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Short communication

Macroinvertebrate communities as bioindicators of water quality in conventional and organic irrigated rice fields in Guanacaste, Costa Rica

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ABSTRACT

The purpose of this study was to compare how aquatic macroinvertebrates are affected by certain management practices and agrochemicals in organic and conventional rice cultivations (treatments) in northwestern of Costa Rica. We sampled macroinvertebrates in both treatments, at the water entrances (irrigation) and exits (drainage) during two cycles (8 months total) of rice field cultivation. We employed a water quality index using macroinvertebrates (BMWP/CR) as bioindicators in both management treatments. Insect family mean ($P = 0.0019$) and species mean richness ($P = 0.0340$) were greater in the organic vs. the conventional treatments as well as at the entrances rather than their exits. Both macroinvertebrates mean abundance ($P = 0.0281$) and insects mean abundances ($P = 0.0065$) were greater at the organic vs. the conventional treatments. The water quality index (BMWP/CR) was greater in the organic treatment at the entrance (124) comparing with the exit (72), and also at the conventional entrance (92) vs. the exit (66), thus showing that the management practices affected the macroinvertebrate community. The organic treatment showed the settlement of a greater number of families and species of macroinvertebrates both in general and in those considered sensitive to pollution than in the conventional treatment. This sensitive group of macroinvertebrates (*Baetis* sp., *Fallceon* sp., *Leptohyphes* sp., *Tricorythodes* sp., *Farrodes* sp., *Phyllogomphoides* sp., *Hydroptila* sp., *Mayatrichia* sp., *Neotrichia* sp., *Oxyethira* sp., *Nectopsyche* sp.1, *Nectopsyche* sp.2, *Oecetis* sp.) can be used as a bioindicators of water quality in these agroecosystems. On the contrary, more macroinvertebrates resistant to pollution were found in the conventional compared to the organic treatment, showing that aquatic macroinvertebrates respond to the type of management/products that are applied to the rice field.

1. Introduction

Rice farming is the main activity and source of income for millions of people and is the most widely cultivated crop worldwide, occupying over 11% of the world's total cultivable land (FAO, 2004a, 2004b). In Latin America and the Caribbean (LAC), rice is one of the most important grains for human consumption (Lentini, 2006). However, rice cultivation has negatively impacted the areas where it is grown due to overuse of water, pesticide, methane emissions and habitat conversion (FAO, 2004a, 2004c; Huang et al., 2003).

Rice is commonly cultivated under irrigated conditions, serving as artificial wetlands for many plant and animal species (FAO, 2004a; Fasola and Ruiz, 1996). As in other complex and multifunctional wetlands, the hydrological regime plays a key role in the ecology of these agroecosystems (Bambaradeniya and Amarasinghe, 2003). The source and frequency of irrigation directly affects the ecology and biodiversity of rice cultivations. The source of water determines both the physiochemical characteristics and the composition of aquatic biota. The duration, regularity and predictability of rice field flooding have effects on the temporal variation of the water depth (volume) and chemistry,

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soil fertility, and biotic community composition (Bambaradeniya and Amarasinghe, 2003; Blanco, 2011). Some organisms regularly found in rice fields are insects, mollusks, crustaceans, fish, amphibians and reptiles. Rice fields also play an important role in migration routes and conservation of waterfowl populations (Bambaradeniya, 2000; Bambaradeniya and Amarasinghe, 2003; Blanco, 2011; Elphick, 2000; Elphick and Lewis, 2003; Lesterhuis, 2011; Minotti, 2011; Rizo-Patrón et al., 2011; Schnack et al., 2000).

1.1. Conventional vs. organic rice treatments

Conventional rice cultivation techniques often include the application of pesticides, which can be lethal to both the wildlife that inhabit rice fields and to humans who work there (Curcó et al., 2001; Fasola and Ruiz,1996; Hidalgo, 1986; Rizo-Patrón, 2003b; Shuford et al., 1998). In general, conventional agricultural rice fields have lower quality runoff water than organic fields (Badii et al., 2005; Martínez, 1998; Rizo-Patrón, 2003b). In addition, some pesticides (Chlorinated) can bio-accumulate in aquatic organisms, causing chronic negative effects and the reduction of population sizes (Fasola and Ruiz, 1996).

In many countries more environmentally friendly rice cultivations that avoid the use of excessive amounts of pesticides are developing (Curcó et al., 2001; López and Romero, 2004; Medina and Navia, 2008; Treto et al., 2001; Barley, 2007; Dinesh et al., 2000; González et al., 2006; Hasegawa et al., 2005; Mäder et al., 2002; Roder et al., 2006). In Costa Rica, organic rice cultivations are being used in experimental areas and on a small scale. In organic rice cultivation, large weeds must be removed by hand and organic fertilizers must be used. In order to control pests in Costa Rica, farmers have used insect-pathogenic fungi such as *Beauveria bassiana*, *Metarrhizium anisopli*, *Paecilomyces lilacinus*, *Verticillium lecanii* which can control *Tibraca limbativentris*, *Tagasodes orizico*, *Oebalus poecila*, *Rupela albinella*, *Hydrellia* spp., and *Spodoptera* spp. (OET, 2003a, 2003b). Biological control eliminates the danger of synthetic pesticide poisoning for farmers and consumers (Roder et al., 2006; Sullivan, 2003). Additionally, post-harvest rice straw is reduced by decomposition in water in organic cultivation management, as opposed to burning in conventional cultivations (Bird et al., 2000). In Costa Rica, Hacienda La Pacifica began organic experimental rice treatments in 2003. Currently, this is the only area in Costa Rica that has organic certification for rice crops.

