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CASE STUDY

Macroinvertebrate composition as a determinant of larval abundance in the dragonfly, *Miathyria marcella* in tropical wetlands

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ABSTRACT

BACKGROUND AND OBJECTIVES: Odonate larvae play an important role in macroinvertebrate trophic networks and are excellent indicators of wetland quality. However, despite their ecological importance, research on odonates and how they interact with their environment is scarce. This study aims to assess macroinvertebrate composition as a determinant of larval abundance in *Miathyria marcella* (Odonata: Anizoptera: Libellulidae).

METHODS: In total, 29 samples were collected from six wetlands with different types of hydrological influence using standardized invertebrate sampling techniques in Atlántico, a department located in northern Colombia. Standardized invertebrate sampling techniques were used at 29 sampling points. Obtained data were used to analyze invertebrate abundance and a non-parametric multidimensional scaling analysis was applied. In addition, a correlation analysis was conducted between macroinvertebrate composition and Miathyria marcella larval abundance.

FINDINGS: A total of 2586 larvae and 12925 individual macroinvertebrates were collected, distributed across 25 orders and 58 families. The most abundant orders were Neotaenioglossa (26 percent), Odonata (15 percent) Calanoida (10 percent) and Diptera (8 percent). Heatmap and scaling analysis indicated different macroinvertebrate compositions in the sampled wetlands. It was found a high positive correlation between Miathyria marcella and the orders Odonata (R^2 = 0.84, p-value ≤ 0.05), Coleoptera (R^2 = 0.52, p-value ≤ 0.05), Basommatophora (R^2 = 0.60, p-value ≤ 0.05), and Hemiptera (R^2 = 0.50, p-value ≤ 0.05).

CONCLUSION: The results suggest that the abundance of *Miathyria marcella* responds to the accompanying macroinvertebrates, the composition of which depends on the type of hydrological influence. Assessment approaches that focus on the relationships between macroinvertebrate taxa are important conservation tools for biodiversity assessment. Results from this study will serve as a baseline to propose monitoring and follow-up strategies for environmental sustainability in wetlands in this region.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
36	6	2

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INTRODUCTION

Odonates are one of the most familiar insect groups. They are predators relatively large in comparison with other insects and are widely distributed across aquatic environments. More than 6300 species have been described, exhibiting considerable variation depending on their habitat, type of prey consumed, and set of ecological conditions needed for establishing populations (Bybee *et al.,* 2021). Due to their large diversity, easy identification, and high sensitivity, Odonate communities have been used as key bioindicators for verification of ecological integrity of ecosystems, assessment of environmental impacts, and making decisions on conservation measures (Carvalho-Soares, 2022). Several authors have found that this insect order adapts to environmental factors such as light, temperature, water currents, substrate, geography, drought and flooding periods, available food, species competition, biotic and abiotic changes, and anthropogenic changes (Bowles and Kleinsasser, 2022). In this regard, habitat integrity is essential to define their distribution and abundance. Population dynamics within an ecosystem are strongly determined by the trophic chain and its components. In the case of macroinvertebrates, they play an important role in maintaining equilibrium in aquatic environments (Ramírez and Gutiérrez-Fonseca, 2014). As a result, several researchers have analyzed the efficiency of odonates as biological control agents in several ecosystems (Akram and Ali-Khan, 2016). These insects are also important for ecosystem trophic networks, as they are part of the diet of birds, reptiles, fish, and amphibians (Abdul, 2017). Dragonflies are important predators of several macroinvertebrates (Vilenica, 2017). Different authors have used correlation analysis to observe the relationships between dragonflies with different biotic and abiotic variables. González-Soriano *et al.* (2021) found relationships between Odonata in terms of monthly diversity, that is, taxonomic divergence with monthly precipitation values. Dou *et al.* (2022) evaluated relationships between species richness, diversity of macroinvertebrates, and biomass of macroinvertebrates. Younes *et al.* (2015) evaluated the predation potential of *Hemianax ephippiger* (Odonata: Aeshnidae) nymphs on the freshwater snail *Lymnaea natalensis*, intermediate host of *Fasciola*, a liver fluke able to cause livestock losses and affect human health. They found that dragonflies are ideal pest predators, playing an important regulatory role in ecosystems. Researchers found that nymphs of *H. ephippiger* are a viable option for snail control in freshwater wetlands, contributing to their conservation through biological control (Younes *et al.,* 2015). Mandal *et al.* (2018) assessed the efficiency of Odonate nymphs for biological control against larvae of the mosquito *Culex quinquefasciatus*. Despite having differing consumption rates depending on the species and developmental stage, nymphs were able to consume a substantial amount of mosquito larvae, increasing their capacity to decrease their numbers. These results highlight the fact that introducing Odonate nymphs into wetlands aids the efficient control of pests and vectors. Table 1 provides an example of recent research on the relationship of Odonata with macroinvertebrates. However, despite the ecological importance of Odonata, research on their interactions with the environment and other macroinvertebrates is scarce. The objective of this study is to evaluate macroinvertebrate composition as a determinant factors in the larval abundance of the Odonate *Miathyria marcella* (Odonata: Anisoptera: Libellulidae). This study was carried out in six wetlands in Atlántico, a department in northern Colombia. Field measurements and laboratory analysis for this study were conducted in 2021.

