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Assessing the service of water quality regulation by quantifying the effects of land use on water quality and public health in central Veracruz, Mexico

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ABSTRACT

The effectiveness of Payments for Ecosystem Services (PES) in Mexico may be reduced by a lack of guidance on intra-watershed priority zones and an overemphasis on water supply versus other services such as water quality. We explored the links between land use, water quality, and public health in central Veracruz. We identified zones of high and low cholera prevalence and evaluated the effects of land use on water quality at different scales. Production functions were used to evaluate relationships between water quality and public health. Additionally, using mitigation and defensive costs methods and a combined regression model, we estimated a marginal value per hectare of forest in avoiding public health costs associated with contaminated water. Prevalence of cholera was associated with *E. coli* concentrations in streams. Primary forest cover was the land use most strongly correlated with *E. coli*, particularly within riparian corridors of 100 m width. Our results suggest a value of water quality regulation of at least $US 90 ha^{-1} in riparian corridors. These results highlight the importance of targeting PES in priority areas within watersheds and considering both water quality and quantity as a means of increasing program efficiency and potencially broadening financial support for these programs.

1. Introduction

Numerous recent studies have highlighted the importance of ecosystems in providing a range of valuable services that satisfy human needs (Pan et al., 2013; Remme et al., 2014). Hydrological services (HS) in particular, including flood regulation, water supply and quality (Brauman et al., 2007; Bruijnzeel et al., 2011) have captured the interest of decision makers seeking to develop policy instruments capable of protecting the forested ecosystems important in providing these services and promoting the sustainable use of natural resources (Bruijnzeel, 2002; Daily et al., 2009). Despite their importance, these services are increasingly threatened in Mexico and other tropical regions of the world (Bubb et al., 2004; Toledo-Aceves et al., 2011; Hamilton et al., 2012).

Tropical montane forests and their HS are being rapidly degraded and converted to other land uses (Douglas et al., 2007), including agriculture, pasture, and urban-industrial uses. Activities in such land uses are associated with HS deterioration through processes such as increased runoff, soil erosion and compaction, and reduced quality of water (Bai et al., 2013). Due to increasing and intensive water usage in all economic sectors, water is widely regarded as the most essential natural resource (WWAP, 2009). However, failures in adequately incorporating the value of HS in watershed management decisions are altering and reducing the capacity of standing forests to provide them (Brauman et al., 2007). The environmental costs of converting tropical forests are generally not taken into account in policy decisions (Douglas et al., 2007). The resulting loss of HS risks harming human health through lower drinking water quality (Pattanayak and Wendland, 2007). Mirroring such global trends, Mexico has exhibited one of the highest annual deforestation rates in Latin America in recent decades, including an estimated loss of temperate forests of up to 0.43% per year (Torres-Rojo and Flores-Xolocotzi, 2001; Mas et al., 2004; Velázquez et al., 2010). Loss of forest cover in turn is contributing to a pronounced deterioration of national hydrological resources in many watersheds, altering floods and droughts cycles, increasing surface runoff and thus contamination of surface waters (Martinez et al., 2009; Muñoz-Villers et al., 2011; Cotler et al., 2010). This situation is being exacerbated by population growth, climate change, and poor management of wastewater (Carabias and Landa, 2005; Wehner et al., 2011). Given the critical situation

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for hydrological and forest resources in Mexico, the conservation and restoration of forest HS was declared a matter of national security (Manson, 2004).

Programs making direct Payments for Ecosystem Services (PES) to support forest conservation and their hydrological services have become increasingly popular (Wunder, 2007; Brouwer et al., 2011). PES are financial tools that aim to maintain or improve service provision (Bennett et al., 2009), and are also an effective way to channel economic resources for the development of rural populations (Sánchez-Azofeifa et al., 2007). While several examples of large scale government PES programs exist, in Mexico, to reverse the deterioration of hydrological and forest resources, the government established in 2003 one of the world´s largest programs making payments for hydrological services, to landowners whose forests provide such services (Muñoz-Piña et al., 2008; Alix-Garciaía et al., 2012). Particular attention was given to tropical montane cloud forests in Mexico's national PES program, due to their rapid disappearance and capacity to provide hydrological and other important services (Bubb et al., 2004; Muñoz-Pina et al., 2008; Toledo-Aceves et al., 2011; Hamilton et al., 2012; Bruijnzeel et al., 2011). This program is operated by the National Forest Commission (CONAFOR) and has provided $US 660 million in payments to protect 4.3 million hectares between 2003 and 2013 (CONAFOR, 2014). The program's main focus has been guaranteeing water supply for localities in zones of water scarcity via forest conservation (Muñoz-Piña et al., 2008), with little mention of other hydrological services, the complexity of their relationship with forest cover, or tradeoffs between services (Jackson et al., 2005; Brauman et al., 2007; Bennett et al., 2009; Martínez et al., 2009). In addition, the effectiveness of this program may be reduced by a lack of guidance on intra-watershed priority zones. While CONAFOR publishes a detailed explanation of the methodology used to select eligible watersheds to receive payments each year, no guidance is provided to specify where these payments should be made within particular watersheds (Alix-Garcia et al., 2012; Manson et al., 2013). In this and other PES programs, protection and long-term sustainability of hydrological resources will only be viable if the full range of HS are quantified and economically accounted for (Wünscher et al., 2008).

