BENTHIC MACROINVERTEBRATES AS INDICATORS OF WATER QUALITY IN STREAMS OF COSTA RICA: USING AN ADAPTATION OF THE BMWP SCORE

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ABSTRACT

Costa Rica is a tropical country that has adopted biological monitoring using macroinvertebrates and has adapted the BMWP score for its water bodies, where the new score is named BMWP-CR. In an experimental survey to assess the application of the BMWP-CR score, we considered seven study sites with a gradient of anthropogenic activities along the Dos Novillos river. The Shannon-Wiener Diversity and Pielou Evenness indexes were computed. The first study site was considered as the reference site. Four taxonomic groups were detected: Annelida, Platyhelminthes, Mollusca and Arthropoda. The last group was the most abundant and diverse. The Shannon-Wiener index ranged between 1.14 in a study site close to a banana processing facility, to 3.49 in a study site near to the confluence of the Dos Novillos River with the Parismina river. In such study sites, the Pielou Evenness index values varied from 0.57 to 0.83, respectively. The BMWP-CR scores ranged from 24 in the study site near the banana processing facility, to 116, in a downstream study site, reaching values higher than the reference site selected upstream in the Dos Novillos river far away from anthropogenic influence. Insects were the most diverse and abundant group. The correlation between the Shannon-Wiener Diversity index and the BMWP-CR scores presented a high significance value ($R^2 = 0.927$). Therefore, we suggest that the Shannon-Wiener index can be used alongside the BMWP-CR scores. The BMWP-CR method is sensitive enough for detecting changes in water quality reflecting differences in land uses along the studied river.

RESUMEN: Macoinvertebrados bénticos como indicadores de la calidad del agua en corrientes de Costa Rica: Usando una adaptación del puntaje BMWP.

Costa Rica es uno de los países de latitudes tropicales que ha adoptado el monitoreo biológico y adaptado el BMWP para sus cuerpos de agua, denominándolo BMWP-CR. En un estudio experimental para evaluar la aplicación del BMWP-CR, consideramos siete sitios de estudio dentro de un gradiente de actividades antropogénicas en el río Dos Novillos. Los índices de diversidad de Shannon-Wiener y de equidad de Pielou fueron también calculados. El primer sitio de estudio fue considerado como sitio de referencia. Se detectó la presencia de cuatro grandes grupos taxonómicos: Anélidos, Platelmintos, Moluscos y Artrópodos. Este último fue el más abundante y diverso. El índice de Shannon-Wiener varió de 1.14 en un sitio cercano a una planta procesadora de bananos, hasta 3.49 en un sitio de estudio cercano a la

desembocadura del río Dos Novillos con el río Parismina. En esos mismos sitios, el índice de equidad de Pielou varió de 0.57 a 0.83, respectivamente. El valor mínimo del índice BMWP-CR fue de 24 y se detectó también en el sitio cercano a la procesadora de bananos, mientras que el máximo fue de 116 en un sitio corriente abajo, alcanzando incluso, un valor más alto que aquél del sitio de referencia sobre el Dos Novillos, el cual está alejado de actividades antropogénicas. La correlación entre el índice de diversidad y el BMWP-CR fue significativa (R^2= 0.927), por lo que sugerimos que el índice de Shannon-Wiener puede ser aplicado en forma conjunta con el BMWP-CR. La sensibilidad del índice BMWP-CR fue capaz de detectar cambios en la calidad del agua como resultado de diferentes usos del suelo alrededor de los sitios de estudio.

REZUMAT: Macronevertebratele bentonice ca indicatori ai calităţii apei în râuri din Costa Rica: utilizând o adaptare a indexului BMWP.

