.

Therefore, although defining the problem presented challenges because UGA and RA had equally important stakes and different goals, the parties succeeded in balancing these goals by: 1) coinciding on the study context and methodology, and 2) sharing costs through the strategic allocation of donor funds and student grants.

<u>Tracking Progress</u>

The *Expert Consultant* aspect of our project started with a research output (the FSW) of immediate field applicability. The FSW was applied in agroforestry farms in Ghana and Costa Rica and modified based on findings concerning cost requirements for widespread monitoring implementation For example, water clarity measures from a Secchi tube correlated strongly with Turbidity (NTU) measures from a turbidity probe (Figure 4.3). The price difference between these two methods is significant (≈$60 for the tube vs >$1,000 for the probe), yet they provide comparable information about water quality.

While adapting the FSW, questions were raised about the validity of using water clarity and other qualitative tools for monitoring certification impact. Accordingly, RA recently started addressing this question in coffee farms in Rwanda by comparing measurements taken using cost effective methods with laboratory measures of aquatic pollution. By developing a new research project based on questions raised during the initial study, this collaboration has effectively progressed towards iterative research. Sustaining research, however, depends on having the human resource capacity to give the project continuity, which we will explore in the next section on Moving Forward.

Moving Forward

Effectively linking knowledge with action requires translating research outputs into management instruments. It also requires iterative research for improving the empirical basis of those management interventions (Roper and Petit 2002). The human capital that develops through NGO-Academia partnerships facilitates this process. Transferring research into management is facilitated through the action network of the NGO (Figure 4.3), which in this case, directly transfers research outputs to certified producers on the ground, and indirectly to other local stakeholders who may benefit from the spillover effects of certification programs. In terms of developing iterative research, we believe that when NGOs partner with early career academics, as occurred in our project, there is a high chance that a closed network of collaborators will emerge, enabling follow up projects to grow naturally from initial collaborative efforts (Figure 4.3).

For example, different generations of the same research group would more feasibly build up on each other's work by transmitting practical knowledge, equipment, and data sets for which the faculty advisor or NGO may be custodians. This generational link, along with connections between graduate students with their advising committees and experts across departments promotes the formation of a “closed network” (Figure

4.3), which some theoreticians argue is essential for maintaining social capital as a collective asset and promoting partnership continuity (Lin 1999). Moreover, graduate students are less influenced by the academic incentives that constrain tenure track faculty (Duchelle, 2009). This flexibility is an asset for working with NGOs that have evolving goals influenced by donor priorities, as was the case on this partnership.

There may be disadvantages to consider when working with graduate students, including their potentially limited research experience relative to faculty. Future studies may focus on determining how the benefits weight against the limitations, and whether the predicted network outlined in Figure 4.3 can be validated with data on long standing collaborative projects.

OTHER EXAMPLES: Additional NGO-Academia partnerships involving sustainability certification

Using our collaborative framework we examine two other examples involving FSC and MSC, to complement our case study with RA. These three organizations pioneered the creation of sustainability certification programs (Table 4.1). Because of their relevance, RA, FSC, and MSC have already been the subjects of collaborative research to assess their impact, providing a reference for other certification initiatives to develop similar projects in the future. Our information comes from semi-structured interviews with lead investigators of the selected projects (IRB ID 00001080, Appendix 4.2), and from reference materials produced by the NGOs.

The World Wildlife Fund/Duke University partnership to evaluate the impact of FSC certification.

The World Wildlife Fund's (WWF) research partnership with the Nicholas School of the Environment (NSOE) at Duke University emerged as an initiative from the Director of WWF United States Conservation Science Program, an alumnus from Duke University with an established relationship with NSOE faculty. Among the collaborative research projects between WWF and Duke, one focused on evaluating the impact of FSC certification on forest conservation, ecosystem services, and village development. The first stages of the project consisted of applying existing data from a Duke University doctoral student's dissertation on forestry concessions in Borneo (Miteva 2013). WWF used the data to evaluate the causal impact of the FSC program on socio-economic and environmental outcomes.

The study used socio-economic and environmental characteristics of villages in FSC logging concessions to match them to observationally similar villages in non-FSC logging concessions. Matching methods are increasingly being applied to establish the causal impact of conservation interventions (Miteva et al. 2012) and certification schemes, in particular (Blackman and Rivera 2010), but they are difficult to implement due to demanding data requirements. Accordingly, there are few published studies using matching to evaluate the impacts of FSC certification. The goal of the WWF-Duke collaboration was to contribute this lacking information and publish the results of the study in a peer-reviewed journal. Because the project focused on filling a research gap, and the main goal was to produce a scientific publication (*output*, Figure 4.1), this partnership followed a *Theory Development* model. Although the collaboration was not designed to produce outputs of immediate field applicability, the researchers will use the study's findings to make recommendations for strengthening FSC standards based on their empirical findings, and to guide on the ground implementation.

The study findings also served as reference for follow up studies. Currently WWF and Duke University are conducting another analysis of FSC impacts in Peru and Cameroon, where two Master's students, with funds provided by WWF, work under the guidance of two Duke Professors. Since the project has expanded to include new researchers and is actively conducting follow up studies, it is effectively moving forward towards iterative research. Additionally, the first student involved, now an academic in her own right, is planning to expand the initial Borneo study and evaluate long-term impacts of FSC on newly certified concessions. The ability for the project to continue past the initial project relied on two key aspects: 1) trust building between WWF and Duke, thanks in part to a successful initial collaboration, and 2) funding opportunities within WWF to sponsor project expansion.

The Marine Stewardship Council's (MSC) study to assess model and data adequacy for compliance with MSC criteria on Low Trophic Level fisheries.

In 2011, the Marine Stewardship Council (MSC) revised its guidelines pertaining Low Trophic Level (LTL) fisheries (e.g. sardines and anchovies). These revisions were based on findings from an inter-institutional collaborative work showing the need for stricter limits on target biomass reference points for key LTL species (Smith et al. 2011). In 2013, MSC contracted a professor from the University of Washington (UW), to conduct follow up studies related to these new guidelines. Because this study emerged from questions raised during a previous research partnership (Smith et al. 2011), it represents the second iteration of a collaborative learning cycle between the MSC and academic researchers (*Inputs to policy/new research questions*, Figure 4.1). Although the UW professor was not part of the initial study, he entered as an expert on the topic due to his involvement with the Lenfest Forage Fish Task Force, a panel of scientists that provide technical advice for the management of *forage fish* (i.e. LTL species).

MSC wanted to evaluate LTL fisheries participating in its program in terms of data and model adequacy for the assessment of the new MSC criteria. For this purpose, the UW professor evaluated over thirty LTL fisheries participating in the MSC certification in terms of how well their existing data sources supported two key requirements: (A) identifying stocks as *key* LTL (i.e of crucial importance for the ecosystem) and (B) setting upper bounds for key LTL stock limits and target biomass reference points. The study evaluated existing databases describing the ecosystems and models of selected MSC certified fisheries. Their approach is characteristic of an *Expert-Consultant* model, as it used available information to address a discreet, pre-defined, output using existing technical knowledge, and the academic was hired as a consultant for a limited time period.

One of the main findings from the project was that the criteria for identifying LTL stocks as "key" were missing important aspects of food web dynamics. In particular, all trophic linkages were treated as having equal strength, and there was a tendency to aggregate predator groups into a single category. When modeled, these deficiencies led to poor discrimination of "key" LTL species (Essington and Pláganyi 2013). To address this issue, a new method for discriminating key LTL species was proposed that revised these deficiencies. This new method is referred to as the SURF index (Supportive Role to Fishery ecosystems) (Essington and Pláganyi 2013) and after a period of public consultation; it was incorporated into the LTL fisheries criteria within MSC certification (*output into policy*, Figure 4.1).

Although there are currently no plans for project expansion, implementation of LTL criteria across MSC certified fisheries is likely to lead to follow up studies on topics such as: a) baseline information needs of food webs within LTL fisheries seeking certification, and b) impact evaluations of default upper bounds for target biomass, among others (MSC personal communication). The academic's connection not only to UW, but also to the Lenfest Forge Fish Task Force provides MSC with access to a rich network of over 10 research institutions from which to seek advice for follow up studies.

Commonalities and contrasts between cases

These three projects were all initiated by NGOs that were involved with sustainability certification and were seeking expert advice from unbiased scientists representing well-established research institutions. From these cases we can derive some similarities and contrasts that allow us to postulate possible NGO-Academia dynamics for further evaluation.

First, existing relationships facilitate the initiative to start an NGO-Academia partnership for conservation research. Both the RA-UGA (Table 4.3) and WWF-Duke partnership emerged from the interest of people that had worked together in the past and that had already established trust in each other's work. In the case of the MSC-UW project, there was no previous relationship, but the academic was a recognized expert in a field related to a discrete need within the organization.

Second, the type of NGO involved may influence the research strategy selected during *Project Definition*. Here, RA and MSC proposed projects that followed the *Expert-Consultant* model. Both of these NGOs manage certification programs and are entrepreneurial in nature. Their preference for the *Expert-Consultant* model may be attributed to the constant need of evaluating certification impact in order to expand their programs to large institutional clients. These goals may be more efficiently achieved by applying existing knowledge rather than by conducting basic research. On the contrary, WWF proposed a *Theory Development* project, which may reflect the organization's well-established research department, and the fact that it is not directly linked to the certification program it was evaluating (FSC). This allows the organization to devote more resources for traditional research of conservation interest, including studies that do not lead to immediate applied outputs.

Furthermore, the type of academic involved in the partnership might influence project outcome. The WWF-Duke project was similar to the RA-UGA partnership in that graduate students carried out the majority of the work, which allowed for cost sharing, and lent itself to follow up questions and project continuation as the student researchers enter the professional and academic worlds. These projects exemplify why incorporating graduate students may enable iterative research by 1) promoting expansion of research networks (Figure 3.4), and 2) by creating opportunities for follow up projects due to the constant demand by incoming graduate students for new research topics.

Contrary to the RA and WWF projects, the MSC collaboration was principally conducted by an established academic, and was distinct from the other cases in that its outputs were directly incorporated into policy instruments. The RA-UGA and WWF-

Duke projects might eventually produce governance tools for the organizations involved. However, it is possible that when NGOs deal with high stakes, short-term needs, they may preferably commission established experts to take the research lead.

Finally, selecting a research strategy is contingent on who has a greater stake in the partnership and whether the institutions have similar incentive structures. If these do not completely align, negotiations will be needed. Contrary to the RA-UGA project, the WWF-Duke and the MSC-UW collaborations were "user-driven" and no negotiation was needed to define research strategy. In the case of the MSC-UW, the NGO had a greater stake in the partnership's outcome, and the academic's role consisted of providing a professional service, primarily as a consultant. In the case of the WWF-Duke collaboration, both institutions had equally important stakes, but the NGO partners represented a science-focused program and thus shared similar incentives with the academics.

CONCLUSIONS

NGO-Academia partnerships help link knowledge to action in conservation. Here we incorporated prior research on effective partnerships into a framework for navigating collaborative conservation research. We illustrate this framework using NGO-Academia partnerships involving sustainability certification, a context we foresee becoming more common in the future due to the need of certification programs to measure their environmental impact through rigorous science.

The first step of our framework, *Problem Definition*, was used on the cases involving WWF-FSC and MSC *post hoc* to describe the nature of the partnerships. This step will be more useful when used at the start of new partnerships to help mediate conflict related to differing project expectations. Our framework was especially useful for *Tracking Progress* as we were able to identify concrete outcomes and whether they contributed to theory, policy or iterative research. The potential for project continuity was tracked through our *Moving Forward* step. Although we made some assumptions about the future of the projects evaluated, these cases are all recent so it is still too early to assess this aspect accurately. Future research should focus on using our framework (Figure 4.1) to get insight about strategies for enduring partnerships, incorporating our predicted graduate student network (Figure 4.3) to assess their role at fostering project continuity.

Future research should also focus on evaluating dynamics of projects initiated by academics, as the projects presented here were all initiated by NGOs. Within ecology, growing incentives for research collaboration across institutions, including NSF's Integrative Graduate Education and Research Traineeship Program (IGERT), will likely result in more NGO-Academia partnerships emerging from academics and provide us with more examples to evaluate our framework. As incentives within the sciences lead academic ecologists to move beyond basic inquiry to include applied collaborative research, it is important to recognize that the political and economic values of scientists and the organizations they collaborate with may present sources of bias in research (Zingales 2014). Academics need to be mindful of these potential biases when reporting and interpreting findings as they bear the responsibility of providing legitimacy to existing regulatory tools, which is the main purpose of NGO-Academia partnerships in the context of impact evaluation research.