MATERIALS AND METHODS

Biological samples were collected and transported to the laboratory for determination of the macroinvertebrate composition. Descriptive analysis was performed and the relationships between macroinvertebrates and larval abundances of *M. marcella* were analyzed using correlation analysis. This research was based on the hypothesis that the abundance of fauna associated with macrophytes in the wetlands of the department of Atlántico is a determinant of the distribution and abundance of *M. marcella* larvae (Odonata: Anizoptera: Libellulidae).

Study area

The study was performed in Atlántico, a department located in northern Colombia, particularly in the wetlands Totumo (TM), Mallorquín (MQ), Sabanagrande (SG), Larga-Luisa (LL), Tocagua (TG), and Luruaco (LU), all of them locally known as *ciénaga*. Two wetlands (SG and LL) with hydrological influence

Table 1: Summary of recent studies about Odonata´s relationship with macroinvertebrates

Location	Relevant aspects	References
Puerto Rico	Freshwater macroinvertebrates play an important role in maintaining food webs. Odonata (dragonflies and damselflies) are important top predators in these communities and serve as indicators of health. Predator–prey interactions and resource competition, may also shape the distribution of a species. For example, macroinvertebrate abundance is often affected by fish predation.	Mariani-Ríos *et al.* (2022)
Poland	This study evaluated the community composition and diversity and the heterogeneity of macroinvertebrate communities. It was found that habitat heterogeneity influenced benthic invertebrates more than water parameters. Thus, other factors, such as fish predation, may have played a leading role in community shaping.	Czerniawska-Kusza *et al.* (2022)
Singapore	The biological control potential of odonata larvae was evaluated. Functional response experiments using *Aedes albopictus* larvae as prey, highlighting their predatory efficiencies at low prey densities and demonstrating that urban odonates can consume substantial numbers of mosquito larvae (up to 44 per day) under experimental conditions. Complementary field-based experiments, however, showed little impact of odonate larvae predation on the overall composition of naturally colonizing aquatic macroinvertebrate communities, but revealed substantial size-selective predation by odonate larvae on mosquito larvae.	Choo *et al.* (2021)
South Kores	Habitat preferences and trophic level of *Brachydiplax chalybea* larvae were identified. Stable isotope analysis showed that *B. chalybea* is likely to consume, as a food source, other species of Odonata larvae.	Choi *et al.* (2020)
USA	Ecosystem Services indicate that Odonata (dragonflies and damselflies) have some impact as predators of disease vectors and agricultural pests. In addition, their larvae are very important as intermediate or top predators in many aquatic ecosystems.	May (2019)
Cuba	They studied the Odonata's larvae associated with the root system of *Eichhornia crassipes*. It was determining the taxonomic composition and the trophic structure. The relationship between climatic variables, root volume and density of individuals suggests that the number of rainy days and accumulated rainfall influence in the abundance of certain taxa and that the roots of *Eichhornia crassipes* can be appraised as an important habitat for dragonflies larvae and a great place to find food for them.	Barbán (2015)

from the Magdalena River, two (TM and MQ) with hydrological influence from the Caribbean Sea, and two (TG and LU) with hydrological influence from seasonal runoff. Sampling sites in the wetlands were selected considering the affluents, effluents, and macrophyte distribution (Fig. 1). Table 2 describes some of the relevant characteristics of the wetlands sampled.