Costa Rica este o ţară tropicală care a adoptat monitoringul biologic, utilizând macronevertebratele şi a adaptat BMWP pentru râuri; noul indice adaptat poartă denumirea BMWP-CR. Într-un studiu experimental, pentru a evalua aplicarea indicelui BMWP-CR, s-au luat în considerare şapte situri cu un gradient al activităţilor antropice de-a lungul râului Dos Novillos. Au fost calculaţi indicele Shannon-Wiener şi indicele de uniformitate Pielou. Primul sit a fost considerat ca sit de referinţă. Au fost identificate patru grupe taxonomice: anelide, platelminţi, moluşte şi artropode. Artropodele au fost cele mai abundente şi diverse ca specii. Indicele Shannon-Wiener are valori de la 1,14 (într-un studiu de caz, aflat în apropierea unor facilităţi de procesare a bananelor) la 3,49 într-un sit din apropierea confluenţei râului Dos Novillos cu râul Parismina. În aceleaşi situri, valoare indicelui Pielou este de 0,57, respectiv 0,83. Indicele BMWP-CR, în aceleaşi situri are valorile 24 în apropierea locului de procesare a bananelor, respectiv 116 în aval, astfel ajungând la valori mai mari decât în situl de referinţă (localizat în amontele râului Dos Novillos, departe de activităţi antropice). Insectele au fost cel mai divers şi abundent grup. Corelaţia valorilor indicelui Shannon-Wiener cu indicele BMWP-CR au prezentat o valoare cu o semnificaţie ridicată (R2= 0.927). De aceea, propunem ca indicele Shannon-Wiener să se utilizeze alături de indicele BMWP-CR. Indicele BMWP-CR este suficient de „sensibil” ca să poată fi utilizat pentru a identifica modificarea calităţii apei, reflectând diferenţele în utilizarea terenurilor de-a lungul râului studiat.

INTRODUCTION

Freshwater ecosystems are one of the most endangered in the world, and many developing countries may be at a greater risk. Biotic indices are widely used in monitoring the health status of various ecosystems (Dos Santos et al., 2011). Biological monitoring is defined as "*the systematic use of living organisms or their responses to determine the condition or changes of the environment*" (Li et al. 2010), and is an effective tool to assess the ecological quality of a watercourse. Chemical monitoring can also be very important to understand water quality, but it is expensive in terms of equipment and time and often offers only limited information. Furthermore, biological monitoring can give an indication of past, as well as present conditions (Fenoglio et al., 2002). Biological water quality assessments use standardised indices of invertebrate biodiversity to assess levels of pollution and other human influences on fresh water resources. These indexes represent measures for nature conservation values for rivers and ponds; they are used to monitor freshwater habitats around polluted sites with organic residues. In addition, biological indexes used to assess water quality based on macroinvertebrates offer advantages over those using other organisms, because

macroinvertebrates are easy to sample, at least in regard to qualitative measurements or relative abundance (Zamora-Muñoz et al., 1995).

Benthic macroinvertebrates are the most commonly suggested group of organisms for freshwater biomonitoring (Li et al., 2010) and have been extensively studied in temperate areas. Contrarily, the methodology and theoretical background of biomonitoring have not been sufficiently adapted yet to tropical aquatic environments, which are generally characterized by a high diversity (Stein et al., 2008; Springer et al., 2010). One of the principal causes for this reason is that the taxonomy of benthic macroinvertebrates in tropical countries is at present poorly known (Thorne and Willians, 1997). However, the use of benthic macroinvertebrate fauna as an indicator for a qualitative classification of freshwater systems has increased in many regions of the world during the last years as has been the case in Spain (Alba-Tercedor 1988, 1996; Alonso and Camargo, 2005), Romania (Tatole, 2004; Balaban and Constantinescu 2007), and has had also a wide acceptance among tropical countries such as Thailand (Mustow, 2002), Cuba (Muñoz-Riveaux et al., 2005), Nicaragua (Fenoglio et al., 2002), Venezuela (Segnini, 2003), Dominican Republic (Soldner et al., 2004), and Costa Rica (Stein et al., 2008). Additionally, bioindicators have the advantage of reflecting water quality conditions that echo prolonged biological time periods, while traditional chemical methods offer only a snapshot of the specific situation of the water status at the time of sampling.

The Biological Monitoring Working Party (BMWP) index was developed in England during the 70's decade. In 1976, the Department of the Environment recommended the development of a score system based on benthic macroinvertebrates to family level (Hawkes, 1997). Since that time, it has been adopted and adapted in several countries, particularly in tropical zones. Costa Rica has been one of such countries that modified the BMWP system. For each family, a sensitivity value ranging from 1 to 10 is assigned, reflecting a certain tolerance level to organic pollution (Roldán, 2003). The values for each family are added, independently from abundance and generic diversity (Stein et al., 2007) in order to obtain a final score, which represents the BMWP index. In terms of the present paper, the BMWP score system adapted to Costa Rica was used (BMWP-CR; Stein et al., 2008).

