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Shade tree cover criteria for non-point source pollution control in the Rainforest Alliance coffee certification program: A snapshot assessment of Costa Rica's Tarrazú coffee region

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ABSTRACT

Management of non-point source pollution is of great importance in the context of coffee agriculture, as this land use often coincides with headwater streams that influence water quality at the basin scale. Sustainability certification programs, such as the Rainforest Alliance (RA), provide management guidelines that promote non-point source pollution control in coffee. One of these practices is the maintenance of shade trees within farms, required by RA at a minimum of 40% shade tree cover. Here we 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 in streams with both high and low shade tree cover. Streams with *High Shade Tree Cover* (HSTC, $N = 5$ subwatersheds) had 35–55% cover, approximating or exceeding the RA recommendation of at least 40%; and streams with *Low Shade Tree Cover* (LSTC, $N = 5$ subwatersheds), had 18–31% cover. We monitored the ten study streams during the dry (April & December), transition (July), and peak (October) rainfall seasons of 2013, and compared responses using *t*-tests. We found support for the effectiveness of shade tree cover in controlling non-point source pollution: HSTC streams had significantly ($p = 0.042$) lower mean annual turbidity and significantly ($p = 0.004$) lower turbidity during the transition season. HSTC streams also had significantly ($p = 0.05$) lower conductivity values during the transition period, although this trend was weaker through the year. Subwatersheds with HSTC streams were characterized by a higher percentage of RA-certified coffee than LSTC streams. Our study provides evidence of the benefits of RA shade tree cover criteria for managing water quality within high elevation tropical agro-ecosystems, especially if implemented at the watershed scale. These results contribute to our understanding of the role of agroforestry certification on tropical ecosystem conservation, and are the first account of the effectiveness of a specific coffee certification guideline on non-point source pollution control.

1. Introduction

Coffee is among the most valuable commodities in world trade (Taugourdeau et al., 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 on the developing tropics.

An important and understudied environmental issue associated with coffee farming is the management of non-point source pollution to streams. Non-point source pollution originates from diffuse sources, such as surface runoff, carrying natural or anthropogenic contaminants to water bodies (USEPA, 2015). Sources of contaminants within 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 is critical, as coffee farms are typically situated at the headwaters of tropical watersheds, and their impact can thus extend throughout the entire river network, reaching coastal environments (Robinson and Mansingh, 1999; Freeman et al., 2007). The high slopes and heavy rainfall that characterize coffee growing landscapes exacerbate pollutant export to waterways (Ali et al., 2011).

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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). One of the leading certifiers in the coffee value chain is the Rainforest Alliance^{TM} (RA), which certifies close to 3.3% of the coffee produced globally (RA, 2012). This study emerged in part from a collaborative effort with RA to evaluate the organization's water quality conservation efforts (De Jesús Crespo, 2015).

For the purpose of non-point source pollution control in coffee, RA guidelines include the conservation of riparian buffers at widths that vary from 5 m to 20 m depending on slope and intensity of agrochemical use (SAN, 2010), as well as the maintenance of at least 40% shade tree cover through the coffee farm (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 (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. >1350 masl, 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 Tarrazú, due to the emergence of specialty coffee markets (Laderach et al., 2011; Rueda and Lambin, 2013). Furthermore, high elevation coffee may provide a more reliable supply in the future due to potentially higher resilience to temperature increases associated to climate change (Rahn et al., 2014).

This study compares turbidity and conductivity values in 10 sub-watersheds within Tarrazú: 5 with High Shade Tree Cover (HSTC, near or greater than 40%) and 5 with Low Shade Tree Cover (LSTC, less than 40%) for a period of one year. Our goal is to determine whether a 40% shade tree cover level significantly impacts non-point source pollution in coffee agroforestry systems. We also ask whether the RA certification program is associated with greater implementation of reforestation practices within coffee agroforestry landscapes by examining percentages of certified coffee in these 10 sub-watersheds. This approach aims to provide empirical data to elucidate the role of the RA sustainable coffee certification at promoting water quality conservation in tropical highland agro-ecosystems.

2. Methods

2.1. Study site

The study focuses on a coffee growing region in Costa Rica, a country that provides an exemplary case of both technified coffee farming under the green revolution paradigm (Wintgens, 2009), and a long history of engagement with environmental initiatives (Campbell, 2002). Within Costa Rica, the Tarrazú region stood out as an ideal study site because it is a high elevation, and high intensity coffee region, where two of its largest cooperatives participate in the RA certification program (Fig. 1a).

Tarrazú is part of the headwaters of the Pirris Watershed, in the central Pacific region of Costa Rica (Fig. 1a and b). 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) in Central America. Coffee in Tarrazú is often grown on gradients as steep as 60% (Castro-Tanzi et al., 2012), rainfall averages 2400 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). Extreme growing conditions translate into areas of high vulnerability to water quality degradation, and thus necessitate effective watershed management.

Land use in Tarrazú consists mainly of coffee plantations (Soto-Montoya and Ortiz-Malavasi, 2008), with production averaging over 1600 kilos per hectare per year (ICAFE, 2012; Castro-Tanzi et al., 2012). Farms usually exhibit a shade monoculture pattern, meaning coffee in association with one to 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 configuration of coffee plantations is considered the most intensive form of shade grown coffee, and is characteristic of highly productive coffee enterprises (Moguel and Toledo, 1999; Mas and Dietsch, 2004). The most commonly applied agrochemicals are nitrogen based fertilizers, applied at an average of 212 kg ha^{-1} y^{-1} (±50 sd) and lime, which is applied at an average of 658 kg ha^{-1} y^{-1} (±445 sd) (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 (Fig. 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 (Fig. 1b), which include both RA certified and uncertified farms.

2.2. Landscape analysis

The study employed two adjacent multispectral, 2-meter resolution images from the Tarrazú coffee region, pansharpened with corresponding Panchromatic, sub-meter resolution images, to classify land cover (Yuen, 1999). The Worldview-2 Satellite collected the images, which were further corrected using the SRTM 900 m Digital Elevation Model. Worldview-2 captured the first image on January 31, 2012 at a 49° angle, and the second on February 27, 2012 at an angle of 41°. Analyzing images independently, as opposed to in a mosaic, allowed this study 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 unshaded coffee), (2) shade tree cover (i.e. upperstory tree cover in coffee farms), (3) forest, (4) urban, (5) pastures and (6) exposed soil (Table 1). The classification process included delimiting forest patches by hand, and erasing them to avoid classification confusion with the shade tree cover category. Removing forest patches that could confound the measurement of shade in coffee, increasing image contrast to 50% and setting brightness to 16%, allowed