1.2. Benthic macroinvertebrates as bioindicators of water quality

The most diverse and abundant organisms in wetlands are aquatic invertebrates (Curcó et al., 2001) and they have been used for monitoring chemicals in the environment for decades (Metcalfe, 1989; Resh, 2007; Resh and Jackson, 1993; Resh and McElvary, 1993; Resh et al., 1996; Wilson, 1994). Macroinvertebrates also occupy key positions at every level of the food webs in aquatic ecosystems.

In Costa Rica there are many studies on the importance of macroinvertebrates as water quality indicators in crop systems. For example, benthic macroinvertebrates have been used as indicators of water quality in banana and conventional rice plantations (Castillo, 2000; Castillo et al., 1997, 2000, 2001, 2006; Martínez, 1998; Monge et al., 2005; Rizo-Patrón, 2003a). However, there have been no studies conducted on organic rice cultivations in Costa Rica.

1.3. Effect of agrochemicals on the physical–chemical properties of water and on macroinvertebrates

Pesticides and other agrochemicals used in conventional rice cultivations can change the natural physical–chemical conditions of water, which may alter macroinvertebrate populations. Higher temperatures can increase pesticide solubility in water and increase pesticide uptake by the fauna. At higher temperatures, dissolved oxygen decreases, making the physical and chemical conditions of water even more challenging for macroinvertebrate survival (Castillo, 2000; IPEN, 2004; Standley and Sweeney, 1995; Vindimian, 2001). The abundance of primary consumers usually increases with Nitrogen based fertilizer due to increase in photosynthetic aquatic biomass sometimes producing eutrophication (Roger et al., 1995). In a healthy cultivation, a high level of biodiversity with several different trophic groups represented is expected, while in a cultivation with many pesticides, a medium level of biodiversity and dominance of one trophic group is expected (Corkum, 1989; Ward, 1992).

Macroinvertebrates biodiversity, especially insects, can be affected by a direct exposure to pesticides (insecticides) reducing species richness and decreased faunal composition after their application (Bambaradeniya and Amarasinghe, 2003; Beketov and Liess, 2008; Brock et al., 2009; Callisto et al., 2004; Canivet and Gibert, 2002; Cuppen et al., 2002; De Szalay and Resh, 2000; Dinesh et al., 2000; Edmunds and Waltz, 1996; Favari et al., 2002; Hose et al., 2002; Huang et al., 2003; Iannacone and Alvariño, 2002; Lauridsen and Friberg, 2005; Mesléard et al., 2005; Pascual-Villalobos et al., 2005; Wilson et al., 2008). Non-lethal effects include shortened lifespan (diseases), alteration of behavior (recruitment), and problems with development and reproduction, which can lead to changes in sensitivity (adaptability, resistance). There may also be demographic changes (abundance, age structure) of populations (Albarino et al., 2007; Maret et al., 2003; Roberts et al., 2009; Sheehan, 1984; Spence et al., 1990; Warwick and Tisdale, 1988).

The aim of this study is to study aquatic macroinvertebrate communities in different rice cultivations management and explore the possibility of their uses as bioindicators of water quality in these agroecosystems. The objectives were to compare benthic macroinvertebrate communities and assess water quality between two rice cultivation treatments: organic (no application of agrochemicals) and conventional (application of agrochemicals) at both the entrance and exit points of irrigation. We hypothesized that there would be differences in the composition and structure of the macroinvertebrate communities in conventional and organic treatments and also between the entrances and the exits of both treatments, as a result of the cultivation management regime (pesticides and nutrient application).

2. Materials and methods

2.1. Study area

This study was conducted in two distinct rice cultivation sites in Guanacaste province, Costa Rica (Fig. 1). The Tempisque River irrigation project provides 80% of the water for agricultural use in the Guanacaste province, including about 55,000 ha of irrigated rice (FAO, 2007). The conventional 9.75 ha cultivation site was located within the 1000 ha Bagatzí Agricultural reform project (10°25′05″N; 85°19′38″W) that uses gravity-fed irrigation water from the Arenal Hydroelectric Project 40 km to the east. It is bordered on the Southwest by Palo Verde National Park, on the North by the Lomas Barbudal Biological Reserve, and on the Southeast by the town of Bagatzí. The organic cultivation site was located in the private Hacienda La Pacifica about 5 km Northwest of the town of Cañas (10°27′53″N; 85°08′02″W). This cultivation site also used gravity-fed irrigation water from the same hydroelectric project; however, only 5 km from the last turbine and was located next to a private protected tropical dry forest that belongs to the same hacienda (1661 ha). This cultivation site received microbial pesticides (biological control) with fungi (Micoboc-Tricoderma) but