MACROINVERTEBRATES AS BIOINDICATORS OF WATER QUALITY IN THE METROPOLITAN REGION OF PANAMA

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ABSTRACT
This research is part of the work on the environmental impact of multi-stressors on the aquatic ecosystems of the metropolitan area of Panama City, which is aligned to the strategy of Resilience of Panama City, about a plan of actions within the economic, social, and environmental field. This paper presents a study of bioindicators of water quality using the macroinvertebrate communities present along (high, middle, and low points) of three different basins of the Pacora, Matasnillo, and Juan Díaz rivers at different times of the year (dry, rainy, and transitional seasons). Biological monitoring carried out in sections of 100 m were taken and samples collected using a D-Net network of 500 µm, the organisms were examined in the laboratory with the support of specialists from the Gorgas Memorial Institute for Health Studies. Based on the compilation and review of the material, we were able to list a total of 2,704 individual freshwater macroinvertebrates. According to the BMWP/PAN results, it is observed that the highest levels of pollution are found in the lower parts of each tributary. The Matasnillo River has the highest pollution range with a value of <19, while the Pacora River has the lowest range. The results are important information about the functional groups of aquatic insects and provide relevant data for monitoring and conserving rivers, streams, and others. Due to the difficulties in educating the population on how to care for our aquatic ecosystems, it is important to diagnose water quality using the presence or absence of aquatic invertebrates.
Keywords: multi-stressors, resilience, bioindicators, macroinvertebrates, basin, BMW-PAN, freshwater, water quality, pollution.

1 INTRODUCTION

Aquatic macroinvertebrates take a huge part of the aquatic diversity, so they are often the main animal component of a lotic ecosystem [1] These provide the following characteristics. They are abundant, widely distributed, and easy to collect, easy to identify, if compared to other minority groups are mostly sedentary and reflect local conditions, have long life cycles, are visible to the naked eye, can be cultivated in the laboratory, very little genetically, respond quickly to environmental stressors [2]. In Panama, watersheds have undergone a great transformation because they are a source of natural resources, receive both agricultural and industrial waste, and are also used for recreation. On a regional scale, the basin of Pacora (146), Matasnillo (8142) and Juan Diaz (144) rivers, especially basin 146, which has a high degree of transformation since it has been modified to generate water supply to remote populations in the region, in addition to sustaining social activities, cultivation, industrial and economic use, extraction of stone and sand from the river, tourist uses, among others [3]. Therefore, it is necessary to evaluate the degree of deterioration of different basins in an integrated manner to allow a more complete analysis, provide a better criterion for the level of affectation of the basin, and provide future solutions.

WIT Transactions on Ecology and the Environment, Vol 257,
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/WMEI220041

2 MATERIALS AND METHODS

2.1 Areas of study

2.1.1 Basin 144 – Juan Díaz River

The sampling stations were in the upper (JD001), middle (JD002), and lower (JD003) basins of the Juan Díaz River at different times, located on the Pacific slope within the province of Panama (Table 1). Between the coordinates 9°00′ and 9°13′ and north latitude 79°18′ and 79°34′ west longitude [4]. It is located southeast of Panama City.