Costa Rica is an ideal reference point for tropical ecology in the world because of its high biodiversity (Springer, 2008). However, it has also served as an important location for agricultural production, including crops such as coffee, bananas, pineapples, wood and wood products (Kohlmann et al., 2008); likewise the rapid population growth and its associated urbanization and industrialization processes have placed an ever increasing pressure on its water resources. For these reasons, the BMWP-CR system has been incorporated into the environmental legislationl of Costa Rica (Reglamento para la evaluación y clasificación de la calidad de cuerpos de agua superficiales No. 33903MINAE-S) since September 17, 2007.

The aim of this work was to assess the water quality of different study sites in the Dos Novillos River, Province of Limón (Fig. 1), applying the BMWP score adapted for Costa Rica.

MATERIALS AND METHODS

The Dos Novillos river drains from the Costa Rican Central Mountain Range, at an elevation of approximately 2380 masl towards the Caribbean lowlands in the province of Limón, in Guácimo, Costa Rica. This region in Costa Rica is characterized by a humid tropical climate with a mean annual temperature of 25.8 °C and annual precipitation values ranging 5000–8000 mm, without a pronounced dry season (Stein et al., 2008). We sampled seven localities along the Dos Novillos river and Quebrada Mercedes in August 2008. The first

sampling site lies on the Dos Novillos inside a tropical forest (Fig. 1), far from anthropogenic activities. The "Establo" (site 2) is close to a housing complex. Sites 3 and 4 (Lavandería and Empacadora) are close to a laundry and a banana processing facility, respectively. "La Hamaca" (Site 5) is located at the start of a banana plantation; while site 6 (Plantación) is located halfway through the same banana plantation. Site 7 (Desembocadura) is located 100 m upstream of the confluence of the Dos Novillos river with the Parismina river (Fig. 1).

Macroinvertebrates were caught using a kick net with a 0.5 mm mesh size. All specimens were collected and preserved in 70% ethanol. Separation was done in the laboratory by placing the collected material in a Petri-dish under a stereoscope. Macroinvertebrates were separated, counted, and identified to the family level using the taxonomic keys of Merrit and Cummnins (1996) and Thorp and Covich (1991). In some cases, identification was only possible at subclass level (Oligochaeta).

For each study site, the Shannon-Wiener Diversity and Pielou Evennes indexes were computed in order to calculate differences in biodiversity. We applied the BMWP-CR index in order to assess water quality at all study sites.

Water quality intervals were coded using colours and categories (Tab. 1) in concordance with Alba Tercedor (1996) and Maue and Springer (2008). In addition, the Average Score Per Taxon (ASPT) was calculated, where a high ASPT value indicates a clean site with a high diversity and low ASPT values correspond to small numbers of taxa indicating the existence of pollution (Armitage et al., 1983).

RESULTS AND DISCUSSIONS

A total of 840 specimens of benthic macroinvertebrates from seven study sites were identified, belonging to 33 families included in 4 higher taxonomic groups: Annelida, Arthropoda, Mollusca, and Platyhelminthes.