Sample collection and preservation

Standardized techniques for macroinvertebrate collection (Correa-Araneda et al., 2021) were used in this study. Macroinvertebrates were collected using a conical net with a diameter of 40 cm, a length of 65 cm, a mesh size of 250 µm, and a metallic handle with a length of 90 cm. The collection method was standardized in each sampling point, five minutes in a 1 m^2 area (Correa-Araneda *et al.,* 2021). Samples were stored in Ziploc plastic bags containing 70% alcohol, labeled with the respective field data in order to be processed in the laboratory.

Macroinvertebrate identification

Collected materials were placed on plastic trays and rinsed with water before separating faunal elements with entomological tweezers. Taxonomic keys were used to identify collected faunal elements to the lowest taxonomic rank possible, and fauna were quantified for each sampling point (Hamada *et al.,* 2018). Sorted macroinvertebrates were deposited in vials containing 70% alcohol and labeled with field data.

Data analysis

To assess macroinvertebrate composition as a determinant factor of *M. marcella* larval abundance,

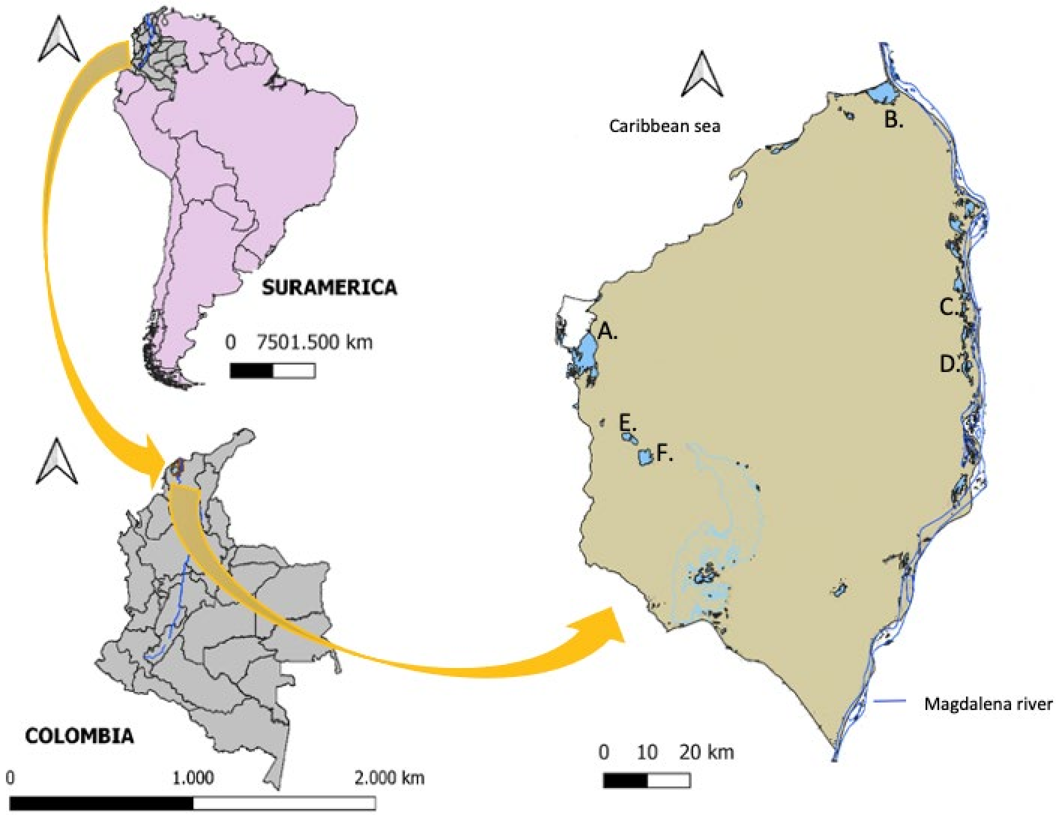

Fig. 1: Geographic location of the studied wetlands and sampling points
(A. TM wetland; B. MQ wetland; C. SG wetland; D. LL wetland; E. TG wetland; F. LU wetland)