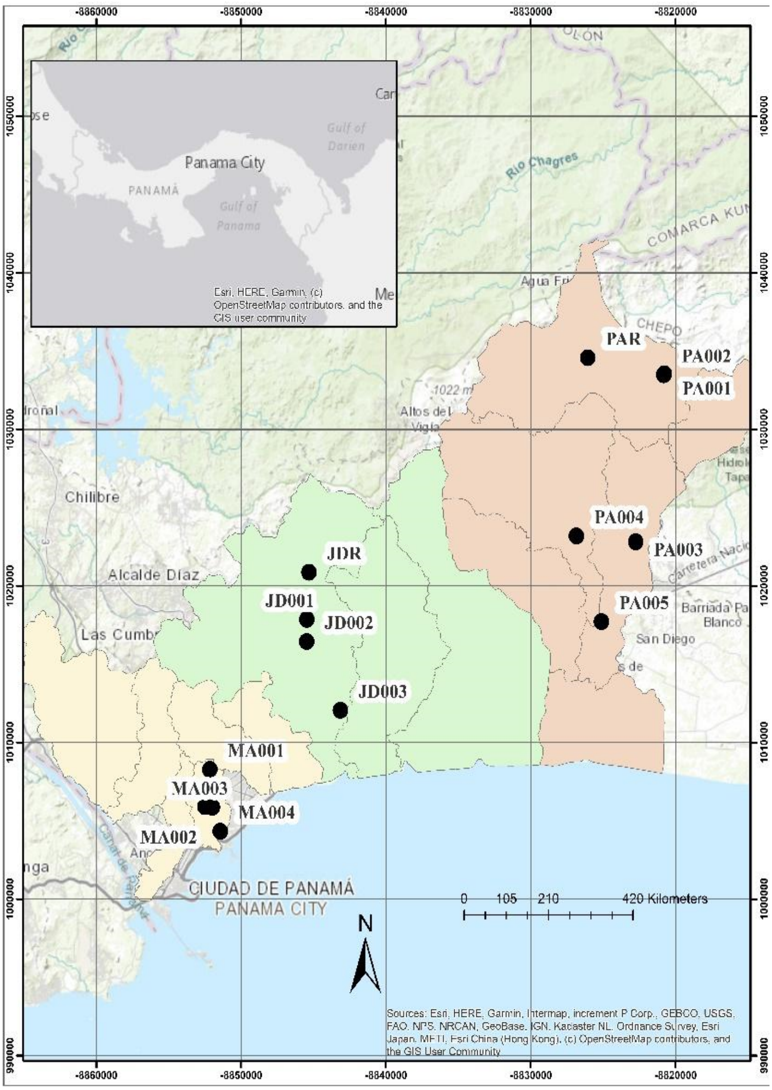


Figure 1: Representative map of the sampling stations of the Juan Díaz, Pacora, and Matasnillo rivers.

Table 1: Data from the rivers Juan Diaz, Pacora, and Matasnillo.

Data from the Juan Diaz, Pacora, and Matasnillo rivers				
Basin	Basin number	Season	X	Y
Juan Diaz	No. 144	JRD	669349	1003785
		JD001	669212	1006831
		JD002	669211	1005437
		JD003	671529	1001140
Pacora	No. 146	PAR	688289	1023313
		PA001	693513.5	1022331.2
		PA002	693479.6	1022271.6
		PA003	691615	1011796
		PA004	687568	1012143
		PA005	689299	1006779
Matasnillo	No. 142	MA001	662638	997397
		MA002	662314	995064
		MA003	662823	995028
		MA004	663364	993524

It has two types of climates, temperate tropical savannah and humid tropical. The basin has an average annual rainfall of 2,466 mm. The vegetation is represented by three ecological communities: area covered by forest (the secondary forest little intervened and secondary forest very intervened), stubble area, and wetlands (mangroves). Of the total area, 8% is used for urban uses, such as low-density residential, commerce and services, institutions, industry, transportation and communication, recreation, and green areas [4].

2.1.2 Basin 146 – Pacora River

The sampling stations were in the upper (PA001, PA002), middle (PA003, PA004), and low (PA005) basins of the Pacora River at different times of the year. This river belongs to the province of Panama, Panama District, located on the pacific slope, between the coordinates 8°00′ and 8°20′ north latitude and 79°15′ and 79°30′ west longitude [3]. On its way, it collects water from important tributaries, such as the Tataré, Utivé, Calobre, and Indio rivers [5].

It has two types of climates, tropical temperate savannah which represents 60% of the total area of the basin, and tropical humid climate that represents 40% [4]. There are diverse ecosystems represented in three life zones: very humid premontane forest, premontane rainforest, and tropical rainforest [5].