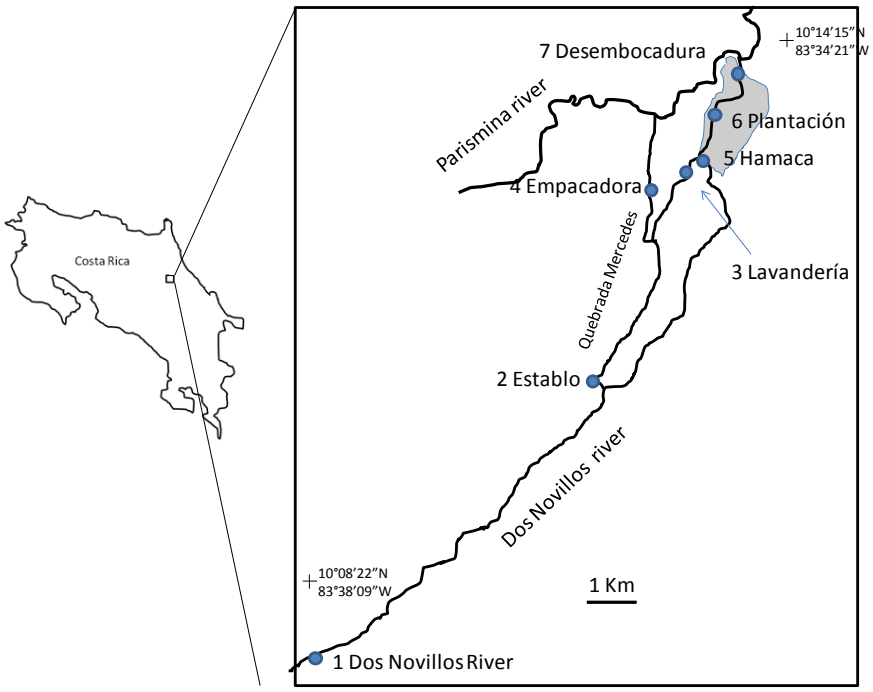

Figure 1. Study area and sampling localities.

Table 1. Water quality categories of the BMWP-CR index according to Maue and Springer (2008).

Colour code	Score	Level of water quality
	>120	Excellent quality
	101 - 120	Good quality, no pollution or obvious distortions
	61 - 100	Regular quality, eutrophic, medium pollution
	36 - 60	Bad quality, polluted
	16 - 35	Bad quality, very polluted
	< 15	Bad quality, extremely polluted

The most numerous groups were the Arthropoda with a 96.55% of the collected specimens, followed by Platyhelminthes (2.26%), Mollusca (0.95%) and finally Annelida with only 0.24% (Fig. 2). Arthropods were represented by 26 insect families, two families of crustaceans (Palaemonidae and Pseudothelphusidae) and one mite family (Hydracharidae). The molluscs were represented by two families (Neritidae and Thiaridae), the annelids by one Subclass (Oligochaeta), and finally, the flatworms by one family (Planariidae).

The dragonflies and damselflies (Odonata) were the most diverse group with six families. However, the most abundant order was the caddisflies (Trichoptera) with 369 specimens, which made up to 43.8% of the total number of the collected individuals. The mean BMWP-CR score for all study sites was 80.85. The individual BMWP-CR scores by taxa and study sites are presented in Table 2.

We found 19 families with a total number of 266 individuals in the Parismina river (site 1). A Shannon-Wiener index value of 3.4 and a Pielou Evenness index value of 0.8 (Figs. 3 and 4) were recorded. The BMWP-CR score attained a value of 112 (Fig. 5) and in concordance with table 1, water quality at this site was good, without pollutants or obvious disturbances. This study site is located on the upper reaches of the Parismina river, where anthropogenic impacts are not present, so we considered this site as our reference point. Study site 2 (Establo) was characterized by 10 families with a Shannon-Wiener index value of 1.56 and a Pielou Evenness index value of 0.47, indicating less diversity and evenness in relation to the reference site (Figs. 3 and 4). The BMWP-CR score for this site was 56, implicating a bad water quality (Fig. 5).

Study sites 3 (Lavandería) and 4 (Empacadora) are located very close to each other. In the Lavandería site we found 8 macroinvertebrate families with a 1.57 value of the Shannon-Wiener index and a 0.52 value of the Pielou Evenness index; whereas the Empacadora site recorded only 4 families, recording index values of 1.14 and 0.57, respectively (Figs. 3 and 4). BMWP-CR scores were 43 and 24, for sites 3 and 4, respectively (Fig. 5). In concordance with table 1, water quality in site 3 was polluted, but in site 4, the water quality was very polluted (Fig 2). Site 3 is associated with a discharge coming from a laundry (Lavandería in Spanish) unit; whereas site 4 is associated with a water discharge coming from the banana packing plant (Empacadora in Spanish), containing agrochemicals and organic matter in the form of latex and small banana pieces that get washed away after the bananas have been washed prior to packing them.