Table 2: Characteristics of wetlands sampled

Wetlands	Hydrological influence	Wetland surface (km)	Max depth/ mean depth (cm)	Water temperature (°C) Mean±SD
TM	Caribbean Sea	Perimeter: 24.80 Max length: 6.9 Max width: 3.5	210/110	30.4±0.2
MQ	Caribbean Sea	Perimeter: 15.90 Max length: 4.0 Max width: 3.1	170/55	28.1±0.2
SG	Magdalena River	Perimeter: 3.15 Max length: 1.12 Max width: 0.60	140/80	31.9±0.4
LL	Magdalena River	Perimeter: 6.92 Max length: 2.90 Max width: 0.38	110/60	30.2±0.3
TG	Local streams	Perimeter: 6.81 Max length: 2.63 Max width: 1.08	180/106	31.8±0.2
LU	Local streams	Perimeter: 7.10 Max length: 2.02 Max width: 1.70	220/84	32.8±0.17

a descriptive analysis with macroinvertebrate compositions and *M. marcella* larval abundance was performed. Macroinvertebrates were organized at the order level. The general distribution was described for each type of hydrological influence. In addition, a heat map was generated and a non-parametric multidimensional scaling (NMDS) analysis was applied using Bray-Curtis distances. Then, a correlation analysis was performed in order to determine the association between macroinvertebrates and larval abundances of *M. marcella*.

RESULTS AND DISCUSSION

The results were separated into the following categories: *Miathyria marcella* abundances, macroinvertebrate composition, and relationship between macroinvertebrate abundance and *Miathyria marcella*.

Miathyria marcella abundances

A total of 2586 individual *M. marcella* larvae were collected and distributed as follows: 1011 individuals in LL, 486 individuals in TG, 465 individuals in LU, 372 individuals in SG, 239 individuals in TM, and 13 individuals in MQ. Mean and standard deviation were greater in wetlands hydrologically influenced by the Magdalena River (19.4±1.7 individuals in LL and 9.3±1.4 individuals in SG), followed by wetlands hydrologically influenced by local drainages (8.1±0.4 individuals in RG and 6.4±0.4 individuals in LU). Lastly, abundances were lowest in wetlands hydrologically influenced by the Caribbean Sea (3.9±0.3 individuals in TM and 0.3±0.1 individuals in MQ) (Fig. 2).

The abundance of *M. marcella* larvae differed among the sampled wetlands. The results indicate that abundances were higher in wetlands influenced by the Magdalena River, as well as in those influenced by seasonal drainage. The lowest abundance was found in wetlands influenced by the Caribbean Sea. Mallorquín is a lagoon bound to the north by the Caribbean Sea, and they exchange water sporadically through a connection that is sometimes natural and sometimes artificial (Torres-Bejarano et al., 2020). Lower values in wetlands with Caribbean influence are consistent with the results of Rychla *et al.* (2011), who assessed the effect of conductivity (113 - 2620 µS/cm) on richness and abundance of dragonfly species. Their results showed that no species was reported in conductivities higher than 1200 µS/cm. In addition, they concluded that high conductivity is harmful for dragonflies. Gómez-Tolosa *et al.* (2015) pointed out that *M. marcella* is a species that may adapt to different aquatic environments. It has been shown that Odonate abundance is directly related to environmental quality due to the sensitivity of members of this order to environmental changes. The