The current interest of stakeholders to bridge science and practice through collaborations, as well as the theoretical tools to help collaborations thrive are finally convening. We hope that the framework proposed here, as well as the examples described, help guide and encourage similar projects for science-based conservation locally and internationally.

References

Anderson, E. P., & Maldonado-Ocampo, J. A. 2011. A Regional Perspective on the Diversity and Conservation of Tropical Andean Fishes. Conservation Biology, 25(1), 30-39.

Aniekwe, C. C., Hayman, R., Mdee, A., Akuni, J., Lall, P., & Stevens, D. (2012). *Academic-NGO collaboration in international development research: A reflection on the issues*. A Working Paper.

Auld G, Gulbrandsen LH, McDermott CL (2008) Certification schemes and the impacts on forests and forestry. Annu Rev Environ Resour 33:187–211.

Barry, M., B. Cashore, J. Clay, M. Fernandez, L. Lebel, T. Lyon, P. Mallet, K. Matus, P. Melchett, M. Vandenbergh, J. Kees Vis, T. Whelan (Steering Committee of the State-of-Knowledge Assessment of Standards and Certification). 2012. Toward sustainability: The roles and limitations of certification. Washington, DC: RESOLVE, Inc.

Bjorkland, R., Pringle, C. M., & Newton, B. 2001. A stream visual assessment protocol (SVAP) for riparian landowners. *Environmental Monitoring and Assessment*, *68*(2), 99-125.

Blackman, A., & Rivera, J. (2010). The evidence base for environmental and socioeconomic impacts of “sustainable” certification. *Resources for the Future: RF-DP-10-17*.

Clark, W.C. and L. Holiday, eds. 2006. Linking Knowledge with Action for Sustainable Development: The Role of Program Managers. Washington, D.C.: National Academy Press.

Crosse, W., D. Newsom and E. Kennedy. 2012. Recommendations for improving research on certification impacts. Appendix I In: Toward sustainability: The roles and limitations of certification. Washington, DC: RESOLVE, Inc.

Dahlgren, R., E. Van Nieuwenhuyse, G. Litton. 2004. Transparency tube provides reliable water-quality measurements. *California Agriculture* 58(3):149-153

Douglas, M., Dowe, J., & Burrows, D. 2006. *Tropical Rapid Appraisal of Riparian Condition*. Land & Water Australia.

Duchelle, A.E., K. Biedenweg, C. Lucas, A. Virapongse, J. Radachowsky, D. J. Wojcik, M. Londres, W. Bartels, D. Alvira, and K. A. Kainer. 2009. Graduate students and knowledge exchange with local stakeholders: possibilities and preparation. *Biotropica 41*(5): 578–585

Dudgeon, D. (Ed.). 2011. Tropical stream ecology. Academic Press.

Essington, T. and E.Pláganyi. 2013. Model and data adequacy for Marine Stewardship Council key low trophic level species designation and criteria and a proposed new assessment index. *Marine Stewardship Council Science Series. 1: 171 – 191.*

Farnsworth, E. J. 2004. Forging Research Partnerships across the Academic–Agency Divide. *Conservation Biology*, *18*(2), 291-293.

Forbes. 2013. The 200 largest US charities. http://www.forbes.com/lists/2011/14/200-largest-us-charities-11_rank-environment-animal.html. Accessed 09/04/2013

Giovannucci, D., A. Byers, and L. Pascal. 2008. Adding value: Certified coffee trade in North America. In Pascal, L. (Ed.) Value-adding standards in the North American food market: Trade opportunities in certified products for developing countries. FAO.Rome, Italy.

Gladwell M. 2000. The Tipping Point: How Little Things Can Make a Big Difference. (New York: Little, Brown & Co.)

Golde, C. M., & Dore, T. M. 2001. At cross purposes: What the experiences of today's doctoral students reveal about doctoral education . ERIC Clearinghouse.

Gómez-Delgado, F., O. Roupsard, G. le Maire, S. Taugourdeau, A. P´erez, M. van

ISEAL. 2013. Principles for Credible and Effective Sustainability Standards Systems: ISEAL Credibility Principles. http://www.isealalliance.org/sites/default/files/Credibility%20Principles%20v1.0%20low%20res.pdf. Accessed 09/20/2014.

Oijen, P. Vaast, B. Rapidel J. M. Harmand1, M. Voltz, J. M. Bonnefond, P. Imbach, and R. Moussa. 2011. Modelling the hydrological behaviour of a coffee agroforestry basin in Costa Rica. Hydrol. Earth Syst. Sci., 15, 369–392.

Hart, D.D. and A. J. K. Calhoun. 2010. Rethinking the role of ecological research in the sustainable management of freshwater ecosystems. *Freshwater Biology* (2010), 55: 258–269

Hannaford, M.J., M. T. Barbour V. H. Resh. 1997. Training reduces observer variability in visual-based assessments of stream habitat. *J. N. Am. Benthol. Soc*. 16(4):853-860.

Hart, D.D. & A. J . K. Calhoun. 2010. Rethinking the role of ecological research in the sustainable management of freshwater ecosystems. Freshwater Biology (2010), 55 (Suppl. 1), 258–269

Hauer, F. R., & Lamberti, G. A. (Eds.). 2011. *Methods in stream ecology*. Academic Press.

Hawkes, H. 1998. Origin and development of the biological monitoring working party score system. *Water Research*, *32*(3), 964-968.

ICO (International Cocoa Organization). 2013. Cocoa beans Daily Price. http://www.indexmundi.com/commodities/?commodity=cocoa-beans. Last accessed 07/20/2013.

Kaplinsky, R. (2004). Competitions policy and the global coffee and cocoa value chains. *UNCTAD, Geneva*.

Kristjanson, P., R Reid, N Dickson, W Clark, D Romney, R Puskur, S MacMillan, D Grace. 2009. Linking International Agricultural Research Knowledge with Action for Sustainable Development. PNAS 106: 5047-52.

Leach, W.D. And P.A. Sabatier. 2005. Are trust and social capital the keys to success? Watershed partnerships in California and Washington. In: Swimming upstream: Collaborative approaches to watershed management. Sabatier, P.A. Focht, W., Lubell, M., Trachtenberg, Z. Vedlitz, A. and Matlock, M (eds.). MIT Press. Cambridge, Massashusetts.

Lin, N. 1999. Building a network theory of social capital. *Connections*, *22*(1), 28-51.

Lubell, M. P.A. Sabatier, A. Vedlitz, W. Focht, Z. Trachtenberg and M. Matlock. 2005. Conclusions and recommendations. In: Swimming upstream: Collaborative approaches to watershed management. Sabatier, P.A. Focht, W., Lubell, M., Trachtenberg, Z. Vedlitz, A. and Matlock, M (eds.). MIT Press. Cambridge, Massashusetts.

Lundy, M. 2003. Learning alliances with development partners: A framework for scaling out research results. In: Scaling up and out: Achieving widespread impact through agricultural research. Pachico, D. and S. Fujisaka (eds.). Cali, Colombia. Centro Internacional de Agricultural Tropical. 293p. Publication No. 140. Economics and impact Series. ISBN 958-694-064-0.

Marine Stewardship Council (MSC). 2014. Program improvements: Low Trophic Level Fisheries. http://improvements.msc.org/database/low-trophic-level-fisheries. Last accessed 10/15/2014.

McCormick, J. 1999. The Role of Environmental NGOs in International Regimes. In: R. Axelrod and S. Vandeveer (Eds), The Global Environment: Institutions, Law and Policy (Washington DC: CQ Press, 2010). Third edition.

McNie, EC. 2007. Reconciling the supply of scientific information with user demands: An analysis of the problem and review of the literature. *Environmental Science and Policy* 10(1): 17-38.

Menter. H., S. Kaaria, N. Johnson and J. Ashby. 2003. Scaling up. In: Scaling up and out: Achieving widespread impact through agricultural research. Pachico, D. and S. Fujisaka (eds.). Cali, Colombia. Centro Internacional de Agricultural Tropical. 293p. Publication No. 140. Economics and impact Series. ISBN 958-694-064-0.

Milder, J. C., Arbuthnot, M., Blackman, A., Brooks, S. E., Giovannucci, D., Gross, L., ... & Zrust, M. (2014). An agenda for assessing and improving conservation impacts of sustainability standards in tropical agriculture. *Conservation Biology*.

Mitchell, H. W. 1988. Cultivation and Harvesting of the Arabica Coffee Tree. Coffee: Agronomy. Ed. R.J. Clarke. New York: Elsevier Applied Science.

Miteva DA, Pattanayak SK, Ferraro PJ (2012) Evaluation of biodiversity policy instruments: what works and what doesn't? Oxford Rev Econ Policy 28:69–92.

Miteva, D. (2013). Three Essays On Protecting Biodiversity In Developing Countries. http://dukespace.lib.duke.edu/dspace/handle/10161/7247. Accessed 03/17/2015.

Odum School of Ecology. 2013. Areas of expertise. http://www.ecology.uga.edu/research.php?Areas_of_Expertise-2/. Accessed 04/09/2013.

Ostrom, E., Dietz, T., Dolsak, N., Stern, P. C., Stonich, S., & Weber, E. U. (Eds.). 2002. The drama of the commons. National Academies Press.

Palmer, M.A. E. S. Bernhardt, E. A. Chornesky, S. L. Collins, A. P. Dobson, C. S. Duke, B. D. Gold, R. Jacobson, S. Kingsland, R. Kranz, M. J Mappin, M. L. Martinez, F. Micheli, J. L. Morse, M. L Pace, M. Pascual, S. Palumbi, O.J. Reichman, A. Townsend, and M. G. Turner. 2005. Ecological science and sustainability for the 21st century. *Front Ecol Environ*; 3(1): 4–11

Poff, N. Leroy, B. D. Richter, A. H. Arthington, S. E. Bunn, R. J. Naiman, E. Kendy, M. Acreman et al.. The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards. *Freshwater Biology*. 55: 147-170.

Putnam, R. D., Leonardi, R., & Nanetti, R. Y. 1993. Making democracy work: Civic traditions in modern Italy. Princeton university press.

Rainforest Alliance (RA). 2008. Certified sustainable product alliance: Final Report. RA/ USAID Regional Mission San Salvador, El Salvador Cooperative Agreement No: 596-A-00-04-00048-00.

Rainforest Alliance (RA). 2012. 25 years of conservation: Highlights of our history. http://www.rainforest-alliance.org/history. Accessed 08/11/ 2012.

Roper, L. 2002. Achieving Successful Academic-Practitioner Research Collaborations. *Development in Practice*. 12: 338-345

Roper, L. and Pettit, J. 2002. Development and the Learning organization: an introduction. . *Development in Practice*. 12: 258-271.

Roper, L. and W. Fitzgerald. 1998. Documenting Strategies for Incorporating Conflict Resolution, Reconciliation, and Peace-Building into Humanitarian Assistance in Complex Emergencies. http://web.mit.edu/cis/www/migration/grantees1998.html#roper

Rowe, M., Essig, D., & Jessup, B. (2003). Guide to selection of sediment targets for use in IdahoTMDLs. Idaho Department of Environmental Quality. Boise, Idaho

Sabatier, P. A., Focht, W., Lubell, M., Trachtenberg, Z., Vedlitz, A., & Matlock, M. 2005. Collaborative approaches to watershed management. In: Swimming upstream: Collaborative approaches to watershed management. Sabatier, P.A.

Sabatier, A. W.D. Leach, M. Lubell, N.W. Pelkey. 2005. Theoretical frameworks explaining partnership success. In: Swimming upstream: Collaborative approaches to watershed management. Sabatier, P.A. Focht, W., Lubell, M., Trachtenberg, Z. Vedlitz, A. and Matlock, M (eds.). MIT Press. Cambridge, Massashusetts.

Sarewitz D. & Pielke R. (2007) The neglected heart of science policy: reconciling the supply of and demand for science. Environmental Science & Policy, 10, 5–16.

Scheffer, M. S. Carpenter, J. A. Foley, C. Folke & B. Walker. 2001. Catastrophic shifts in ecosystems. Nature (413): 591-596.

Schwartzman, S., A. Moreira, and D. Nepstad. Rethinking tropical forest conservation: perils in parks. *Conservation Biology*. 14.5: 1351-1357.

Soto-Montoya, C and Ortiz-Malavasi, E. 2008. Atlas digital de Costa Rica. InstitutoTecnológico de Costa Rica. Vice rectoría de investigación y extension. Escuela de Ingeniería Forestal.

Steffan-Dewenter, I., Kessler, M., Barkmann, J., Bos, M. M., Buchori, D., Erasmi, S., ... & Tscharntke, T. 2007. Tradeoffs between income, biodiversity, and ecosystem functioning during tropical rainforest conversion and agroforestry intensification. *Proceedings of the National Academy of Sciences*, *104*(12), 4973-4978.