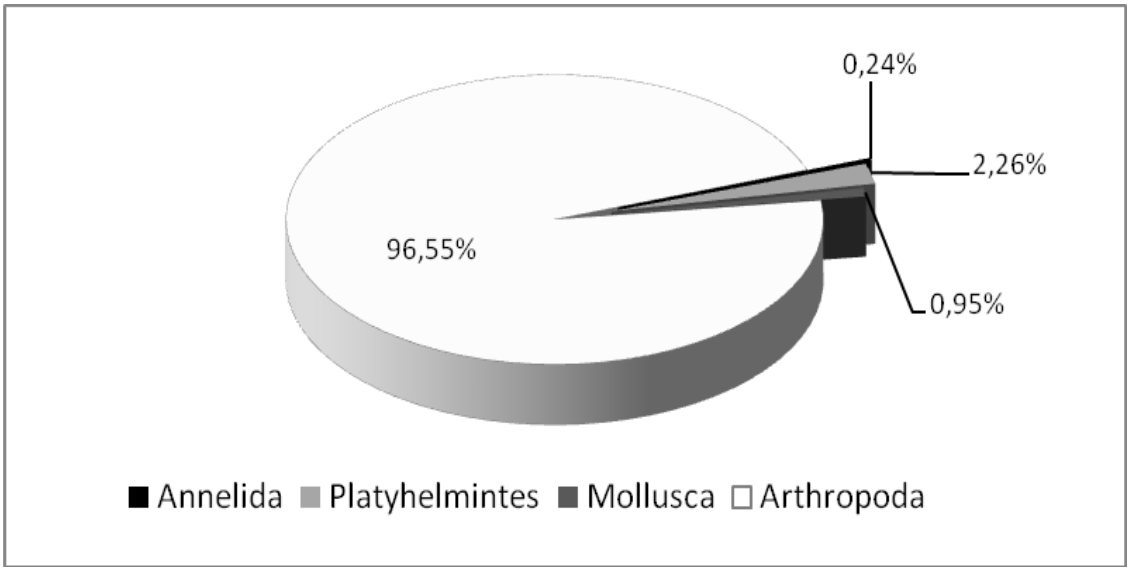

Figure 2: Major taxonomic groups registered in all study sites.

On the other hand, at study site 5 (La Hamaca), 15 families were found with a Shannon-Wiener diversity index value of 2.69 and a Pielou Evenness index value of 0.69, showing an increment in diversity and taxa richness (Figs. 3 and 4). In this case, the BMWP-CR index score showed a value of 80 (Fig. 5), implicating water with regular quality, eutrophic, and medium pollution levels (Tab. 1). La Hamaca study site is located at the beginning of a banana plantation which could be possibly affecting the river through agrochemical run-off.

Study site 6 (Plantación) recorded 22 families of macroinvertebrates with a Shannon-Wiener diversity index value of 3.3 and a Pielou Evenness index value of 0.74 (Figs. 3 and 4). These values are very close to those of the reference site. Regarding the BMWP-CR index, we computed a score of 116 (Fig. 5); therefore, in this site we obtained a slightly higher value than the reference site, probably because the river is broader in this place possibly presenting more variety of habitats.

The last study site, site 7 (Desembocadura) presented diversity indexes (Shannon-Wiener) and evenness (Pielou) values of 3.49 and 0.83, respectively (Figs. 3 and 4). In this site we collected 18 families of macroinvertebrates, which indicate that the diversity and evenness indexes have recovered, reaching the same values as those of the reference site. The BMWP score for this study site was 96 (Tab. 2).

Contrary to Armitage et al. (1983), we found ASPT values ranging from 3.29 (study site 3) to 6 (study site 4) (Fig. 6), where the maximum ASPT value corresponded to the lowest BMWP-score. Armitage et al. (1983) point out several factors affecting ASPT values: seasonal variation, sample replication, and river location (ASPT values were usually higher in the upper reaches). This study was carried out during the summer season, with single sampling and at a middle reach. Therefore, the ASPT system should be taken with caution considering the factors that affect this metric, especially where agroindustrial activities seem to be affecting water quality, as is the present case at site 4 (banana packing plant).

Table 2: Collected aquatic macroinvertebrates and BMWP-CR scores by taxa and study site.