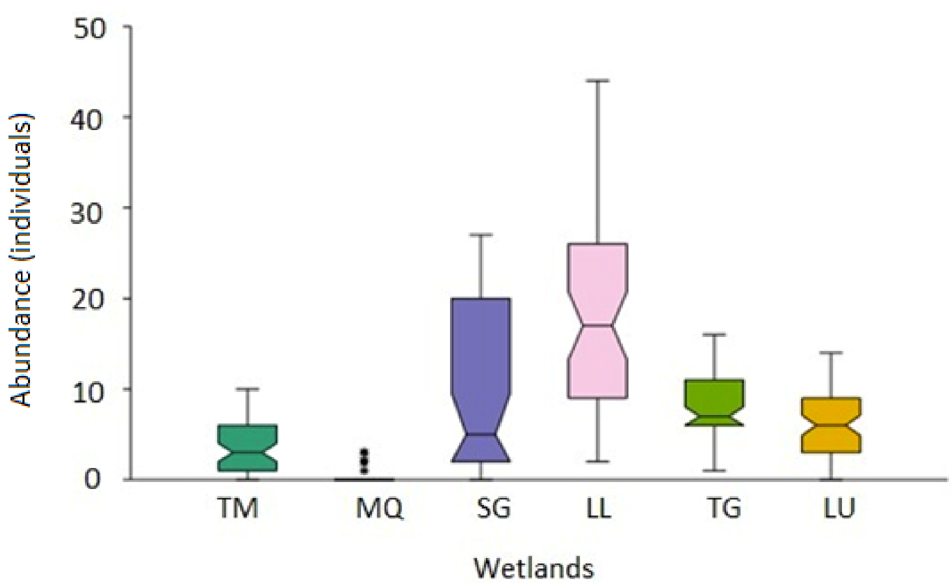

Fig. 2: Abundance of *M. marcella* larvae in sampled wetlands.

most significant threats to freshwater ecosystems are changes in land use that alter sediment loads or nutrient inputs, increase interactions with exotic species, change flow regulation and habitat fragmentation, and alter hydrology (Hecca *et al.,* 2018; Karbassi and Pazoki, 2015).

Macroinvertebrate composition

A total of 12925 individuals were collected, distributed across 25 orders and 58 families. Comparing wetland abundances, more individuals were found in LU, with 3496 individuals, followed by wetlands influenced by the Magdalena River, with 2378 individuals, and 2181 individuals in LL and SG, respectively. The abundance in wetlands TG, TM, and MQ was 2142, 1854, and 874 individuals, respectively. The most abundant orders were Neotaenioglossa (26%), Odonata (15%), Calanoida (10%), and Diptera (8%) (Fig. 3). Orders with abundances lower than 1% were Eunicida, Lepidoptera, Megaloptera, Mytiloida, Neogastropoda, Neritopsina, Stylommatophora, Trichoptera, and Unionoida.

Macroinvertebrate composition differed among wetlands. The most abundant orders in TM were Diptera, with 340 individuals, and Calanoida, with 369 individuals. In MQ, the most abundant group was Neotaenioglossa, with 292 individuals; in SG Odonata, with 404 individuals; LL Odonata, with 545 individuals; and Diplostraca, with 433 individuals. In TG Neotaenioglossa, there were 528 individuals, and Odonata had 526 individuals. LU Neotaenioglossa had 1511 individuals (Fig. 4). Similarly, NMDS results indicated differences in macroinvertebrate abundances among sampled wetlands (Fig. 5).

Insect orders Coleoptera, Diptera, Hemiptera, and Odonata are generally found in lentic systems (Rivera-Usme *et al.,* 2015). However, it was found that Neotaenioglossa (Mollusca), Diplostraca (Crustacea), and Calanoida (Copepoda) were also among the most abundant orders. In studies of coastal wetlands, mollusks and copepods are among the most abundant elements (Suárez-Morales, 2015), which is consistent with the results obtained for wetlands TM and MQ. Diplostracans are important elements of temporal waterbodies. The abundance of this group depends on precipitation frequency and magnitude (Schwentner *et al.,* 2015), being associated with inundation pulses in wetlands LL and SG. Flow increase during rainy