Sustainable Agriculture Network (SAN). 2010. Sustainable Agriculture Standard. http://san.ag/web/our-standard/. Accessed 09/20/2014.

Stokes, D. E. (1997). *Pasteur's quadrant: Basic science and technological innovation*. Brookings Institution Press.

The Nature Conservancy. 2013. History & milestones of the Nature Conservancy. http://www.nature.org/about-us/vision-mission/history/index.htm.Accesed 09/04/2013.

United Nations. 1987. Our common future: Report of the World Commission on Environment and Development. http://conspect.nl/pdf/Our_Common_Future-Brundtland_Report_1987.pdf. Accesed 09/09/2013.

United Nations Environmental Program (UNEP). 1999. United Nations Environmental Program Global Environmental Outlook. GEO-2000. www.unep.org/geo2000/.

United Nations. 2012. The future we want. Sustainable Development Kowledge Platform. A/RES/66/288. http://sustainabledevelopment.un.org/index.php?menu=1298. Accessed 09/04/2013.

van Kerkhoff, L.and L. Lebel. 2006. Linking knowledge and action for sustainable development. Annu. Rev. Environ. Resour. 31:445–77

World Bank Group. 2013. Managing forest resources for sustainable development: An evaluation of World Bank Group experience. http://ieg.worldbank.org/Data/reports/chapters/forest_eval.pdf

WWF. 2013. Assessing the impact of conservation. http://www.worldwildlife.org/initiatives/assessing-the-impact-of-conservation.

Yin, R. K. 2009. *Case study research: Design and methods* (Vol. 5). Sage.

Zingales, L. 2014. Preventing Economists' Capture. CEPR Discussion Paper No. DP9867. Available at SSRN: http://ssrn.com/abstract=2444888. Accessded 09/11/14.

TABLE 4.1**.** Standard-setting/certifying NGOs with an environmental focus that are full members of the International Social and Environmental Accreditation and Labeling Alliance. (ISEAL). * Organizations selected for case studies.

Organization	Mission	Scope	Year Founded
RAINFOREST ALLIANCE (RA) *	To conserve biodiversity and ensure sustainable livelihoods by transforming land-use practices, business practices and consumer behavior.	Agriculture, Forestry, Tourism	1987
FORESTRY STEWARDSHIP COUNCIL (FSC) *	To promote environmentally sound, socially beneficial and economically prosperous management of the world's forests.	Forestry	1992
MARINE STEWARDSHIP COUNCIL (MSC)*	Contribute to the health of the world's oceans by recognizing and rewarding sustainable fishing practices, influencing the choices people make when buying seafood, and working with our partners to transform the seafood market to a sustainable basis.	Fisheries	1997
UTZ Certified	Create a world where sustainable farming is the norm.	Agriculture	1999
4C ASSOCIATION	To improve economic, social and environmental conditions for all who make a living in the coffee sector.	Coffee	2003
RESPONSIBLE JEWELRY COUNCIL	To promote responsible ethical, human rights, social and environmental practices in a transparent and accountable manner throughout the jewelry industry from mine to retail.	Mining	2004
ROUNDATBLE ON SUSTAINABLE MATERIALS	Provide and promote the global standard for socially, environmentally and economically sustainable production and conversion of biomass.	Biofuels	2007
UNION FOR ETHICAL BIO-TRADE	To promote Ethical BioTrade practices by offering members independent verification, technical support and networking opportunities for biodiversity-based innovation and sourcing.	Bio-trade	2007
EQUITABLE ORIGIN	To protect the people, environment and biodiversity affected by oil and gas exploration and production through an independent, stakeholder-negotiated, market-driven certification system	Oil and Gas Exploration	2009
BONSUCRO	Foster the sustainability of the sugarcane sector through a metric-based certification scheme and by supporting continuous improvement for members.	Sugarcane	2011

Table 4.2. Sustainability Certification at the Forefront of International Conservation
NGOs involved in sustainability certification include those that set voluntary sustainability standards, such as the Sustainable Agriculture Network and the Forestry Stewardship Council, as well certification bodies, such as the Rainforest Alliance and UTZ. They emerged from initiatives in the early 1990's to address the weaknesses of international regulatory tools for the sustainable production and harvest of highly valued products such as fisheries, timber, and coffee (McCormick, 1999, Auld et al. 2008,). These organizations represent a new form of governance, where experts from different sectors of society outline social and environmental best management practices that are voluntarily applied by producers on an international scale. Items produced in compliance with such standards are marketed as "sustainable" to environmentally conscious consumers who, through their purchases, support the implementation and maintenance of such initiatives (Barry et al. 2012). Voluntary sustainability standards often link the three pillars of sustainability: economic, social, and environmental wellbeing, as defined in the Brundtland Report (UN 1987). By incorporating social and economic aspects into their core missions, NGOs promoting comprehensive standards are well suited to tackle complex environmental challenges of global scope (Milder et al. 2014). This is particularly important in an era where rapidly expanding human populations demand conservation strategies beyond the traditional "reserves" model, in order to include sustainable development initiatives that allow emerging economies to thrive while safeguarding their natural assets (Schwartzman et al. 2000, United Nations 2012).

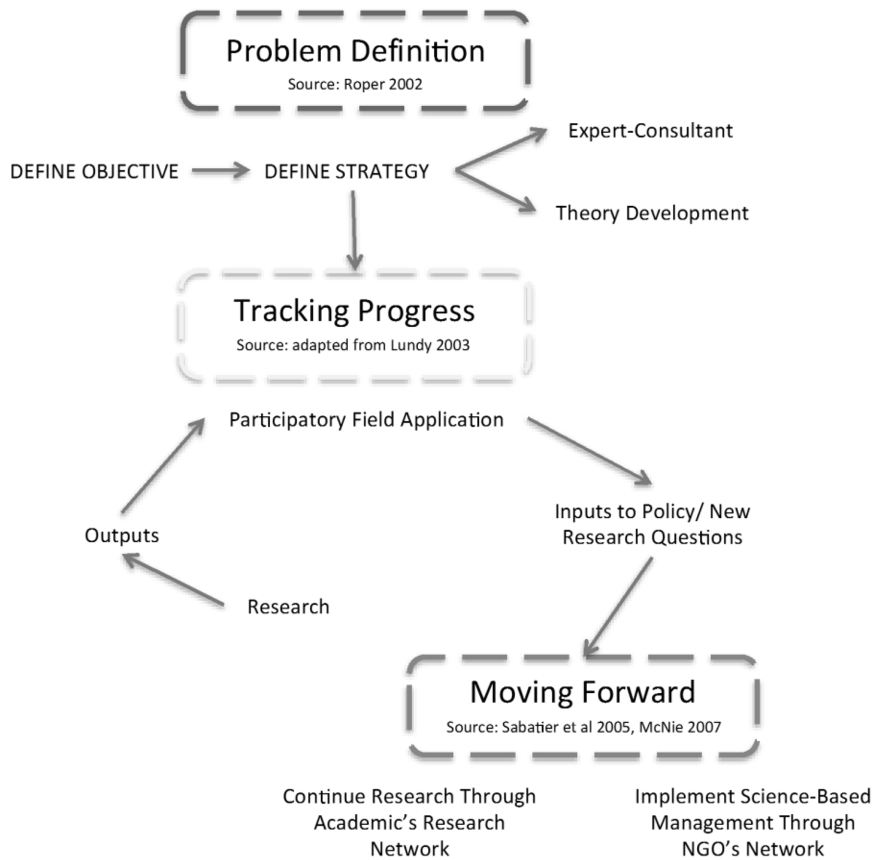


FIGURE 4.1. Framework for navigating NGO-Academia partnerships. This proposed framework broadly build ups on insights from Clark and Holliday 2006. Individual steps incorporate work by Roper 2002, Lundy 2003, Sabatier et al. 2005 and McNie 2007.

Table 4.3. Background of Collaborative Partnership between the University of Georgia's (UGA) Odum School of Ecology and the Rainforest Alliance

The linkage between the Rainforest Alliance (RA) and UGA was facilitated by an existing professional relationship between a faculty member of the Odum School of Ecology (Pringle, C. P) and the then Research Coordinator for RA. RA is an organization that certifies compliance with sustainability standards in the forestry, agriculture and carbon/climate sectors, and runs the oldest (Table 1) and one of fastest growing (Giovannucci et al. 2008) certification programs worldwide. Given RA's growing interest in "results based standards" (Crosse 2012), in 2009 it approached the Odum School of Ecology (OSE) at UGA for assistance in creating a strategy to evaluate the role of its agriculture certification program in advancing freshwater conservation. Aquatic Ecology constitutes one of the five core areas of expertise within OSE (OSE 2013), and it is also a research field that has suffered from limited information transfer between academia and practice (Hart et al. 2010). This is particularly true in the tropics, where freshwater resources have been historically under-studied and science-based freshwater regulations are limited (Anderson and Maldonado-Ocampo 2011, Dudgeon 2011). Given RA's prominent role in the tropics, we saw our partnership as an opportunity to advance tropical stream research and conservation. Research supported by this partnership was incorporated into the PhD Dissertation project of the first author of this article (de Jesús Crespo, R.). Here we document the activities and outcomes that have taken place during five years of partnership using our collaborative framework (Figure 1).

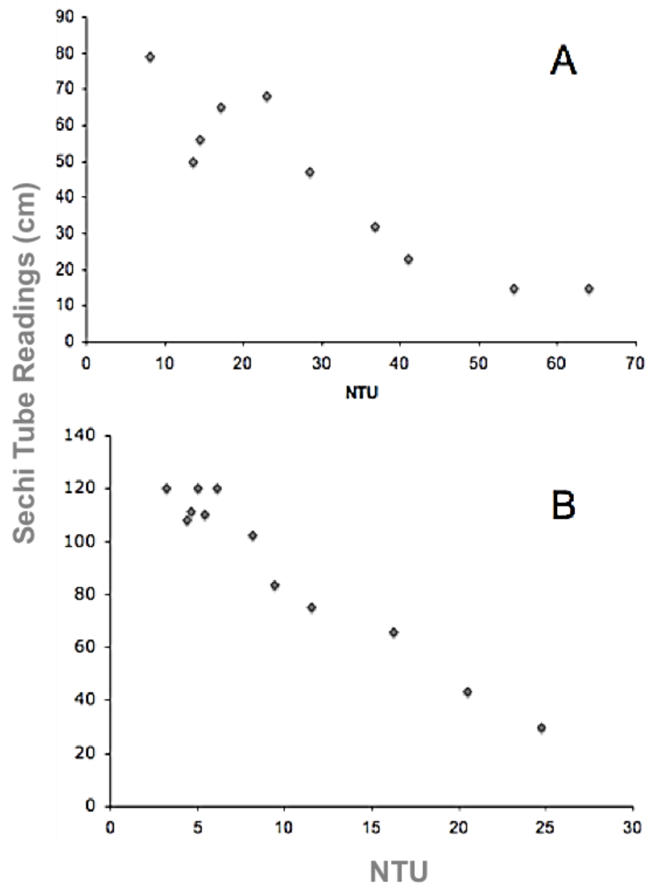


FIGURE 4.2. Correlations between NTU readings from a probe and water clarity readings from a Secchi tube in Ghana (A; R^2=0.49, p<0.009, N=11) and Costa Rica (B; R^2=0.95, p<0.001, N=12). Note lower Secchi tube readings and higher NTU values both indicate high turbidity.