Taxa	Site 1, Dos Novillos river	Site 2, Establo	Site 3, Lavandería	Site 4, Empa-cadora	Site 5, La Hamaca	Site 6, Plantación	Site 7, Desembo-cadura
Amphizoidae	5						
Baetidae	5				5	5	5
Calopterygidae			4			4	2
Chironomidae		2				2	
Coenagrionidae	4		4	4	4	4	
Corydalidae	6				6	6	6
Pseudothelphusidae		5					
Dryopidae	5						
Elmidae	5				5	5	5
Gomphidae						7	
Heptageniidae							10
Hydracaridae						8	
Hydropsychidae	5	5	5	5	5	5	5
Leptoceridae	8						
Leptohyphidae	5		5		5	5	5
Leptophlebiidae	8		8	8	8	8	8
Libellulidae						6	6
Lutrochidae		7				7	
Megapodagrionidae	7						
Naucoridae	4				4	4	4
Neritidae		3			3		
Oligochaeta						1	1
Palaemonidae	5	5	5			5	5
Perlidae	10	10			10		
Philopotamidae	7		7	7	7	7	7
Planariidae	5	5				5	5
Platysticitidae					7	7	7
Psephenidae	7	7				7	7
Ptilodactylidae	7	7					
Pyralidae			5				
Simulidae					4	4	4
Thiaridae					3		
Tipulidae	4				4	4	4
BMWP-CR	112	56	43	24	80	116	96

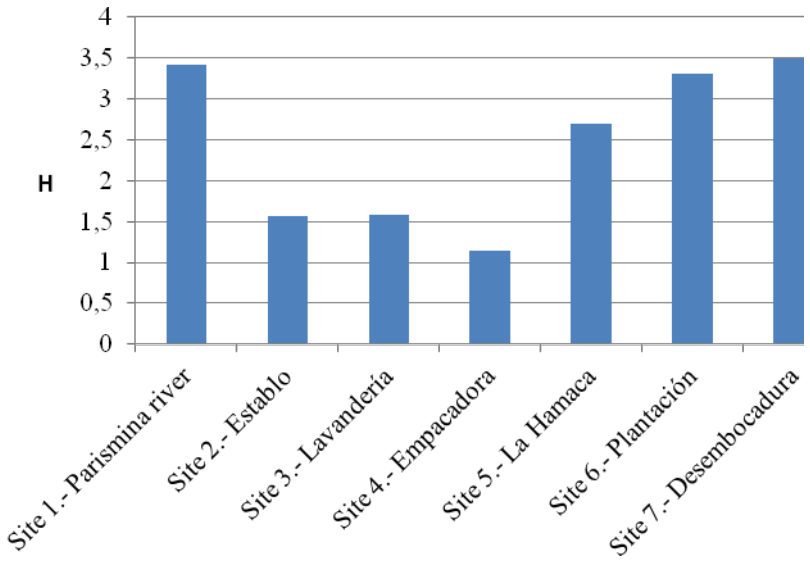

Figure 3: Shannon-Wiener Diversity index (H) by study site.

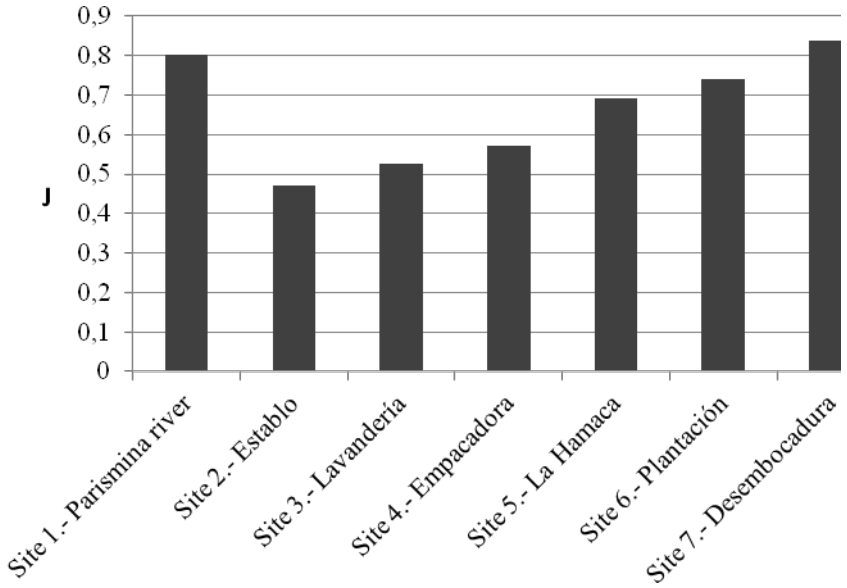

Figure 4: Pielou Evenness index (J) by study site.