2.1.3 Basin 142 – Matasnillo River

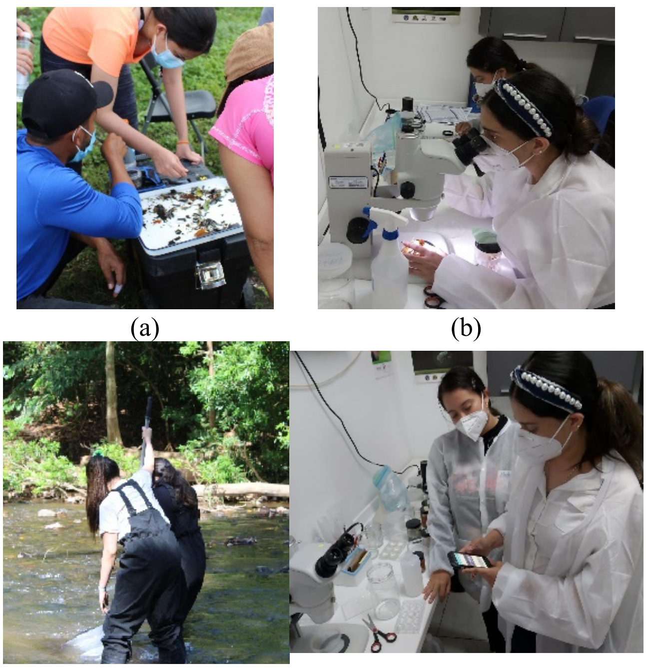
The samplings stations were in the upper (MA001), middle media (MA002, MA003), and lower (MA004) basins of the Matasnillo River at different times of the year. It is the only river that rises and flows into the Panamanian capital, its length is six km.

It has no main course, and its course is the result of a series of streams that extend in the district of Bethania (northernmost point), Pueblo Nuevo, Bella Vista, and San Francisco. It is located on the pacific slope, within the province of Panama, and occupies an area of

383 km^2, representing 0.51% of the national territory. Its geographical coordinates are 8°50′ and 9°05′ north latitude and 79°30′ and 79°40′ west longitude [5].

2.2 Field and laboratory work

Qualitative collections were made in three different seasons (rainy, dry, and transition) in each season a sampling effort of 30 minutes was made. To do this, the samples were collected using 500 μm D-net in vertical position taking it by the highest part of the handle (grip) and placing it against the river current in contact with the bottom of the surface of the river to be sampled, depending on the case of the river, it will be sampled once in each of the groups of microhabitats that we identified trying that the sample does not spread outside the net. The samples were then placed in labelled bottles with screw caps and preserved in 96% alcohol. These were transferred to the laboratory where they were processed. When we settled in, we examined the collected material thoroughly, under optical equipment, for the process of cleaning and separation into larger groups, with 96% alcohol. And we proceeded to make the identification at the taxonomic level of the family. The data of the identified organism were grouped by season (rainy, dry, and transition), so we obtained a few families, genera, and individuals for each sampling season. Water quality was determined at the 14 sampling points in the Pacora, Matasnillo and Juan Díaz rivers, using BMWP/PAN (Biological Monitoring Working Party/Panama) [6].



(a) (b) (c) (d)

Figure 2: (a) Separation of macroinvertebrates in the field; (b) Identification at the taxonomic level of families; (c) Using red of collect in vertical position taking it by the highest part of the handle (grip) and placing it against the river current in contact with the bottom of the surface of the river to be sampled; and (d) Determining the BMWP.

3 RESULTS

3.1 Abundance and wealth of macroinvertebrates in the basin 144 – Río Juan Díaz

A total of 2,704 individuals of freshwater macroinvertebrates were collected. Ninety-three families distributed in eight orders were recorded, being the Ephemeroptera (309 individuals) and Diptera (261 individuals) the most abundant order.

The most abundant families were Chironomidae (Diptera) with 30.14% of the total reported, Leptohyphidae (Ephemeroptera) with 18.29%, Baetidae (Ephemeroptera) with 17.43%, Leptophlebiidae (Ephemeroptera) con 8.43%, Glossosomatidae (Trichoptera) with 7.14%, Hydropsychidae (Trichoptera) with 4.57%, Simuliidae (Diptera) with 3.43%, Psephenidae (Coleoptera) with 2.14% and Psychodidae (Diptera) with 1.71%. These families represented 70.01% of the total reported of this basin.