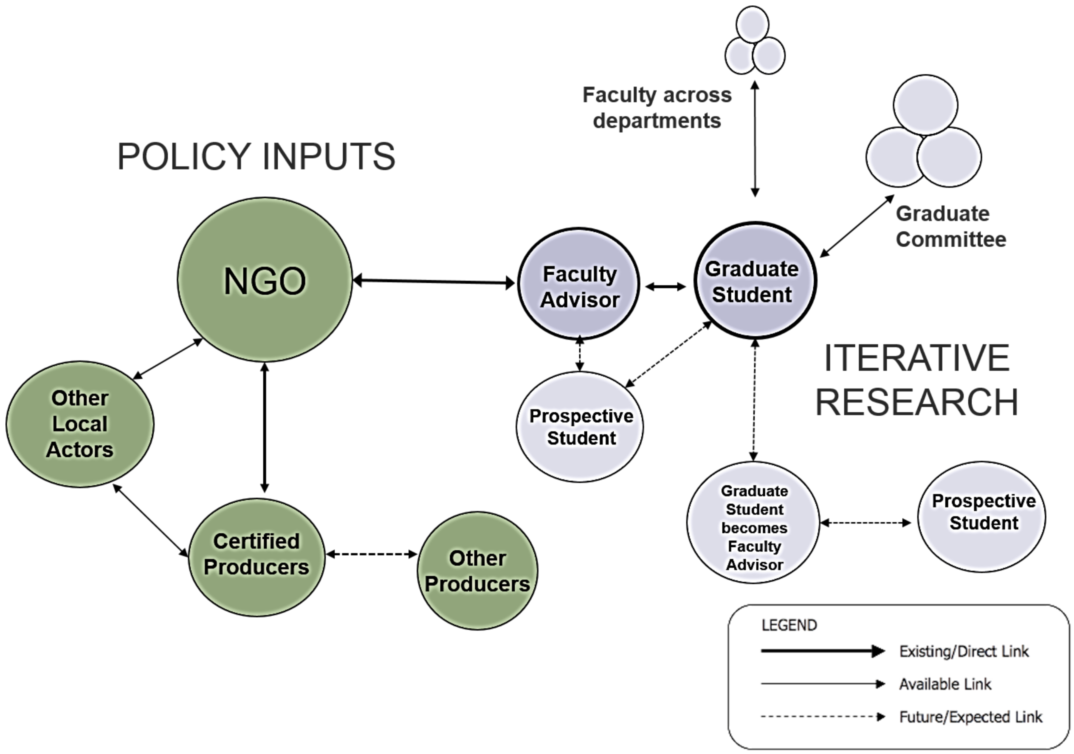


FIGURE 4.3. Network of NGO-Academia partnerships with graduate students as strategic partners for enabling iterative research, and NGOs that provide sustainability certifications as bridges between research and policy within certified regions.

APPENDIX 4.1. Farm, Stream and Watershed (FSW) assessment protocol

Contents

Farm Survey

a. Management Survey:

   i. Has the farm implemented any of the following water and soil conservation measures? Mark all that apply

      1. Drip irrigation
      2. Mulching or planted soil cover
      3. Water catchments (rainwater cisterns)
      4. Low-water pulping systems
      5. Check dams
      6. Drainage channels or diversion ditches
      7. Soil ridges around plants
      8. Contour planting and terracing
      9. Live fences (i.e. trees and shrubs)
      10. Prohibition of cropping and of keeping animals close to natural water sources
      11. Other: Please Specify

   ii. What measures has the farm undertaken during the past production year to prevent water contamination?

      1. Equipment for biocide application cleaned in designated areas away from water sources
      2. Ensuring that untreated water from cocoa processing does not enter water bodies
      3. Other: Please specify:

b. Agrochemical Application:

   i. List the agrochemicals that the farm uses most frequently. This could be done by interviewing the farmer or by looking at existing certification documents.

   ii. Determine the details of the agrochemical application:

      1. How often?
      2. How much?

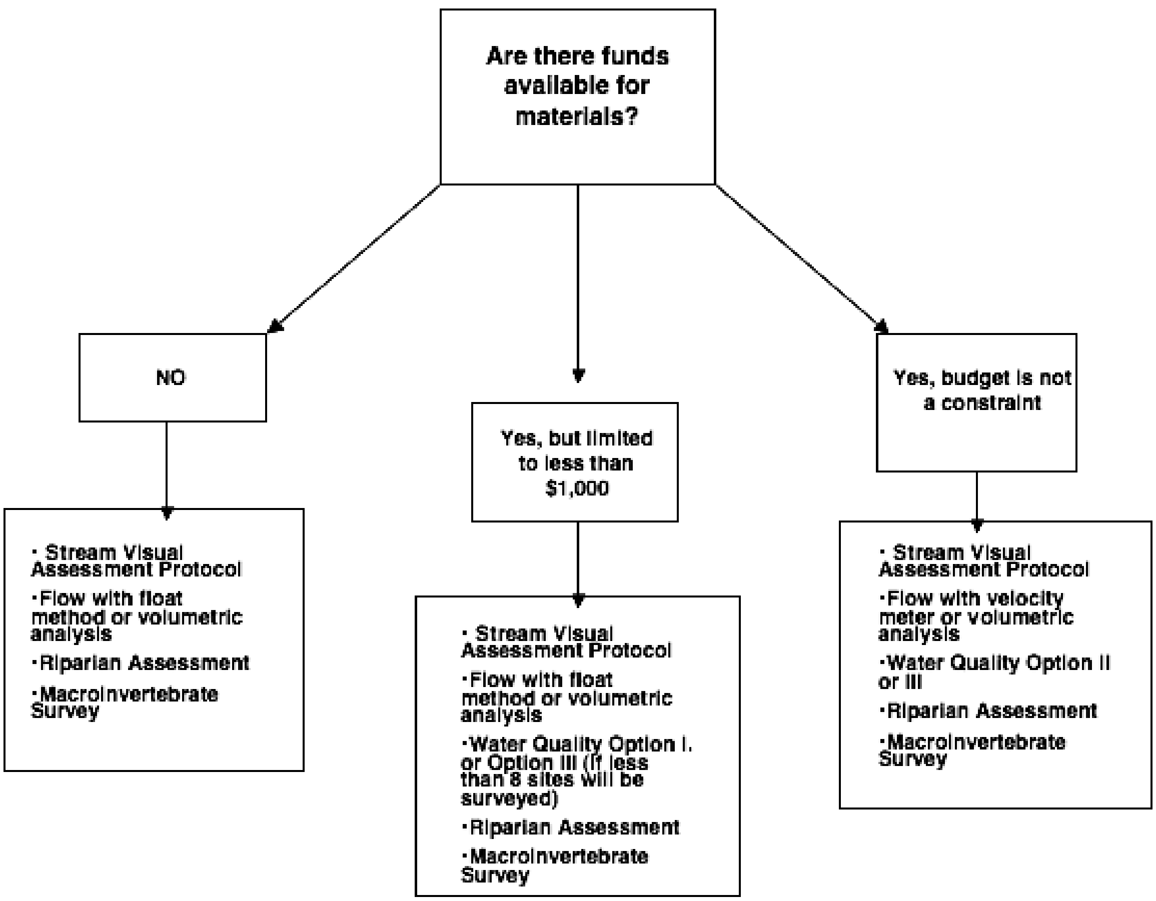
3. Are the agrochemicals applied all through the year, during the rainy season or during the dry season?

(In general the more frequent application and/or the greater the quantity applied, the greater the impact. Also, timing of application matters.)

c. Waste Water Disposal:
    i. Identify the location where waste water is disposed:
        1. Is the wastewater disposed into a retention pond?
        2. If so, is the pond being adequately maintained? If it is overflowing with sediment or wastes or if it has significant algae growth, then the pond needs more maintenance.
        3. If the water is disposed directly into a stream, note the characteristics of that wastewater:
            a. Does it smell?
            b. Does it have color?
            c. Are there large solids being discarded into the stream?

Stream Assessment

Apply the methods described below on a length of stream (reach) that is 12 times the active channel width. For example if the stream is 1m wide, then assess a 12m long reach. The stream assessment consists of four parts: 1) visual assessment, 2) water analysis, 3) riparian assessment and 4) macroinvertebrate survey. We provide several options based on availability of funds for materials. The chart below should help you decide which option is right for the project at hand.



A. Stream Visual Assessment Protocol:

Apply the USDA Stream Visual Assessment (SVAP) (USDA-NRCS 1998, USDA-NRCS 2009) to visually estimate the condition of the stream. If you are applying this tool in the tropics, you can apply the adaptations made for Costa Rica by Mafla-Herrera (2005), or the Hawaii SVAP (USDA-NRCS 2001)

B. Water Analysis:

For the water analysis we chose parameters used by the US EPA for monitoring of surface waters (http://water.epa.gov/type/rsl/monitoring/vms50.cfm). We provide three options based on level of detail and budget availability. All these options require baseline information from a reference site within the same eco-region where the study sites are located. The water quality options are:

1. **General Field Based Method**: this option can be used when there are limited funds available and many sites need to be sampled. It includes methods to measure stream flow and water quality using low budget options. The water quality parameters suggested are temperature, turbidity and conductivity. Turbidity provides information about erosion and sedimentation problems. Conductivity measures the ability of water to pass an electrical current. Increases in dissolved ions such as nitrate and phosphate increases conductivity level, providing a good proxy for agrochemical pollution.

2. **Detailed Field Based Method**: this option also includes methods to measure stream flow and water quality. It can be used when there is greater fund availability, many sites need to be sampled and a greater level of detail is needed. The water quality parameters suggested are turbidity, conductivity, nitrogen, phosphorus, dissolved oxygen, and temperature.

3. **Detailed Field and Laboratory method**: this option may be used when there is low fund availability and not many sites need to be surveyed, or when many sites need to be surveyed and there are enough funds available. It consists of a field component in which you measure stream flow choosing either one of the methods suggested for the field based options and collecting water samples for analysis in a laboratory. Specifications on how to collect store and send samples for analysis vary by laboratory and parameter. We will not discuss this method further on this document but more information can be found through the University of Georgia Cooperative Extension Service (http://aesl.ces.uga.edu/FeeSchedule.pdf).

C. Sample Frequency

Water quality and quantity varies through time. To get a good estimate of the conditions of a site, water quality and quantity need to be assessed several times through the year. Sampling events need to be programmed taking the natural hydrology of the system into account (Figure 1). To get an accurate estimate of water quality of a stream within this region, we should measure water quality during the following times:

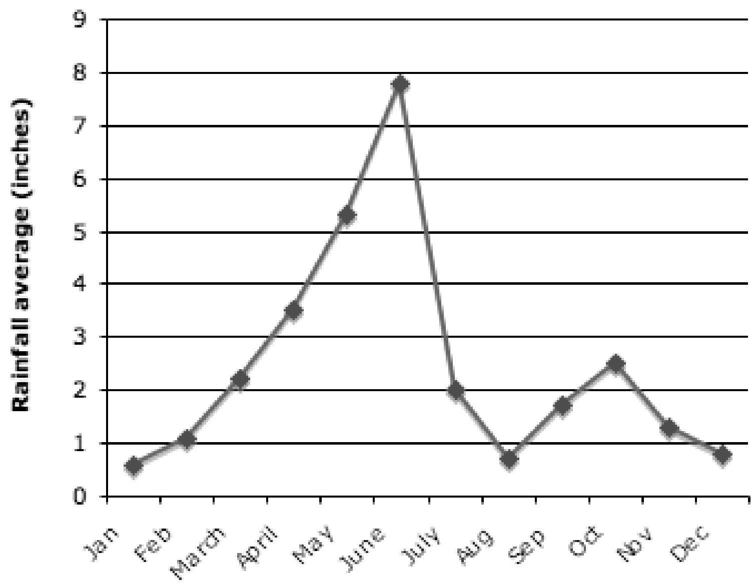


Figure 1. Average annual rainfall in Accra,Ghana (2012) (http://www.ghanaweb.com/GhanaHomePage/geography/climate.php).

A) **Baseflow** During this part of the year there should be high solute concentration due to low flow. In this case this would be around January.

B) **Onset of the rainy season**. This sampling event is very important, as it is when most of the solutes in the soil are washed away for the first time to the stream. After this event, runoff coming to the stream will have less pollutant concentration. In this case it would be around May, ideally the sampling should take place after the first big storm event of the rainy season.

C) **End of the rainy season**. By this time solutes are in low concentration as they have been washed out by rain events and there is still a lot of water within the stream. In this case it would be around November.

Many countries have data on rainfall patterns available to help inform this decision. In the case where this is not an option, interviewing locals about seasonality would provide similar information for this purpose.

Water Quality: General Field Based Method

This option can be used when there are limited funds available and many sites need to be sampled. It includes methods to measure stream flow and water quality using low budget options. The water quality parameters suggested are temperature, turbidity and conductivity. Turbidity provides information about erosion and sedimentation problems. Conductivity measures the ability of water to pass an electrical current. Increases in dissolved ions such as nitrate and phosphate increases conductivity level, providing a good proxy for agrochemical pollution.

Discharge

Materials Needed:

1. Flagging tape
2. Meter tape
3. Meter stick
4. Orange peel or ping pall ball (if using float method)
5. Container of known volume (if using volumetric analysis)
6. Calculator
7. Stopwatch

a. Cross Section

4. Select the spot of the reach of deepest and fastest flow. Mark this spot with a flagging tape for reference in future occasions. Measure the active channel width with a meter tape. The width is __________________
5. Divide that width into ten equally spaced cells.
6. On each cell measure width and depth.

b. Velocity

ii. Float Method

1. Mark two points, three channel widths apart, at the fastest flowing area within the channel cross section.

2. One person tosses the float (orange peel, ping pong ball) at the upstream point. The downstream observer tracks the time it takes the float to travel to that point. Repeat 3-5 times and average the results.

