Science of the Total Environment 542 (2016) 12–21

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Influence of rice field agrochemicals on the ecological status of a tropical stream

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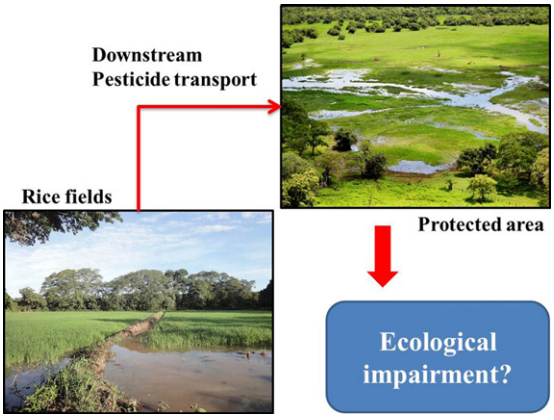
HIGHLIGHTS

- Pesticides are transported via streams to protected downstream nature reserves.
- Pesticide concentrations were highest during the rainy season due to flooded fields.
- Pesticide concentrations in the protected area exceeded safety thresholds.
- Current Costa Rican biomonitoring indices did not reflect environmental gradients.
- Macroinvertebrate communities were impaired especially during the rainy season.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 3 July 2015
Received in revised form 7 October 2015
Accepted 11 October 2015
Available online 27 October 2015

Editor: D. Barcelo

Keywords:
Tropical streams
Macroinvertebrates
Pesticides
Risk assessment
Ecological quality indices
Protected areas

ABSTRACT

Many tropical countries contain a high density of protected ecosystems, and these may often be bordered by intensive agricultural systems. We investigated the chemical and ecological status of a stream connecting an area with conventional rice production and a downstream protected nature reserve; Mata Redonda. Three sites were sampled: 1) an upstream control, 2) in the rice production area and 3) a downstream site in Mata Redonda. We sampled benthic macroinvertebrates and pesticides in water and sediments along with supporting physical and chemical data. Pesticide concentrations in water exceeded current safety thresholds at sites 2 and 3, especially during the rainy season, and sediment associated pesticide concentrations exceeded current safety thresholds in three of six samples. Importantly, the highest predicted pesticide toxicity in sediments was observed at site 3 in the Mata Redonda confirming that the nature reserve received critical levels of pesticide pollution from upstream sections. The currently used macroinvertebrate index in Costa Rica (BMWP-CR) and an adjusted version of the SPecies At Risk index (SPEAR) were not significantly correlated to any measure of anthropogenic stress, but the Average Score Per Taxon (ASPT) index was significantly correlated with the predicted pesticide toxicity ($sumTU_{D.\ magna}$), oxygen concentrations and substrate composition. Our results suggest that pesticide pollution was likely involved in the impairment of the ecological status of the sampling sites, including site 3 in Mata

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http://dx.doi.org/10.1016/j.scitotenv.2015.10.062

Redonda. Based on our results, we give guidance to biomonitoring in Costa Rica and call for increased focus on pesticide transport from agricultural regions to protected areas.

1. Introduction

Costa Rica is known for having a high density of pristine ecosystems, and the country harbors 5% of the global biodiversity (MINAE, 1992). This concentration of biodiversity is among the highest in the world and more than 25% of the surface area is protected and classified as nature reserves. Tropical streams and wetlands are important habitats for wildlife, flora and fauna, and several streams and wetlands constitute central parts of Costa Rican nature reserves. However, tropical nature reserves are increasingly at risk of being influenced by conventional agriculture or even converted to agricultural production (Schiesari et al., 2013).

The area specific annual consumption of pesticides in conventional agriculture in Costa Rica is among the highest in Central America; from 2006 to 2009 approximately 50% of the consumed pesticides belong to the group of fungicides, 30% belong to the group of herbicides, and the remaining 20% is comprised of insecticides and fumigants (Vega, 2012). From the same time period, the highest area specific amounts of pesticides were applied to high value crops such as fruits (e.g. bananas and melons) and vegetables (e.g. potatoes and tomatoes), but considerable quantities were additionally used in rice production (Vega, 2012).

Dense river networks connect areal patches of conventional agriculture and protected nature reserves. Consequently, stream biota in nature reserves may be exposed to agricultural pesticides that enter stream systems at upstream reaches embedded in agricultural landscape (Marchesan et al., 2007). In rice production, the risk of pesticide transport to stream recipients increases when the rice is cultivated under flooded conditions (Nicosia et al., 1991), and the highest concentrations of pesticides in such tropical streams have been detected during the rainy season where the flooding frequency of rice fields increases (Sangchan et al., 2014). However, the transport of pesticides from flooded rice fields to stream recipients is not temporally restricted to the rainy season as large quantities of surface water are extracted to irrigate the rice fields especially during the dry season (FAO, 2013).