A clear signal of the failure in HS provision is the proliferation of gastrointestinal diseases (Pattanayak and Wendland, 2007). Recent studies have highlighted the problems and high public health costs associated with the global deterioration of surface water quality (Schwarzenbach et al., 2010). Microbiological contamination of water and food (e.g. fecal bacteria), is a common and persistent problem affecting public health and impacting local economies (Ishii and Sadowsky, 2008). Water-related diseases generate significant medical expenses associated with mitigation and defensive costs for the public health sector, as well as for individuals in terms of medicines, doctors' visits and lost time at work (Dasgupta, 2004; Clasen et al., 2007). Diarrheal diseases associated with the lack of access to clean water (e.g. direct ingestion of unsafe drinking water, contact by washing hands and food) are considered the most important type of water-related disease and

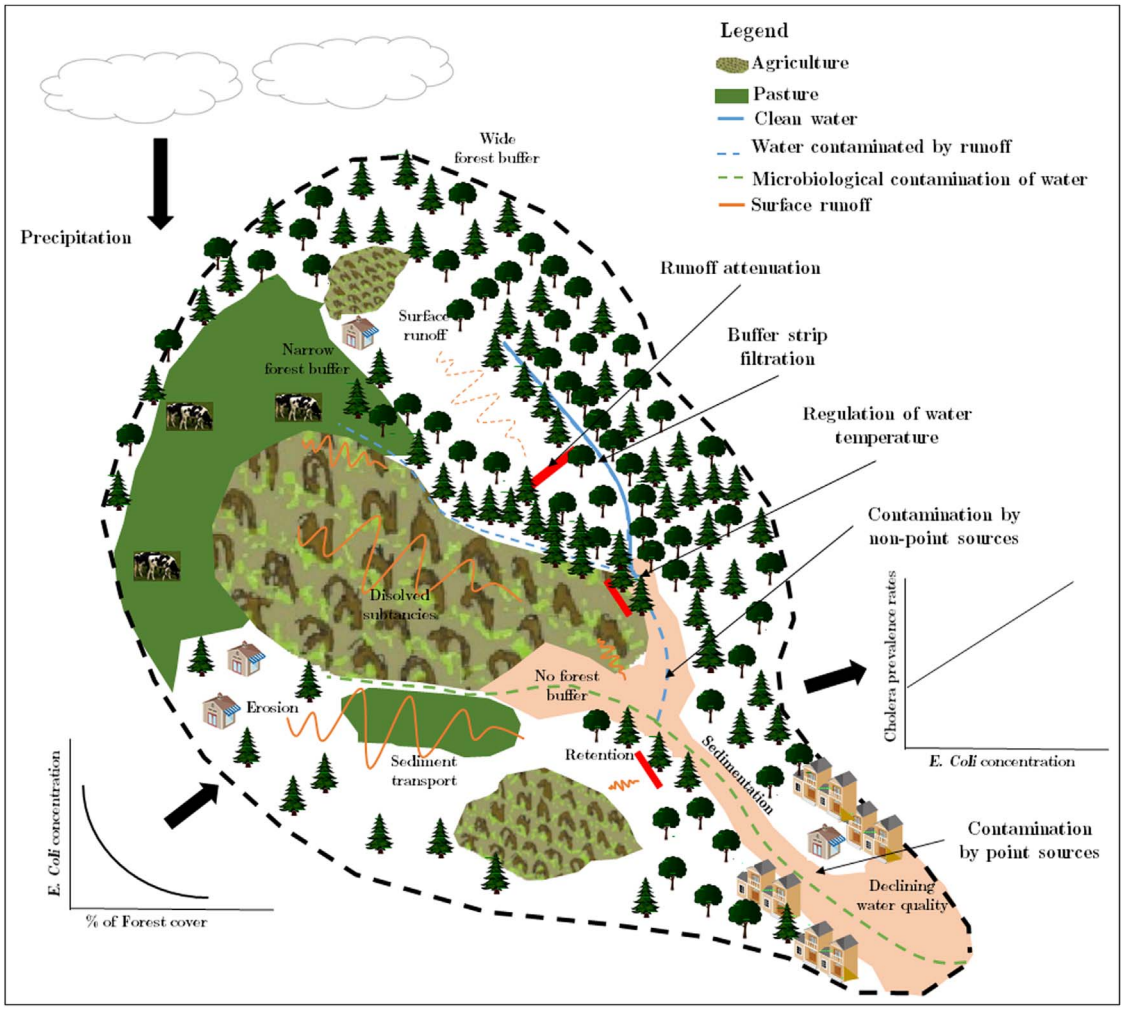

Fig. 1. Scheme representing the impact of different spatial distributions of forest and other land uses on surface water quality.