3.1.1 Biological water quality

"Indirectly, rainfall influences the behaviour of the chemical parameters of the water" [2]. Directly, insects are dragged by currents and deposited in different parts of the river channel, influencing their distribution [7]. Therefore, the fact that our data show few individuals during the rainy season compared to the dry season and the transition period may be due to these relationships. Also, it is worth noting the strong currents and rocky substrates, which complicate sampling a bit at the time of kicking.

Table 2: Biological water quality in the 144 river basin (rainy season).

Biological water quality in the 144 river basin			
	JD001LL	JD002LL	JD003LL
Family richness	7	15	9
Numbers of individuals	40	160	115
BMWP/PAN score	23	50	27
Significance	Highly polluted	Polluted	Highly polluted

Table 3: Biological water quality in the 144 river basin (dry season).

Biological water quality in the 144 river basin				
	JDR	JD001SE	JD002SE	JD003SE
Family richness	35	34	27	7
Numbers of individuals	442	438	546	241
BMWP/PAN score	155	151	103	15
Significance	Excellent	Excellent	Good	Extremely polluted

Table 4: Biological water quality in the 144 river basin (transition season).

Biological water quality in the 144 river basin			
	JD001TR	JD002TR	JD003TR
Family richness	33	28	6
Numbers of individuals	288	363	74
BMWP/PAN score	76	86	13
Significance	Regular	Good	Extremely polluted

3.2 Abundance and richness of macroinvertebrates in the basin 146 – Río Pacora

A total of 2,143 individuals of freshwater macroinvertebrates were collected, divided into three classes, being Insecta (2,112 individuals) the most represented. Only 31 individuals were part of other taxonomic groups (Gasteropoda and Malacostraca). Twenty-eight families distributed in 10 orders were recorded, being the orders Ephemeroptera (1165 individuals), Trichopteran (517 individuals), and Diptera (203 individuals) the most abundant. The most abundant families were Leptophlebiidae (Ephemeroptera) with 18.11%, Hydropsychidae (Trichoptera) with 10.73% Philopotamidae (Trichoptera) witch 9.38%, Chironomidae (Diptera) with 6.86%, Glossosomatidae (Trichoptera) with 5.97%, Baetidae (Ephemeroptera) with 4.53%, Psephenidae (Coleoptera) with 1.91% and Coenagrionidae (Odonata) with 1.59%. These families represented 90.71% of the reported for this basin.

3.2.1 Biological water quality

Table 5: Biological water quality in the 146 river basin (rainy season).

Biological water quality in the 146 river basin					
	PA001LL	PA002LL	PA003LL	PA004LL	PA005LL
Family richness	19	18	12	17	14
Numbers of individuals	170	113	140	165	239
BMWP/PAN score	62	54	41	58	49
Significance	Regular	Polluted	Polluted	Polluted	Polluted

Table 6: Biological water quality in the 146 river basin (dry season).

Biological water quality in the 146 river basin						
	PAR	PA001SE	PA002SE	PA003SE	PA004SE	PA005SE
Family richness	35	38	26	18	24	16
Numbers of individuals	465	389	318	220	229	365
BMWP/PAN score	154	171	103	76	88	53
Significance	Excellent	Excellent	Good	Regular	Good	Polluted

Table 7: Biological water quality in the 146 river basin (transition season).

Biological water quality in the 146 river basin					
	PA001TR	PA002TR	PA003TR	PA004TR	PA005TR
Family richness	34	36	41	23	12
Numbers of individuals	282	310	412	106	150
BMWP/PAN score	88	101	65	61	30
Significance	Good	Good	Regular	Regular	Highly polluted

3.3 Abundance and richness of macroinvertebrates in the basin 142 – Matasnillo River

A total of 434 individuals of freshwater macroinvertebrates were collected. In which, 21 families were recorded, being Thiaridae (309 individuals) and Ceratopogonidae (261 individuals) the most abundant.

The most abundant families were: Thiaridae (Mesogastropoda) with 39.17% of the total reported, Ceratopogonidae (Diptera) with 21.66%, Chironomidae (Diptera) with 11.29%, Tubificidae (Haplotaxida) with 9.91%, Tubificidae (Haplotaxida) with 5.53%, Syrphidae (Diptera) with 3.00%, and Tipulidae (Diptera) with 1.38%. These families represented 91.94% of the total reported for this basin.