Despite high quantities of applied pesticides in many Central American countries and in other tropical regions in general, a disproportionately low amount of studies, which address ecological effects of pesticides in freshwater systems, has been conducted. Some studies suggest that the degradation of pesticides may increase in tropical freshwater systems due to increased microbial activity at higher temperatures consequently reducing the risk of ecological effects (Sethunathan, 1989). Conversely, the toxicity of pesticides may increase with increasing temperature (Howe et al., 1994). It is currently unknown whether tropical stream ecosystems are more or less sensitive to pesticide pollution compared to temperate stream ecosystems since the trophic structure and community composition are highly different between these climate zones. For example, the abundance and species richness of omnivorous fish are higher and the body size of fish is lower in tropical streams compared to temperate streams (Gonzalez-Bergonzoni et al., 2012; Teixeira-de Mello et al., 2012). Moreover, there is a scarcity of studies addressing the sensitivity of tropical freshwater macroinvertebrates to pesticides (but see e.g. Castillo et al., 2006; Nandi and Gupta, 2009). Therefore, the pesticide authorization and risk assessment procedures in tropical countries generally rely on toxicological data produced on temperate species.

The currently used method for assessing ecological quality of streams in Costa Rica (the Biological Monitoring Working Party Costa Rica index; BMWP-CR) aims at quantifying impacts of mainly organic pollution (negatively affecting oxygen concentrations) on benthic macroinvertebrates (Mafla, 2005). The BMWP indices have been further developed by adjusting the BMWP index scores according to the taxa-specific abundances (the Average Score Per Taxon index; ASPT) (Armitage et al., 1983). Adjusting the index scores according to taxa-specific abundances generally provides a stronger link to anthropogenic stressors (Morais et al., 2004; Silveira et al., 2005) and additionally increases the temporal stability of the index scores (Zamora-Munoz et al., 1995). Benthic stream macroinvertebrates have traditionally been used as indicators for various anthropogenic stressors (Rosenberg and Resh, 1993), but the use of oxygen sensitive species as positive indicators of ecological quality may not capture effects of environmental contaminants such as pesticides (Liess and von der Ohe, 2005; McKnight et al., 2012).

Using a priori selected traits the macroinvertebrate based SPEcies At Risk (SPEAR) index was developed by Liess & von der Ohe (2005) aiming to quantify ecological effects of periodic pesticide pollution. The traits considered in the SPEAR index are: i) taxon-specific physiological sensitivity to organic contaminants, ii) migratory ability, iii) reproductive capacity and iv) the presence of aquatic life stages during the primary insecticide application season in the temperate region (Liess and von der Ohe, 2005). The SPEAR index has currently not been tested on tropical streams, and since it is based on temperate macroinvertebrate species and traits characteristics ascribed to these species are based on the temperature profiles of the temperate climatic zone, the SPEAR index is not necessarily equipped to capture effects of pesticide pollution in tropical streams. However, Schäfer et al. (2007, 2011) showed that a modified version of SPEAR, termed SPEARpm, (the two life cycle traits; reproductive capacity and timing of terrestrial life stages were removed since they depend on the ambient temperature rendering comparisons between different climatic regions difficult) was a strong predictor for pesticide induced macroinvertebrate community changes in Australia (Schäfer et al., 2011) and along a latitudinal gradient in Europe (Schäfer et al., 2007).

We studied the potential impact of pesticides originating from conventional rice production in the hydrological catchment of River San Lázaro, a tributary stream of the River Tempisque in Costa Rica. The Chorotega region that includes the Tempisque river basin is an important agricultural area accounting for 45% of the total rice production in Costa Rica (ConArroz, 2015). Conventional rice production in the Chorotega region includes two crop cycles per year; from January to May (irrigated) and from July to November (non-irrigated). The Mata Redonda nature reserve is located downstream of one of the rice production areas in the Chorotega region (Fig. 1). We hypothesized that i) pesticides originating from the rice fields will be transported downstream to the nature reserve leading to concentrations that exceed environmental protective threshold concentrations; ii) predicted pesticide induced community effects on macroinvertebrates (quantified as SPEARpm index scores) will be strongest during the rainy season in late August to October and iii) the currently used BMWP-CR index and ASPT will be outperformed by SPEARpm in terms of the correlation to predicted pesticide toxicity of measured pesticide concentrations (sum of toxic units approach), since the BMWP and ASPT indices target effects of low oxygen concentrations.

2. Methods

2.1. Study area and sampling sites

Climatic conditions are tropical with mean night and day temperatures of 22 °C and 37 °C, respectively. The mean annual rainfall is