3. Divide the resulting time over the distance travel to get velocity in ft^3/s. Multiply that number for a roughness adjustment coefficient of 0.8.

iii. Volumetric Analysis; for streams that are two shallow for the float method (Kaufmann 1998)

1. Select a cross section with a natural spillway that collects the entire stream flow. A temporary spillway may also be constructed with plastic sheets.

2. Record the time it takes in for the water to fill a known volume of water (a graduated bucket for example). Divide the volume by the time in ft^3/s to get velocity. Multiply that number for a roughness adjustment coefficient of 0.8.

THIS IS THE END OF THE FIELD PORTION

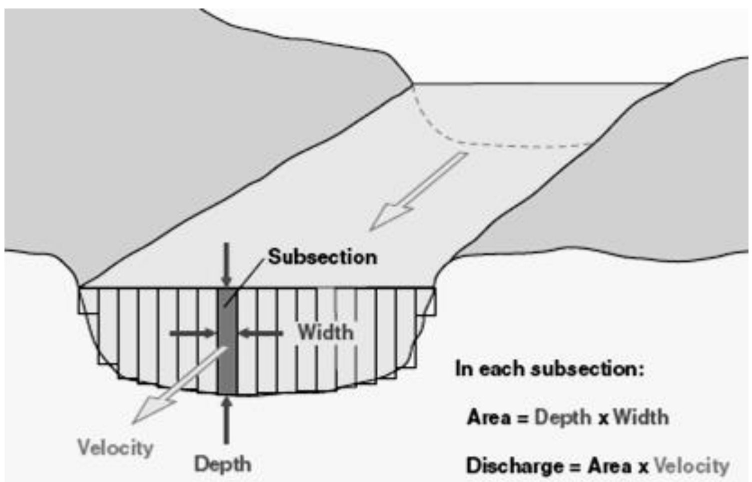


Figure 2. Example of how to conduct discharge assessment. Image was obtained at the following website: http://ga.water.usgs.gov/edu/streamflow2.html. Note that here they use more cells. For this protocol we will only use 10.

Table 1. Discharge Data Sheet

Cell	Width	Depth	Velocity	cell Q
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
StreamQ				**Σ=**

Office portion of discharge measurements:

1. Calculate the discharge on each cell with the formula: CellQ= (width*depth)*velocity
2. With this information, calculate the discharge for the entire stream as follows: StreamQ=Σ(CellQ)

Answer: 1) Is there enough flow to maintain habitat for species? 2) Is the water flowing or is it stagnant through most of the stream? 3) Is there a different trend upstream of the hydrologic alteration?

Water Quality Analysis

Materials Needed:

1. Water clarity tube
2. Conductivity+Temperature meter/probe

Procedure

1. Select three locations across the stream reach. **Each of these locations should be located under a shaded area of the stream.**
2. On each location measure the following parameters:
    a. **Turbidity**: Fill the water clarity tube all the way to the top. Slowly release some of the water by opening the valve at the bottom. Stop the water release when you are able to see the sechi disc at the bottom of the tube. Write down the level of water still in the tube in cm. The greater the number the clearer the water and thus the lower the turbidity
    b. **Conductivity and Temperature**: Measure using an automated probe such as the following: http://www.forestry-suppliers.com/product_pages/Products.asp?mi=78911&itemnum=76496.
3. Average your results for each of the three locations.

Table 2. Water Quality Data Sheet

Parameter	Location 1	Location 2	Location 3	Average
Turbidity				
Conductivity				
Temperature				

Conduct analysis three times a year: base-flow, start of the rainy season and end of the rainy season.

Water Quality: Detailed Field Based Method

This option also includes methods to measure stream flow and water quality. It can be used when there is greater fund availability, many sites need to be sampled and a greater level of detail is needed. The water quality parameters suggested are turbidity, conductivity, nitrogen, phosphorus, pH, dissolved oxygen, and temperature.

Discharge

Materials Needed:

1. Flagging tape
2. Meter tape
3. Meter stick
4. Velocity meter
5. Calculator
6. Stopwatch

Procedure (Gore 1998)

1. Select the spot of the reach of deepest and fastest flow. Mark this spot with a flagging tape for reference in future occasions. Measure the active channel width with a meter tape. The width is __________________
2. Divide that width into ten equally spaced cells.
3. On each cell measure width, depth and velocity. Velocity should be measured using a velocity meter at around mid-depth.

THIS IS THE END OF THE FIELD PORTION (See Figure 1 and Table 1 to collect and enter data).

Water Quality Analysis

Materials Needed:

1. Multi-parameter Probe with the following meters:
    a. Optical DO
    b. pH
    c. Turbidity
    d. Conductivity
    e. Temperature
    f. NH_4 & NO_3
2. Calibrating Solutions for each meter.

Procedure:

Select three locations across the stream reach. Each of these locations should be located under a shaded area of the stream. The selected locations should also be deep enough to completely submerge the probes. Avoid areas with high turbulence.

Table 3. Water Quality Data Sheet

Parameter	**Location 1**	**Location 2**	**Location 3**	**Average**
Temperature				
Ammonia NH_4				
Nitrate NO3				
Dissolved Oxygen				
pH				
Conductivity				
Turbidity				

Estimated Budget

Table 3. Estimate for Water Quality Option II Detailed Field Analysis		
	Estimated Cost	Details
Data Logger with Conductivity and Temperature Probes	$4,758.00	YSI 6820-02 and conductivity calibrating solution YSI 060911
Turbidity	$1,890.00	YSI 606136 probe and calibrating solution YSI 607300
Oxygen	$580.00	YSI 6450 Anti-fouling ROX Optical Dissolved Oxygen Sensor
pH	$365.00	YSI 006565 probe
Nitrogen	$1,030.00	YSI 006883 ammonia probe, YSI 006884 nitrate probe, YSI 003842 ammonia calibrating solution, YSI 003886 nitrate calibrating solution
Memory logger and field cable	$2,720.00	YSI 650 and YSI 6091
Estimated Total		**$11,343.00**
Note: This estimate is a one-time investment, except in the case where parts or calibrating solutions need to be replaced. For example, Nitrogen probes expire after six months of use.		

Water Quality: Detailed Field and Laboratory Method

This option may be used when there is low fund availability and not many sites need to be surveyed, or when many sites need to be surveyed and there are enough funds available. It consists of a field component in which you measure stream flow choosing either one of the methods suggested for the field based options and collecting water samples for analysis in a laboratory. Specifications on how to collect store and send samples for analysis vary by laboratory and parameter. We will not discuss this method further on this document but more information can be found through the University of Georgia Cooperative Extension Service (http://aesl.ces.uga.edu/FeeSchedule.pdf). An estimate of the budget needed to conduct this type of assessment is detailed in the chart below.

Estimated Budget

Table 4. Estimate for Water Quality Option III Detailed Field/Laboratory Analysis

	Estimated Cost	Details
Turbidity	$14.00	Costs estimates are per sample, analyzed at the University of Georgia Cooperative Extension Service (http://aesl.ces.uga.edu/FeeSchedule.pdf). Shipping costs are not included.
Conductivity	$12.00	
Nitrogen	$10.00	
Phosphorus	$14.00	
Fecal Coliforms	$40.00	
Biochemical Oxygen Demand	$30.00	
Estimated Total		$120.00/per sample

Riparian Zone Assessment

Materials Needed

1. Concave densiometer
2. Meter tape
3. Clinometer
    a. Select three points across the stream reach (A:downstream, B:midstream, C:upstream).
    b. On each point measure canopy cover with a concave densiometer

(four cardinal points), bank slope with a clinometer (once left and once right), and riparian width (once left and once right). If the banks are steep, or the vegetation is difficult to access, measure 5m on each side of the bank and mark it with flagging tape. Based on that visually estimate the width. Also estimate: percent of invasive weeds on each side, percent of exposed soil on each side and count the number of large trees within a five meter radius.

Table 5. Riparian assessment data sheet

Points	Canopy Cover	%Slope	Riparian Width	%Weeds	%Exposed Soil	# Large Trees
A downstream	1. 2. 3. 4. avg_____	Right _______ Left ________	Right _______ Left ________	Right _______ Left _______	Right _______ Left ________	
B midstream	1. 2. 3. 4. avg_____	Right _______ Left ________	Right _______ Left ________	Right _______ Left _______	Right _______ Left ________	
C upstream	1. 2. 3. 4. avg_____	Right _______ Left ________	Right _______ Left ________	Right _______ Left _______	Right _______ Left ________	

Macroinvertebrate Assessment

Materials needed:

1. D-net
2. 70% ethanol
3. Vials
4. Forceps
5. Stopwatch
6. Calculator
7. White tray
8. Carson®magniscope or stereoscope
   a. Walk across the reach and determine the types of habitat present (e.g. leaf packs, macrophytes riffles, pools). Using a D-net collect macroinvertebrates from each habitat. Place on a vial with 70% alcohol.
   b. Repeat until 100 individuals have been collected or 1 hour has passed.

Office Portion of Macroinvertebrate Assessment

c. Place insects on a white tray; identify them to family level using a Carson®magniscope or a stereoscope when available. We include some common families in the guide below, and recommend supplementing with Merritt and Cummins 1996.

d. Count how many of each family you find. Determine each family's BMWP and FBI scores. We include some sample scores in the guide below, and recommend supplementing with Hilssenhoff 1988 and Hawkes 1998. Write that information in Table 1 (below).

e. Calculate the site's BMWP index by summing all the BMWP scores.

f. Calculate the site's Family Biotic Index with the formula:

$$\Sigma = \text{FBI score} * n / N$$

where n= is the number of individuals from that family and N=total number of individuals collected

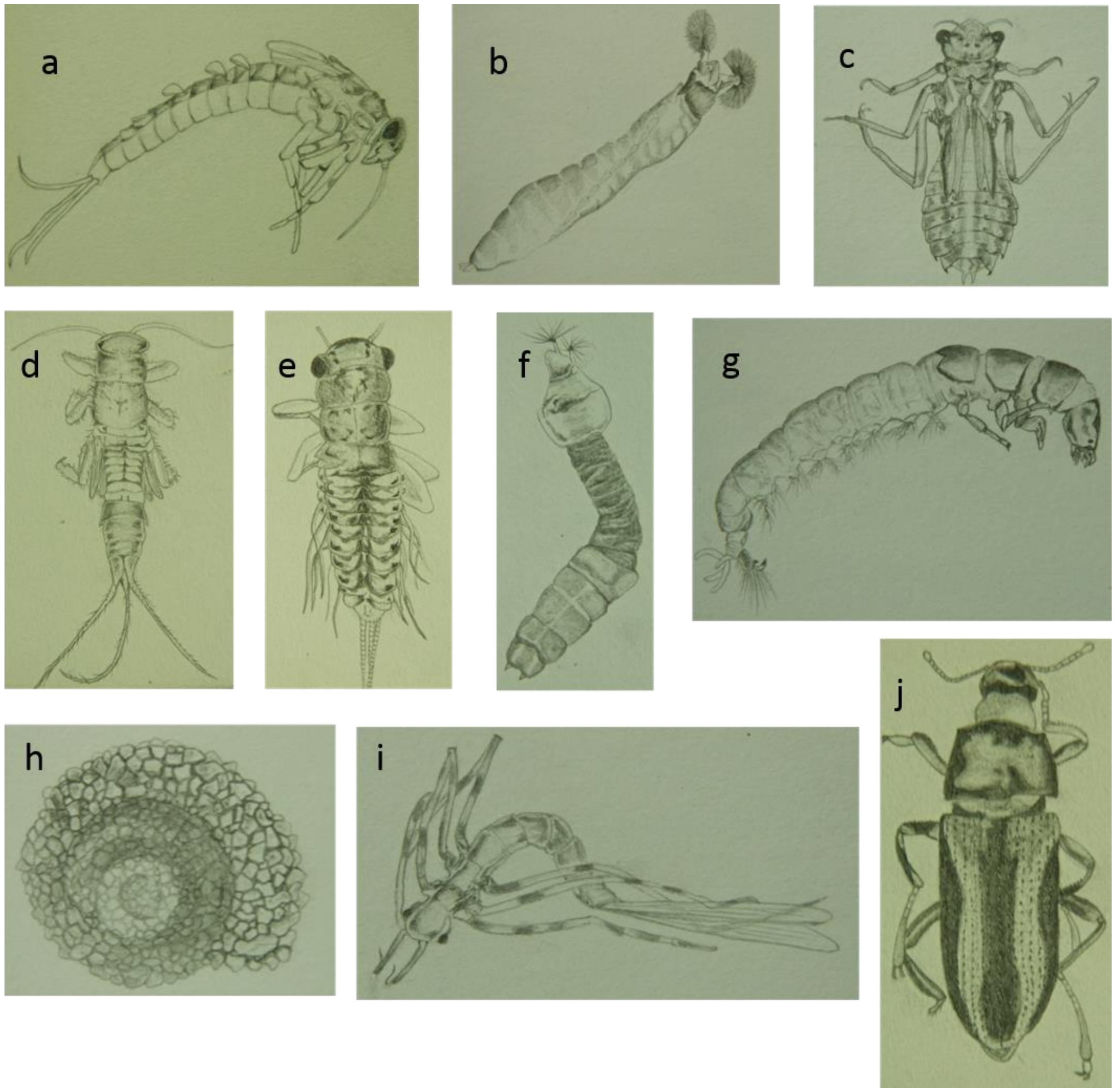
Table 6. Macroinvertebrate Data Sheet

Family	#	BMWP Score	FBI Score	FBI score*n/ N
N:Σ (n)				
BMWP				
FBI				

Is the site dominated by pollution tolerant or pollution sensitive taxa? (i.e. BMWP < 100; FBI >5) .