3.3.1 Biological water quality

Table 8: Biological water quality in the 142 river basin (rainy season).

Biological water quality in the 142 river basin				
	MA001LL	MA002LL	MA003LL	MA004LL
Family richness	4	2	2	2
Numbers of individuals	83	9	4	9
BMWP/PAN score	14	3	3	3
Significance	Extremely polluted	Extremely polluted	Extremely polluted	Extremely polluted

Table 9: Biological water quality in the 142 river basin (dry season).

Biological water quality in the 142 river basin				
	MA001SE	MA002SE	MA003SE	MA004SE
Family richness	8	8	2	4
Numbers of individuals	88	65	2	58
BMWP/PAN score	22	17	3	5
Significance	Highly polluted	Extremely polluted	Extremely polluted	Extremely polluted

Table 10: Biological water quality in the 142-river basin (transition season).

Biological water quality in the 142 river basin				
	MA001TR	MA002TR	MA003TR	MA004TR
Family richness	9	2	2	8
Numbers of individuals	37	3	8	68
BMWP/PAN score	20	3	4	11
Significance	Highly polluted	Extremely polluted	Extremely polluted	Extremely polluted

4 DISCUSSION

4.1 Biotic water quality index BMWP/PAN (Biological Monitoring Working Party)

Our study shows that watersheds 142 and 144 show serious deterioration. In the first tributary, four of the sites evaluated showed low richness of macroinvertebrate families and with a dominance of those that are tolerant to pollution. Stations MA001SE and MA001TR showed the highest richness of families and obtained values of 20 and 22, which corresponds to the category of highly polluted water quality. Meanwhile, in the second basin, three of the sites evaluated showed low richness of families in different seasons of the year, and with dominance to those that are tolerant to pollution. This is mainly the case of stations JD003LLL, JD003SE and JD001TR, which registered the lowest richness of families and obtained scores between 13 and 27, corresponding to extremely polluted waters. The second station with the highest richness was JD001SE, which corresponds to the category of excellent water quality. However, we can observe that as the rainy season approaches it shows a decrease in the number of taxa found. This is due to the fact that “the abundance of insects is mainly observed when rainfall is low and decreases when it increases” [7]. Similar results to those found in this study were documented in the Garachiné river [8], who also found a low abundance of EPT during periods of high rainfall “probably caused by an increase in water flow, which produces a consequent drift effect of individuals, the removal of insects and a reduction in their local abundance” [9].

It is important to highlight the small tributaries that cross the urbanizations and shopping centres, which have become recipients of all kinds of waste, either by runoff or simply because they are thrown directly into the tributaries due to a lack of environmental culture.

The JDR station was the one that presented the highest richness of families and obtained a value of 155, which corresponds to the category of Excellent water quality (Table 6); however, this is a reference point with one of the highest altitudes in the basin. This shows that the basin is being affected by the different activities carried out by people and will show greater deterioration every day if necessary, measure are not taken to mitigate the problem.

In the case of watershed 146, the quality of the watershed was acceptable despite the activities carried out along the watershed. However, of our six sampling points, three showed low richness of macroinvertebrate families in different seasons of the year. And with this we confirm once again that: “Rainfall indirectly influences the behavior of the chemical parameters of the water” [11]. In a direct way the insects are dragged by the currents and deposited in different parts of the riverbed influencing their distribution [7]. Therefore, the fact that our data have few individuals during the rainy season compared to the dry and transitional seasons is due to these relationships. This is the case of stations PA003, PA004 and PA005; which registered the lowest richness of families and obtained low scores, which on average corresponds to very polluted waters. With this, we can deduce that the signs of deterioration in their ecological quality are mainly in the middle and lower reaches of the river, which correspond to 50 and 100 m alongside the river. PA005 is the most affected at both times of the year. It should be noted that in this sampling station is located the water intake that supplies the water treatment plant of Pacora and where economic activities are developed. "Therefore, it is necessary to make interventions on the issue of the elimination of vegetation cover on the riverbanks, the extraction of stone material, the management of wastewater and solid waste" [6]. Similar results to those found in this study, were documented in Cornejo [6] precisely in this same watershed. Where, she obtained a BMWPA/PAN index of 62 which corresponds to a regular quality. While we obtained an index of 49 during the rainy season, 53 during the dry season and 30 during the transition period, which means that this point is being affected on a large scale and we see quite marked deterioration in a short period of time.