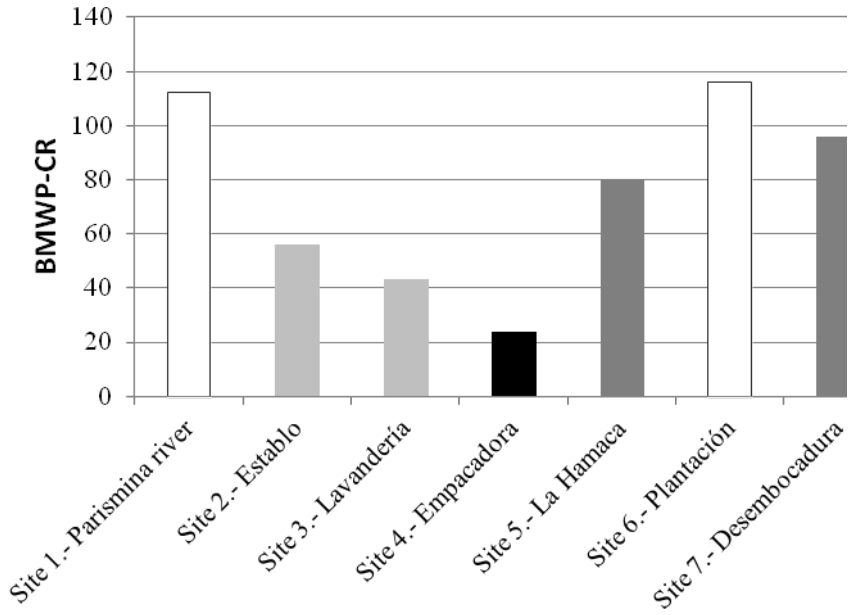

Figure 5: BMWP-CR scores by study site. Bar colours as in the table number one.

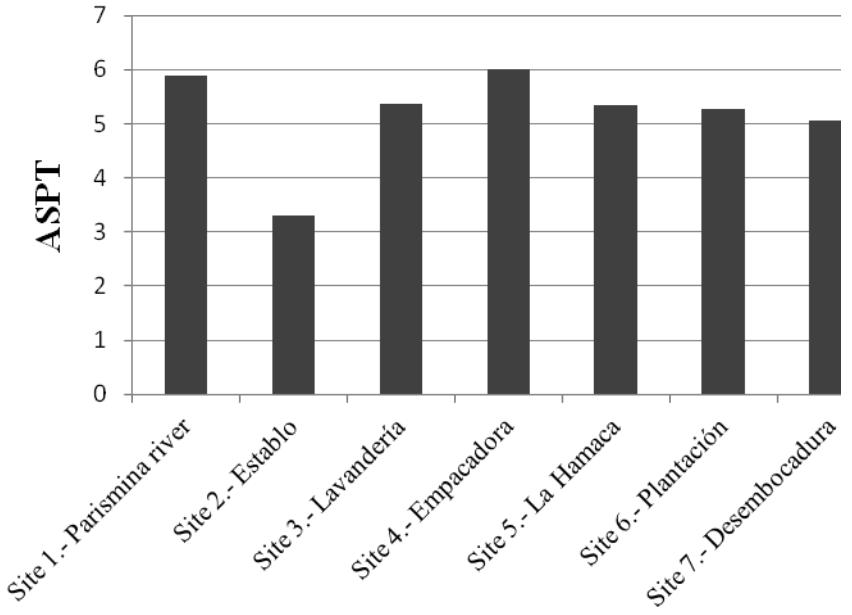

Figure 6: ASPT values by study site.