GUIDE FOR COFFEE STREAMS

Common macroinvertebrate families in streams draining coffee farms (Drawings by Viviana Gonzalez©)



a. Baetidae (Ephemeroptera): FBI (4), BMWP (4)
b. Simuliidae (Diptera) FBI (6), BMWP (5)
c. Libellulidae (Odonata) FBI (9), BMWP (8)
d. Leptohyphidae (Ephemeroptera) FBI (4), BMWP (5)
e. Leptophlebiidae (Ephemeroptera) FBI (2), BMWP (10)
f. Tipuliidae (Diptera) FBI (3), BMWP (5)
g. Hydropsychidae (Trichoptera) FBI (4), BMWP (5)
h. Helicopsychidae (Trichptera) FBI (3), BMWP (10)
i. Calopterygidae (Odonata) FBI (5), BMWP (8)
j. Elmidae (Coleoptera) FBI (4), BMWP (5)

Watershed Evaluation

Materials needed

1. Arc-GIS software
2. A **GPS point** of the stream under evaluation
3. High resolution **Digital Elevation Models** of the region around your GPS point. For most places around the word these are available for free on the following websites

a. http://gcmd.nasa.gov/records/GCMD_NCAR_DS758.0.html

b. http://asterweb.jpl.nasa.gov/gdem.asp

Step 1: Locate Stream:

Determine the position of the stream with respect to its surrounding landscape using a **GPS-device. Upload that point into Arc-GIS or a similar geographical analysis tool if possible. If not possible, load the GPS point in Google Earth.**

Step 2A: Landscape Description Using GIS:

i. Delineate the stream's basin area using the Spatial Analyst tool in **Arc-GIS and Digital Elevation Models** (details in Appendix 4.1.a)

ii. Evaluate the types of landuse upstream of the stream. Determine which type of land use could impact the stream the most and whether the stream assessment reflects this impact. If evaluating agroforestry systems, estimate the percent of shade tree cover in the certified farms.

Step 2B: Landscape Analysis Using Google Earth:

iii. Estimate the stream's basin area by turning on the *terrain* tool in Google Earth and noting the water divides upstream of the GPS point. Outline the divide that drains into the stream.

iv. Evaluate the types of landuse within the estimated watershed area. Determine which type of land use could impact the stream the most and whether the stream assessment reflects this impact. If evaluating agroforestry systems, estimate the percent of shade tree cover in the certified farms.

References

Dixon, I., Douglas, M., Dowe, J. and Burrows, D. 2006, 'Tropical Rapid Appraisal of Riparian Condition Version 1 (for use in tropical savannas)', River Management Technical Guideline No. 7, Land & Water Australia, Canberra.

Gore, A.J. 1998. Discharge measurements and stream flow analysis. In: Methods in Stream Ecology. Hauer F.R and G.A. Lamberty (eds.). 2nd edition. Academic Press. Burlington, MA.

Hawkes, H. A. (1998). Origin and development of the biological monitoring working party score system. Water Research, 32(3), 964-968.

Hilsenhoff, W. L. (1988). Rapid field assessment of organic pollution with a family-level biotic index. Journal of the North American Benthological Society, 65-68.

Kaufmann, P.R. Stream Discharge. In: Environmental monitoring and assessment program-surface waters. Field operations and methods for measuring the ecological of wadeable streams. Lazorchak, J.M., D.J. Klemm. and D.V. Peck. (eds.). EPA/620/R-94/004F. http://www.epa.gov/emap/html/pubs/docs/groupdocs/surfwatr/field/Sec06.PDF.

Merritt, R. W., & Cummins, K. W. (Eds.). (1996). An introduction to the aquatic insects of North America. Kendall Hunt.

Mueller, D.K., and N.E. Spahr. 2005. Water-quality, streamflow, and ancillary data for nutrients in streams and rivers across the nation, 1992-2001: U.S. Geological Survey data series 152. http://pubs.usgs.gov/ds/2005/152/

Rowe, M, D. Essig and B.Jessup. 2003. Guide to Selection of Sediment Targets for Use in Idaho TMDLs.

http://water.epa.gov/scitech/swguidance/standards/criteria/aqlife/pollutants/sediment/upload/2004_08_17_criteria_sediment_appendix5.pdf

US Department of Agriculture – Natural Resource and Conservation Service (USDA-NRCS). 1998. *Stream visual assessment protocol*. NWCC-TN-99-1. National Water and Climate Center: Portland, OR.

US Department of Agriculture, Natural Resource and Conservation Service (USDA-NRCS). Hawaii Stream Visual Assessment Protocol. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_036776.pdf. Accessed 03/30/2015

US Department of Agriculture, Natural Resource and Conservation Service (USDA-NRCS). 2009. Stream visual assessment protocol Version 2. 190–VI–NBH, Amend. 3, December 2009. National Biology Handbook. Subpart B: Conservation Planning. Aquatic and Terrestrial Habitat Resources

Appendix 4.1.a Watershed Delineation Protocol

A watershed is an area defined by a topographic boundary that diverts all runoff to a single outlet. The delineation of watersheds can be done manually using topographic maps, or electronically, using Digital Elevation Models (DEMs). Using DEMs, the drainage boundaries, and the associated stream network can be determined in a relatively straightforward way. This document will guide you through the steps to follow in Arc-GIS to achieve this **(**adapted from Heppinstall 2011).

Materials Needed:

1. Arc-GIS software
2. A **GPS point** of the stream under evaluation
3. High resolution **Digital Elevation Models** of the region around your GPS point. For most places around the word these are available for free on the following websites
    a. http://gcmd.nasa.gov/records/GCMD_NCAR_DS758.0.html
    b. http://asterweb.jpl.nasa.gov/gdem.asp

Note: Make sure that your DEM and GPS point are in the same coordinate system. If they are not, project one or the other.

Step 1: Prepare the DEM

Once you have downloaded the DEM layers from the suggested websites, save them in Arc Catalog and then open them using Arc Map. You may have noticed that DEMs come in pieces or "tiles" and that sometimes you need more than one tile to cover your study area. If this is the case, you need to follow these steps to combine your tiles and correct for any missing spaces between them. If you are only using one tile, you may proceed to Step 2.

Navigate to: Data Management Tools → Raster → Raster Dataset → Mosaic to New Raster

- Input: the DEM tiles
- Name of the new layer: Mosaic_DEM
- Mosaic Operator: Blend
- Number of Bands: Same as base layers

Step 2: Fill the sinks

Water cannot flow across grid cells that contain a depression or "sink". Therefore you have to locate and identify these obstructions to flow so that your basin is "hydrologically" correct.

Navigate to: Spatial Analyst Tools → Hydrology → Fill.

- Input: Mosaic_DEM
- Name of the new layer: Fill
- “Z limit”: Use default

The new GRID called "Fill" will look almost identical to your original DEM, except minor depressions have been filled to enable water to flow across grid cells.

Step 3: Identify flow direction

This process establishes the flow direction within in your DEM so that the procedures that follow will be able to determine the hydrologic flow along adjacent areas.

Navigate to: Spatial Analyst Tools → Hydrology → Flow Direction tool.

- Input: Fill
- Name of the new layer: Flow_Dir

Step 4: Characterize flow accumulation

This process will create a new layer that shows the upstream portions that flow into any given area within your DEM. Different colors will appear and indicating a cumulative increase in water flow in a downstream fashion.

Navigate to: Spatial Analyst Tools → Hydrology → Flow Accumulation tool.

- Input: Flow_Dir
- Name of new layer: Flow_Acc.

The grid will likely be displayed using a ‘graduated color’ scheme. This is useful at first for finding streams since those pixels that accumulate the most flow appear the brightest.

Zoom around your ‘Flow Accumulation’ raster and use the "identify" tool to click on a single cell. The values represent the upstream cells contributing flow to this point in the basin... note how the values increase downstream.

Step 5: Define the stream network

This process will allow you to visualize streams based on their position within the network. A stream segment with no tributaries will be designated as a first-order stream. When two first-order segments join, they form a second-order stream; two second-order segments join to form a third-order segment, and so forth. This step is optional and it is not needed to conduct the next steps of the protocol. However, defining the order of a stream is helpful for decision and the establishment of management practices in the future.

First create a raster with unique values for each stream section in your linear network

Navigate to: Spatial Analyst Tools → Hydrology → Stream Link tool

- Input: Flow_Acc
- Name the new layer: Streamlink

Now to create a stream order layer:

Navigate to: Spatial Analyst Tools → Hydrology → Stream Order tool,

- Input: Streamlink
- Name the new layer: stream_order
- Method: Strahler

For future use, you can transform the stream order grid into a shapefile following these steps:

Navigate to: Spatial Analyst Tools → Hydrology → Stream to Feature tool

- Input: stream_order
- Name the new layer: stream_network

Step 6: Match your GPS point

Now you will add your GPS point to Arc Map and match it with the closest stream from your Flow_Acc layer. This step corrects for minor differences between the location given by the GPS and the output from the DEM.

Navigate to: Spatial Analyst Tools → Hydrology → Snap Pour Point tool

- Input: GPS point.
- Flow accumulation raster: Flow_Acc.
- Name the new layer: pour_snap
- Snap distance: 100 meters.

Also, to make sure the output matches your other layers, you will need to set the Output Extent. Do this by clicking on the “Environments…” button in the Snap to Pour Points tool, then click on the “General Settings” tab and select your Mosaic_DEM layer as your Output Extent.

Step 7: Delineate the Watershed

Navigate to: Spatial Analyst Tools → Hydrology → Watershed.

- Input: pour_snap
- Flow Direction Grid: Flow_Dir
- Name the new layer: watershed_x

Now you can use your watershed_x layer for land use analysis. For example, you can overlay the watershed on aerial images to estimate what percentage of the drainage area of a stream is composed of high impact land uses such as urbanization, roads, and cattle farms, among others. You can also use this boundary to determine the relative influence of a particular farm over the condition of a particular stream.

Step 8: Convert watershed_x from Raster to Shapefile

Reference

Heppinstall J. 2011. Drainage Basin Delineation and Morphometric Analysis. University of Georgia course: FANR 3800. Lab 11: Watershed Modeling.

Appendix 4.1.b Memo to the Rainforest Alliance summarizing findings of pilot studies evaluating the FSW protocol

December 22, 2013

To: Rainforest Alliance

Evaluation and Research Division

233 Broadway

New York, NY 10279 USA

From: Rebeca de Jesús-Crespo

PhD Candidate

Integrative Conservation and Ecology

The University of Georgia

140 E. Green St. Athens, GA.

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Re: Findings from collaborative projects between The University of Georgia and Rainforest Alliance to evaluate the FSW Protocol.

Since Spring 2010, I have collaborated with the Rainforest Alliance (RA) as part of a partnership between RA and Dr. Catherine Pringle's laboratory at the University of Georgia. The UGA-RA partnership focuses on evaluating monitoring tools that could be applied to determine the impact of RA's Certification Programs in protecting healthy aquatic ecosystems. As part of this initiative, I have completed the following outputs: 1) Design of a "Farm Stream and Watershed" (FSW) assessment protocol for comprehensive water quality evaluations, 2) Execution of a pilot study in Ghana to determine time and budget requirements of the FSW protocol, 3) Application of the USDA Stream Visual Assessment Protocol (SVAP) on streams in agro-forestry systems, 4) Workshop for RA auditors on the use of the SVAP.

This report includes a summary of my main findings so far related to 1) The Feasibility of the FSW protocol and 2) Precision and accuracy of the SVAP.