4.2 Physical and chemical variables

4.2.1 Basin 144 – Juan Díaz River

In the dry season, on average, the levels of dissolved oxygen (8.17 mg/L), pH (7.78), and conductivity (199.9 µS/cm) remained at normal levels in all sampling stations (Table 11), by the values established by the primary environmental quality standards and quality levels for inland waters for recreational use with and without direct contact [4]. During the rainy season, levels were below the established limits for dissolved oxygen (5.56 mg/L) and pH (7.05). Conductivity values remained within the accepted range (112.38 µS/cm). Normal values of dissolved oxygen (≥ 5 mg/L) and pH (6.0–9.0) are important in aquatic ecosystems, as they are related to the metabolic processes of aerobic organisms and biological productivity, respectively [1]. In sampling stations JD001 and JD003, where the highest conductivity values were obtained, possibly influenced by wastewater discharge, lower species diversity was observed, compared to that of station JD002, in the rainy season. Although the influence of other factors, such as altitude and/or water temperature, is not ruled out, it is known that conductivity affects species diversity; as conductivity increases, diversity decreases [10].

4.2.2 Basin 146 – Pacora River

In the dry season, on average, the levels of dissolved oxygen (8.31 mg/L), pH (7.97), and conductivity (182.06 µS/cm) remained at normal levels at all sampling stations (Table 12), by the values established by the primary environmental quality standards and quality levels for inland waters for recreational use with and without direct contact [4]. During the rainy season, levels were below the established limits for dissolved oxygen (7.51 mg/L) and pH (7.52).

In the dry season, on average, dissolved oxygen levels (8.17 mg/L), pH (7.78) and conductivity (199.9 µS/cm) remained at normal levels at all sampling stations (Table 11), by the values established by the primary environmental quality standards and quality levels for inland waters for recreational use with and without direct contact [4]. Whereas, in the rainy season, the levels were lower than the limits established for dissolved oxygen (5.56 mg/L) and pH (7.05). Conductivity values were maintained within the accepted range (112.38 µS/cm).

Table 11: Values of the BMWP/PAN biotic index for water quality and physicochemical variables at each sampling station during the rainy (LL), dry (SE), and transition (TR) seasons in the Juan Diaz River basin. Normal ranges: LDO: 7.0–8.0 mg/L, pH: 6.0–9.0, conductivity: 100–200 µS/cm [7], [10].

Physical and chemical variables of the 144 Juan Diaz river basin in the rainy, dry and transition periods					
Season	Variable	BMWP/PAN	LDO (mg/L)	pH	Conductivity (µS/cm)
JD001	JDR	155	8.65	7.97	133.6
	LL	23	8.7	7.07	134.5
	SE	151	8.35	8.05	140.5
	TR	76	8.27	7.65	116.8
JD002	LL	50	7.88	7.2	370
	SE	103	7.9	7.75	135.6
	TR	86	7.34	7.58	131.5
JD003	LL	27	0.1	6.9	138.8
	SE	15	7.81	7.35	323.6
	TR	13	7.55	6.68	316.8
Average	LL	33.33	5.56	7.05	214.43
	SE	89.66	8.2	7.78	199.9
	TR	58.33	7.72	7.3	188.36

Table 12: Values of the BMWP/PAN biotic index for water quality and physicochemical variables at each sampling station during the rainy (LL), dry (SE) and transition (TR) seasons in the Pacora River basin. Normal ranges: LDO: 7.0–8.0 mg/L, pH: 6.0–9.0, conductivity: 100–200 µS/cm [7], [10].