The Biological Monitoring Working Party is an index that is related to family taxa richness, and is based on two hypothesis. First, the changes in abundance and biodiversity of the macroinvertebrate communities are caused by reduction of dissolved oxygen levels due to organic pollution. Second, some invertebrates are more sensitive to pollution than others. Based on this, pollution-sensitive families receive higher scores than less tolerant families (Ocampo-Duque et al., 2007). Following this train of thought, we can observe that the Shannon-Wiener, more than the Pielou Evenness index, show similar trends as the BMWP-CR index because both are based on group richness, but the first two, in addition, take into account, the abundance of organisms. In order to illustrate the relationship between the Shannon-Wiener Diversity (H) and the BMWP-CR indexes on one hand, and the Pielou Evenness (J) and the BMWP-CR indexes on the other, a linear regression was calculated (Fig. 7) for each case. The respective equations for the H-BMWP-CR and the J-BMWP-CR relationships are:

$$BMWP\text{-}CR = 33.853H - 7.84 \quad (R^2=0.927, p<0.001)$$

$$BMWP\text{-}CR = 205.93J - 61.20 \quad (R^2=0.686, p<0.001)$$

The importance of comparability in bioassessments has been recognized by several authors (Yuan and Norton, 2003; Cao and Hawkins, 2011). In this case, the use of other biometrics (such as the Shannon-Wiener Diversity index) helped us confirm the trends for the BMWP-CR index.

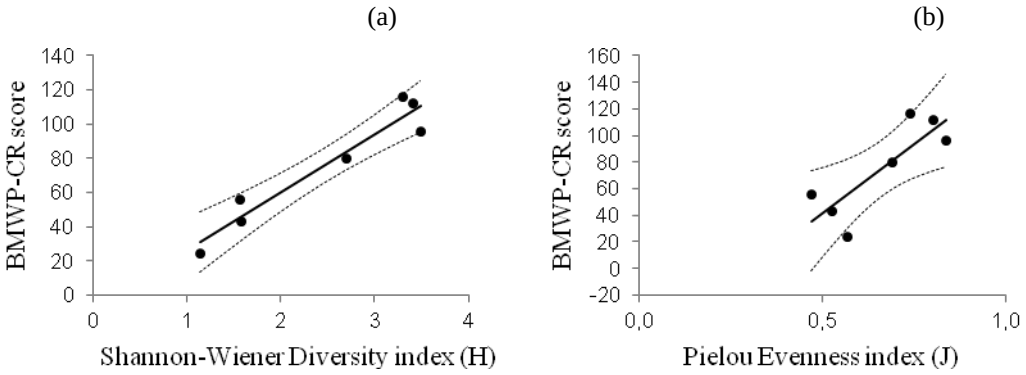

Figure 7: Linear regressions between (a) the Shannon-Wiener Diversity index and the BMWP-CR score, and (b) the Pielou Evenness index and the BMWP-CR score (----- 95% confidence limits).

Stein et al. (2008) obtained BMWP-CR scores higher than 120 in the Dos Novillos river using a combination of two collecting methods; however, the time effort for the collection of macroinvertebrates was much higher than in the present study (130 min). Conversely, in our study, we detected differences that can be attributed to the influence of anthropogenic activities. Such is the case of the study sites 2, 3 and 4, where the BMWP-CR scores were lowest. In the same way, as mentioned above, the Shannon-Wiener diversity and Pielou Evenness indexes showed the same trend as the BMWP-CR score. Balaban and Constantinescu (2007) found spatial and temporal differences in the BMWP scores for the Danube river in Romania, with the highest scores in the upstream reaches. Auquilla et al. (2005) in a study of water quality of the Jabonal river, Costa Rica, found also differences in the BMWP-CR index due to the effect of different land uses.

CONCLUSIONS

Insects were the most abundant and diverse taxa. Low diversity and evenness values were observed in study sites close to anthropogenic activities. The Shannon-Wiener index presented a high correlation with the BMWP-CR score. The mean average value of the BMWP-CR index for all study sites was 80.85; however, in study sites close to anthropogenic activities, the BMWP-CR score was lower. Responses of macroinvertebrate communities were very sensitive to anthropogenic activities and the BMWP-CR index was able to detect it, whereas the ASPT index did not.

According to the categories of water quality, we found water levels ranging from bad quality at the banana packing plant, to water with good quality without apparent disturbances in the reference site, as well as before the confluence of the Dos Novillos river with the Parismina river.

The use of the BMWP-CR index is an excellent tool for assessing river water quality on the Costa Rican Caribbean slope.

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