Feasibility of the FSW protocol

The FSW is a comprehensive methodology to assess aquatic ecosystem health using biological, physicochemical and landscape variables of streams within certified farms. In Summer 2012, I conducted a pilot study in Juabeso Ghana, to test the budgetary and time resource feasibility of applying the FSW protocol in RA monitoring projects. With the help of a RA Ghana technician, I performed the FSW protocol in 10 streams draining cocoa plantations in Ghana. For this study I applied the Option 2 water quality analysis, which is a detailed, probe-based water assessment included in the FSW protocol. My main findings from this project are the following:

1. Conducting the FSW requires approximately 2.5 hours of fieldwork per site, 1.5 hours of macroinvertebrate sorting, and 2 hours of land use analysis. It requires 2 people in the field (one with stream ecology experience), 1 person to process and identify biological samples (w. experience in macroinvertebrate taxonomy) and 1 person to conduct land use analysis (with GIS experience). Applying the other water assessments options within the FSW would not significantly change time on the field, but it could reduce costs. Therefore, when choosing a lower cost alternative, time considerations should still be taken into account.

2. The most time consuming portion of the protocol is the macroinvertebrate assessment. This option could be omitted if there are time and staff limitations. Note that macroinvertebrates provide more time integrated stream appraisals, whereas water quality measures alone represent a snapshot of one moment of water quality. **When omitting macroinvertebrates, make sure to include several water measures representative of rain patterns through the year, rather than isolated field events.**

3. The FSW protocol includes widely accepted methods for quantifying stream condition. We recommend its use for projects aimed at determining the impact of RA's certification program. However, the FSW protocol entails time, budget, and staff requirements that may not be available for water quality monitoring during audits or similar wide-ranging technical assistance interventions. For these specific circumstances, we recommend the measurement of the following variables:

    a. **Water Clarity**: Studies from coffee farms in Costa Rica suggest that turbidity is a good indicator of erosion problems through agroforestry farms including road management and reforestation practices (R^2=0.32, p=0.05; Table I). We found water clarity measures obtained from a water clarity tube correlate strongly with NTU measures from a turbidity probe (Figure 1 and 2). Therefore, we recommend the use of a water clarity tube instead, as the price difference between these two methods is significant ($60 vs >$1,000), yet they provide comparable information. The water clarity tube does not detect differences among streams with turbidities below 5 NTU's. This fact should be considered when higher accuracy is needed. However, the level of accuracy provided by the water clarity tube is sufficient in most instances, as most aquatic organisms become affected by turbidities that surpass 10 NTU (Rowe et al. 2003).

    b. **Riparian Appraisal**: Maintaining riparian health in the 5m buffer zone correlates with biological indicators (Figure 3). Emphasis should be placed on the number of riparian trees, areas of exposed soil, and canopy cover. These variables can be estimated visually in a 5m radius of the stream at three points within the length of the reach of stream under assessment. The goal should be to have about 15 trees per assessment reach (See Pilot Study Report) and have little to no exposed soil. The evaluator could complement this estimate with semi-quantitative canopy cover data from a concave densiometer (~$100). Canopy cover should ideally be > 75% in wadeable streams.

c. **SVAP:** The SVAP provides guidelines to visually detect habitat degradation, water pollution, nutrient enrichment and other impacts. It entails little to no cost and takes approximately 10 minutes to complete. It would help RA staff communicate goals and strategies to farmers in a standardized manner. Since the SVAP is a qualitative method, accuracy and precision are issues that need consideration and that we discuss in the following section.

Precision and Accuracy of the SVAP

I tested accuracy, precision and feasibility of the SVAP in order to evaluate the value of applying the tool as part of RA's water monitoring strategies. Below I provide details of these assessments and main findings.

1. **Accuracy**: To assess accuracy, I conducted the SVAP on 17 streams in coffee dominated watersheds in Costa Rica. I selected the maximum, median and minimum scoring sites to represent high, medium and low condition. I added two more sites, by selecting the median scoring site of the higher end group, and the median scoring site of the lower end group, for a total sample size of 5. I measured physicochemistry on these sites in July, October and December 2013, to represent rain variability. I also conducted a macroinvertebrate survey in July, during the onset of the rainy season. Results show good correlations between the SVAP and all physicochemical parameters (Figures 4-6). Results also show agreement between the SVAP and biological indicators (Figure 7). These results partially support the accuracy of the SVAP for conducting basic and rapid screenings of stream condition.

2. **Precision**: During the 2012 pilot study in Ghana, I compared SVAP scores provided by one RA technician and myself, on 11 streams in cocoa growing regions. These assessments where conducted after a brief introduction to the method, and without a practice stream. The scores among ratings had an average variation coefficient of 12.56% and stream classifications differed in 7 out of 11 sites. Some of these differences included sites being rated as poor by one rater and fair by another. During Fall 2013, I conducted a one-day workshop for RA auditors on how to use and apply the SVAP. The workshop took place in a coffee growing region of Costa Rica After the workshop; we practiced the use of the SVAP as a group on one stream, and then conducted the SVAP individually on another stream. To assess precision of the tool, I compared the scores provided by each participant on the individually rated site (N=10). Half of the participants rated the site as

fair and half rated the site as good. The variation coefficient among raters was 5.4%. These results suggest that more training can lead to improve consistency among raters, but that even with basic training, precision may be an issue for applying the SVAP.

3. **Feasibility**: I interviewed SVAP workshop participants in Costa Rica about their perceptions of the need, usefulness and feasibility of the SVAP during audits and technical assistance activities. **The majority agreed that having a standardized method to assess streams was "Very Necessary"** as they currently follow different strategies to assess water bodies within certified farms. **Most participants thought the SVAP was feasible to apply during audits,** and that it was easy to use after an initial training session. Some of the respondents suggested that precision on the SVAP could be improved by using a simpler stream classification system such as low medium and high, instead of poor, fair, good and excellent. This entails lumping good and fair into one category. The change may be useful, as priority for management interventions would be focused on sites rated as poor, while medium and high sites could be considered in compliance. When adapting the SVAP to this rating system, consistency among participants of the workshop increased to 100% from 50%.

4. **Recommendation**: I recommend the use of the SVAP during technical assistance and audits. Precision improves with training and practice and it is expected to increase with extended application of the tool. Applying the SVAP helps auditors and technicians use a standardized rapid and cost effective method when assessing water bodies. This tool would help RA staff identify potential problems and communicate these problems to landowners more effectively. Consistency among raters could be improved by simplifying the final classification system to High, Medium and Low for compliance purposes. However, in order to ensure accuracy, the finer rating scale should be maintained on individual assessment elements in order to detect subtle changes during long-term monitoring and when making comparisons among sites. The reliability of this scale has been supported by physicochemical and biological data from streams in Costa Rica, as well as streams through the US (Bjorkland et al. 2001) and Puerto Rico (de Jesus-Crespo and Ramirez 2011).

Additional information regarding the studies conducted during this collaborative agreement, specific data sets and additional references will be provided upon request.

Sincerely;

Rebeca de Jesús Crespo

References

- Bjorkland, R., Pringle, C. M., & Newton, B. (2001). A stream visual assessment protocol (SVAP) for riparian landowners. Environmental Monitoring and Assessment, 68(2), 99-125.
- de Jesús-Crespo, R., & Ramirez, A. (2011). The use of a Stream Visual Assessment Protocol to determine ecosystem integrity in an urban watershed in Puerto Rico. Physics and Chemistry of the Earth, Parts A/B/C, 36(12), 560-566.
- Rowe, M., Essig, D., & Jessup, B. (2003). Guide to selection of sediment targets for use in IdahoTMDLs. *Idaho Department of Environmental Quality*. *Boise, Idaho*.

TABLE 1. Landscape variables that best explained variations in NTU on a study in coffee watersheds in Costa Rica (N=12). The table includes correlation coefficients between NTU and farm management variables such as shade tree cover and dirt road density.

		NTU	%Shade	Slope	Roads(km/SqKm)	Area(SqKm)
Pearson Correlation	NTU	1.000	-.324	.474	.601	.489
	%Shade	-.324	1.000	-.339	-.541	-.322
	Slope	.474	-.339	1.000	.323	.310
	Roads(km/SqKm)	.601	-.541	.323	1.000	.896

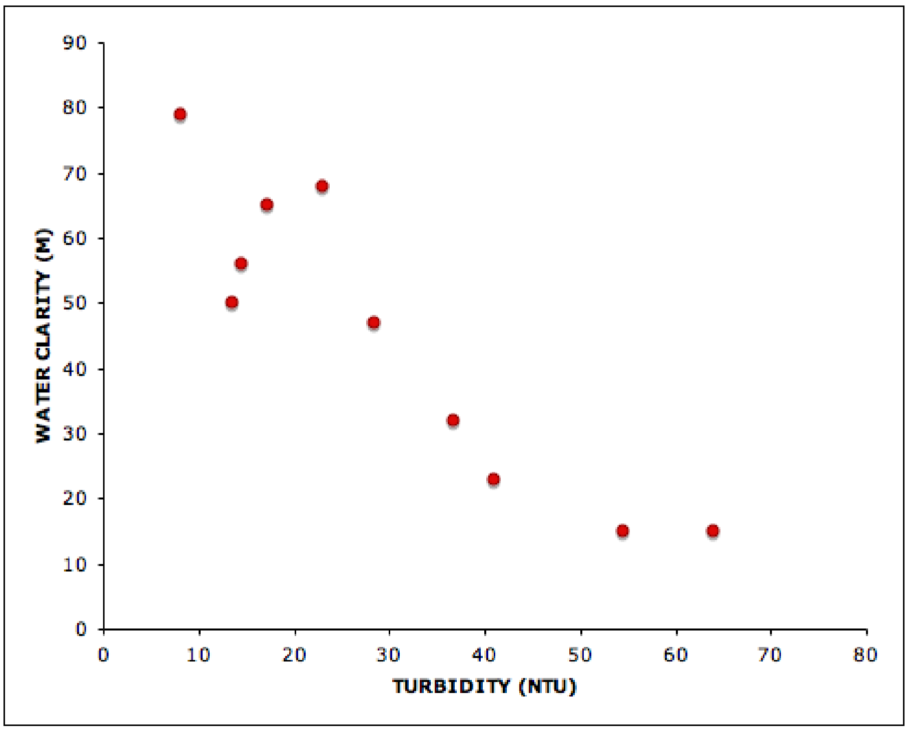

Figure 1. Turbidity measured in NTU vs Water Clarity tube readings from streams within cocoa farms in Ghana.

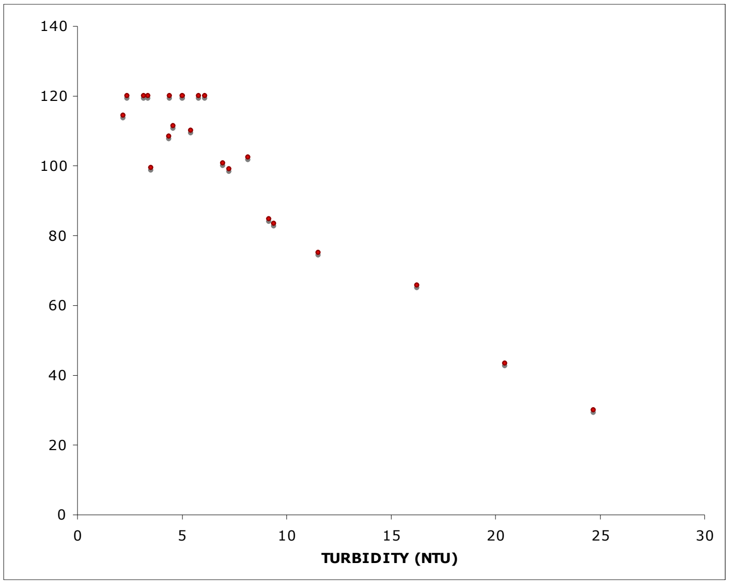

Figure 2. Turbidity measured in NTU vs Water Clarity tube readings from streams within coffee farms in Costa Rica.