Physical and chemical variables of the 146 Pacora river basin in the rainy, dry and transition periods					
	Variable	BMWP/PAN	LDO (mg/L)	pH	Conductivity (µS/cm)
PA001	PAR	154	9.41	8.07	159.1
	LL	62	9.15	7.11	124.4
	SE	171	7.76	8.5	177.4
	TR	88	7.68	7.91	170.6
PA002	LL	54	9.34	7.5	135.3
	SE	103	9.21	7.93	165.9
	TR	101	8.08	8.03	161.3
PA003	LL	41	6.16	7.6	154.5
	SE	76	8.19	8.14	198.5
	TR	65	7.93	7.82	178.6
PA004	LL	58	6.11	7.66	139.8
	SE	88	7.66	7.62	178.2
	TR	61	6.89	7.73	179.6
PA005	LL	49	6.8	7.77	169.2
	SE	53	8.73	7.68	190.3
	TR	30	8.61	7.58	207.1
Average	LL	52.8	7.51	7.52	144.64
	SE	98.2	8.5	7.99	182.06
	TR	69	7.83	7.81	179.44

Table 13: Values of the BMWP/PAN biotic index for water quality and physicochemical variables at each sampling station during the rainy (LL), dry (SE), and transition (TR) seasons in the Pacora River basin. Normal ranges: LDO: 7.0–8.0 mg/L, pH: 6.0–9.0, conductivity: 100–200 µS/cm [7], [10].

Physical and chemical variables of the 142 Matasnillo river basin in the rainy, dry and transition periods					
	Variable	BMWP/PAN	LDO (mg/L)	pH	Conductivity (µS/cm)
MA001	LL	14	3.8	7.77	302
	SE	22	3.61	7.36	380.4
	TR	20	3.83	7.08	384.1
MA002	LL	3	1.15	7.54	600
	SE	17	1.99	7.23	629
	TR	3	2.91	6.58	613
MA003	LL	3	0.9	6.81	600
	SE	3	2.78	7.37	546
	TR	4	2.44	7.4	510
MA004	LL	3	1	7.91	554
	SE	5	2.84	7.84	568
	TR	11	1.2	7.08	555
Average	LL	5.75	1.71	7.5	514
	SE	11.75	2.8	7.45	530.85
	TR	9.5	2.59	7.03	515.52

5 CONCLUSION

In the first place, we were able to evaluate the quality of the water with macroinvertebrates in an altitudinal gradient comparing with the biological results and previous studies of water quality, we were able to classify the most representative families of benthic macroinvertebrates present in the Juan Diaz, Matasnillo and Pacora rivers.

Of the three watersheds treated and according to the BMWP, we were able to observe that the Matasnillo River has the highest range of contamination with a value of <19 and the Pacora River has the lowest range.

The physical and chemical variables showed that during the rainy season the levels were low, by the values established by the primary environmental quality standards and quality levels for inland waters for recreational use with and without direct contact, influencing the heterogeneity of the aquatic macroinvertebrates found in each sampling station. We consider that climate was an important factor in our sampling. Since it, directly and indirectly, influenced the abundance of insects in the river.

In the Matasnillo River, we obtained a total of 434 individuals distributed in 21 families, in the Juan Díaz River 2707 individuals were distributed in 48 families, and in the Pacora River 4073 individuals were distributed in 54 families. The total number of individuals in our sampling basins was 7214. Of which, the highest to the lowest abundance of families we have in the Pacora River; and the most predominant Atyidae. In the Juan Díaz River, Atyidae, and the Matasnillo River, the Thiaridae family, therefore, it is corroborated that in the higher areas less contamination can be observed.

www.witpress.com, ISSN 1743-3541 (on-line)

ACKNOWLEDGEMENTS

We thank the National Secretariat of Science, Technology, and IOMA Project 19-008: Environmental impact of multistressors on aquatic ecosystems of the metropolitan area of Panama, Innovation (SENACYT), Quiriatjaryn Ortega, the Wetland International Foundation, our advisors Aramis Averza, Edgar Araúz, and Edgardo Muñoz, and researchers Aydeé Cornejo and Carlos Nieto of the Gorgas Memorial Center for their support and expanding our knowledge. and to our colleague Adolfo Alba for supporting us and helping us in the grammar of the paper.

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