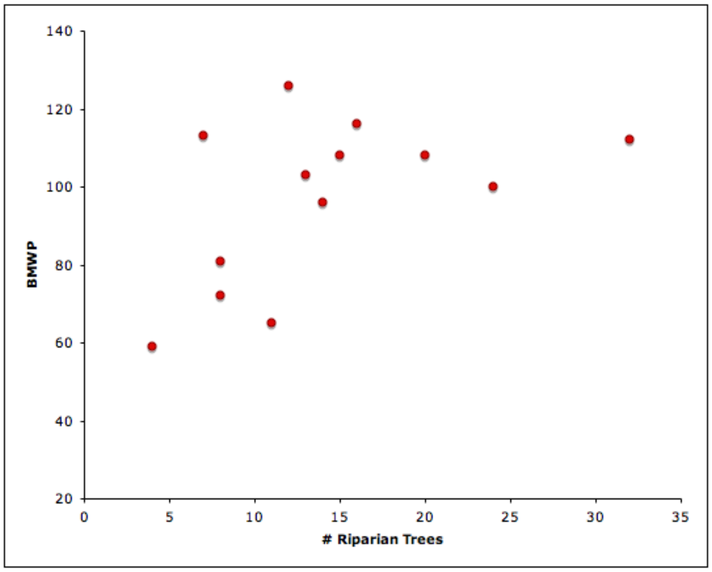

Figure 3. Correlation between Riparian trees and the BMWP index in cocoa farms in Ghana. The higher the BMWP the higher the biological integrity. Values over 100 indicate healthy streams. This can be achieved at around 15 trees per reach. Trees were counted on three separate segments and then summed. Therefore, the aim should be to have at least 5 trees on 5-m radius segments through the reach.

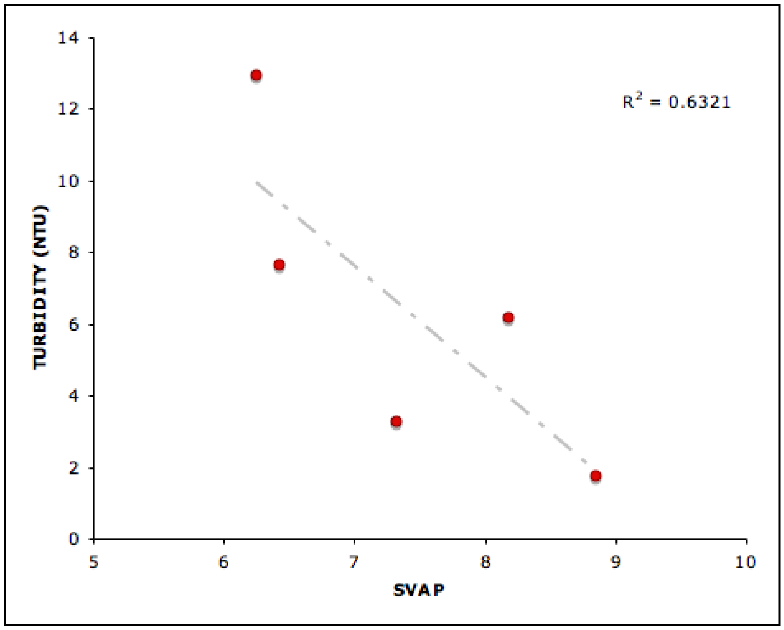

Figure 4. Higher SVAP scores correlate with lower Turbidity in Costa Rica

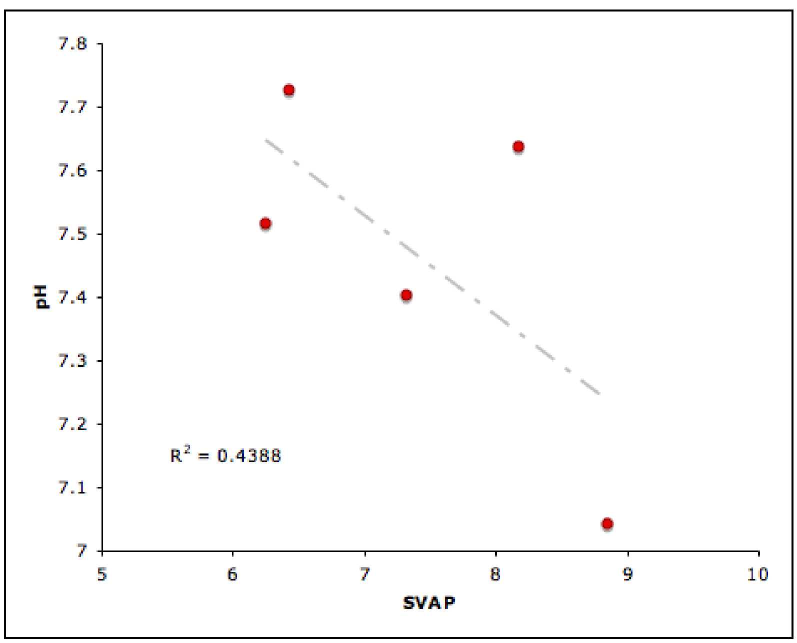

Figure 5. Higher SVAP scores correlate with more neutral pH in Costa Rica.

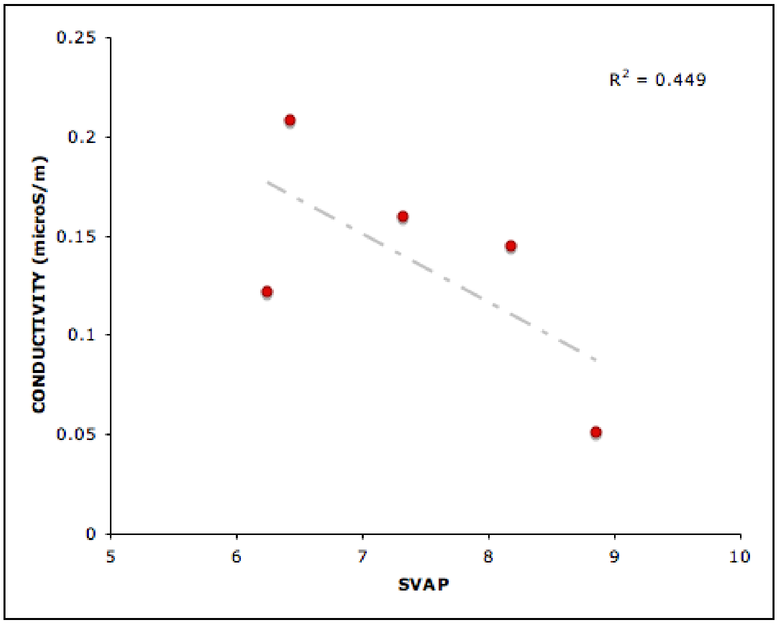

Figure 6. Higher SVAP scores correlate with lower conductivity. Conductivity is an indicator of ionic compounds in water such as agrochemical pollutants in Costa Rica.

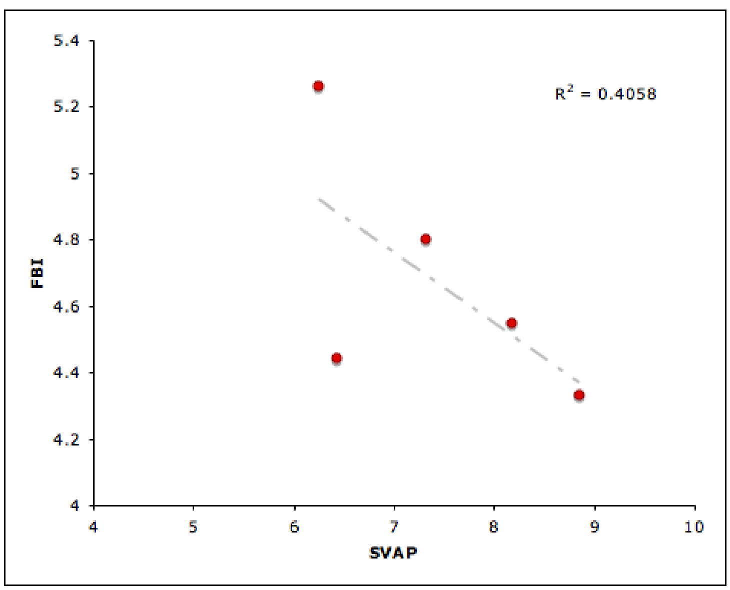

Figure 7. Higher SVAP scores correlate with lower FBI values in Costa Rica. Lower FBI values indicate lower proportion of pollution tolerant taxa, and therefore higher biological integrity.

APPENDIX 4.2. Internal Review Board Approval

The University of Georgia

Phone 706-542-3199

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Office of the Vice President for Research
Institutional Review Board

APPROVAL OF PROTOCOL

September 3, 2014

Dear Elizabeth King:

On 9/3/2014, the IRB reviewed the following submission:

Type of Review:	Initial Study
Title of Study:	Strategies for navigating NGO-Academia partnerships.
Investigator:	Elizabeth King
IRB ID:	STUDY00001080
Funding:	None
Grant ID:	None

The IRB approved the protocol from 9/3/2014.

In conducting this study, you are required to follow the requirements listed in the Investigator Manual (HRP-103).

Sincerely,

Larry Nackerud, Ph.D.
University of Georgia
Institutional Review Board Chairperson

CHAPTER 5

CONCLUSIONS AND FUTURE DIRECTIONS

Through our collaborative project with the Rainforest Alliance (RA) we developed and tested monitoring tools to assess the impact of the RA certification program on tropical stream conservation. With these tools, we were able to gather baseline data about the impact of high elevation coffee agriculture on stream ecosystems and evaluate management practices to mitigate these impacts. To our knowledge, this is the first study to document the response of aquatic ecosystems to coffee farming practices while incorporating sub-watershed scale land use analysis and detailed descriptions of the type of coffee farms influencing the streams under evaluation.

In Chapter 2 we show how streams within the high elevation, high intensity coffee growing region of the Pirris watershed, Costa Rica, exhibit impairment relative to a forested reference site, with higher levels of non-point source pollution indicators and a decrease in Shredder taxa. These streams, however, maintained levels of physicochemistry considered adequate for aquatic ecosystem conservation, and supported high levels of diversity and pollution sensitive taxa. Our findings suggest that the impacts of coffee agriculture on streams within coffee growing regions are moderate, and are likely lower than the impacts of other anthropogenic impacts in tropical highlands such as urbanization and cattle ranching. We recommend the development of future studies to assess whether levels stream integrity described in this study are due to low impact of coffee farming, or efficient export of non-point source pollution from highlands to lowlands. Based on our findings on conductivity levels and macroinvertebrate assemblages, we recommend that moderating the application of agrochemicals and reforesting riparian vegetation with native trees should be a priority for promoting stream ecosystem conservation within coffee farms of the Pirris watershed.

Another practice that should be a priority for tropical stream conservation is the reforestation of coffee farms with shade trees. In Chapter 3 we documented the effectiveness of preserving ~40% shade tree cover at the sub-watershed scale at reducing non-point source pollution, particularly during the transition months from dry to rainy season. These findings represent the first empirical evidence of the effectiveness of one of RA's management criteria for the purpose of non-point source pollution management. Accordingly, we found a trend for a greater proportion of RA certified farms in sub-watersheds that meet the 40% shade tree cover criterion. This provides some support for the effectiveness of the program at implementing this management practice. Future studies should assess if shade tree cover increase in the Pirris watershed before and after the implementation of RA's certification program to more accurately assess the influence of the program at promoting large scale reforestation in high elevation coffee growing regions. Future studies should also re-evaluate the correlation of shade tree cover and other indicators of non-point source pollution, such as nitrogen and phosphorus, as well as conduct more detailed quantification of sediment exports from sites above and below 40% shade tree cover. These assessments would allow us to have a more clear understanding of the ecological significance of RA's management guidelines and the role of their certification program on stream ecosystem conservation.

The future studies we suggest here should be developed in partnership with RA or other conservation organizations concerned with the management of aquatic ecosystems in high elevation coffee growing regions. This would allow research outputs to effectively transfer into management policies and advance the use of science based conservation guidelines. Our work with RA provided us the opportunity to gain insights about the dynamics of research within NGO-Academia partnerships (Chapter 4), and develop a collaborative framework which could be used as a model to guide similar projects in the future. We provide examples of how our framework can be used for three stages of the project's cycle: 1) Problem Definition, 2) Tracking Progress and, 3) Moving Forward. The examples we used were from NGO-Academia projects evaluating the impact of certification programs, but we believe this framework has wide applicability for academic-practitioner collaborations. More research is needed for understanding the factors that enable research collaboration continuity. From our experience, we propose that incorporating graduate students into collaborative projects is key for promoting long term research partnerships. Within ecology, growing incentives for research collaboration across institutions, including NSF's Integrative Graduate Education and Research Traineeship Program (IGERT), will likely result in more NGO-Academia partnerships incorporating graduate students and allowing the opportunity to test this proposition in the future.

By gathering baseline data about the impact of non-point source pollution from coffee farming on streams, creating monitoring tools for detecting those impacts and evaluating the effectiveness of shade tree reforestation guidelines for non-point source pollution management, this works provided the Rainforest Alliance with tools to better achieve aquatic ecosystem conservation through their certification program. By developing an NGO-Academia collaboration framework, we hope to help similar partnerships in the future progress effectively towards their goals, and help bridge the gap between ecological research and conservation practice.