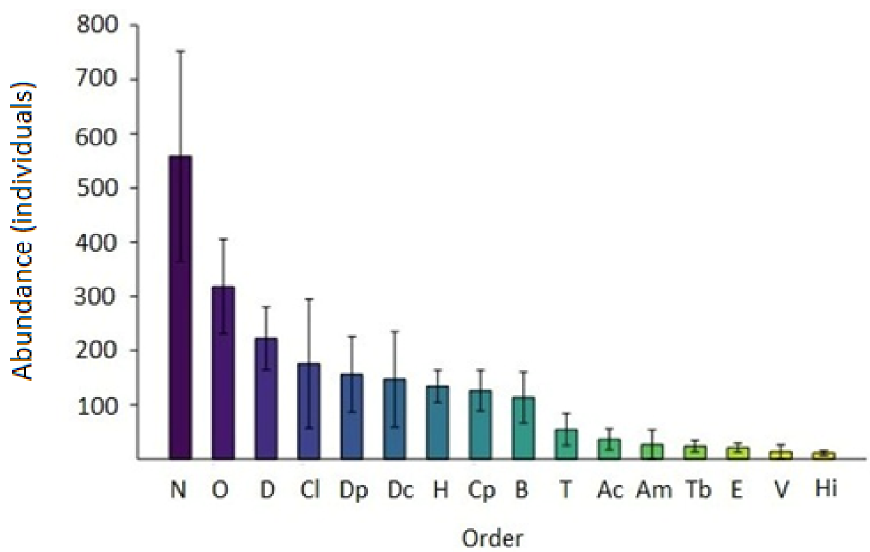

Fig. 3: Macroinvertebrate order abundances. Orders with abundances below 1% were excluded.
Bars represent standard error. N: Neotaenioglossa (Mollusca: Gastropoda). O: Odonata (Arthropoda: Insecta). D: Diptera (Arthropoda: Insecta). Cl: Calanoida (Arthropoda: Maxillopoda). Dp: Diplostraca (Arthropoda: Branchiopoda). Dc: Decapoda (Arthropoda: Malacostraca). H: Hemiptera (Arthropoda: Insecta). Cp: Coleoptera (Arthropoda: Insecta). B: Basommatophora (Mollusca: Gastropoda). T: Tubificida (Annelida: Clitellata). Ac: Architaenioglossa (Mollusca: Gastropoda). Am: Amphipoda (Arthropoda: Malacostraca). Tb: Trombidiformes (Arthropoda: Euchelicerata). E: Ephemeroptera (Arthropoda: Insecta). V: Veneroida (Mollusca: Bivalvia). Hi: Hirudinida (Annelida: Clitellata).

periods has a significant influence on sediment and nutrient load and promotes the fast colonization of species adapted to this type of wetland (Cid *et al.*, 2017). Castillo and Huamantico (2020) indicated that differences in macroinvertebrate composition among wetlands are caused by hydrology, aquatic vegetation, anthropogenic perturbations, and accompanying faunal elements. Composition differences among wetlands, as indicated by heat map and NMDS, are mediated by these factors along with differences in wetland hydrological influence (Magdalena River, Caribbean Sea, or Seasonal Drainages). In addition,

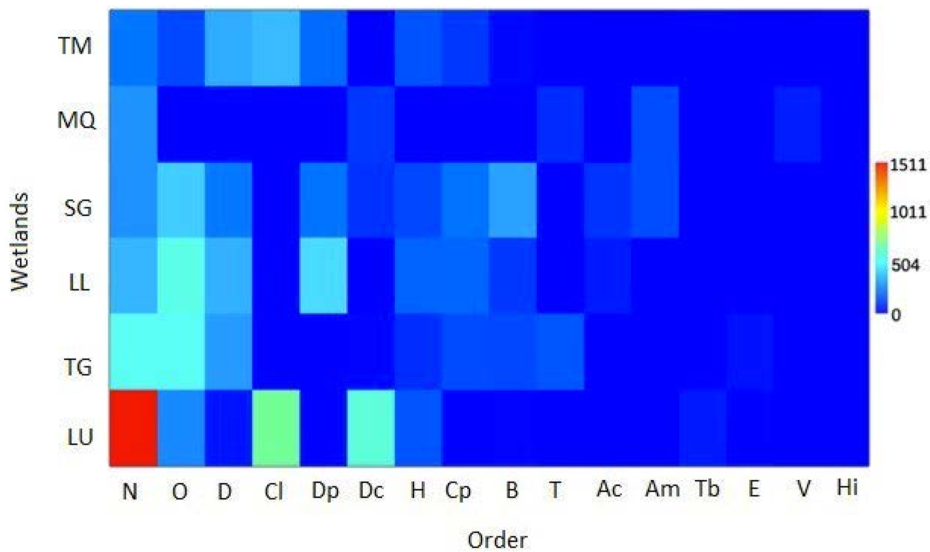

Fig. 4: Macroinvertebrate abundance heatmap in sampled wetlands.

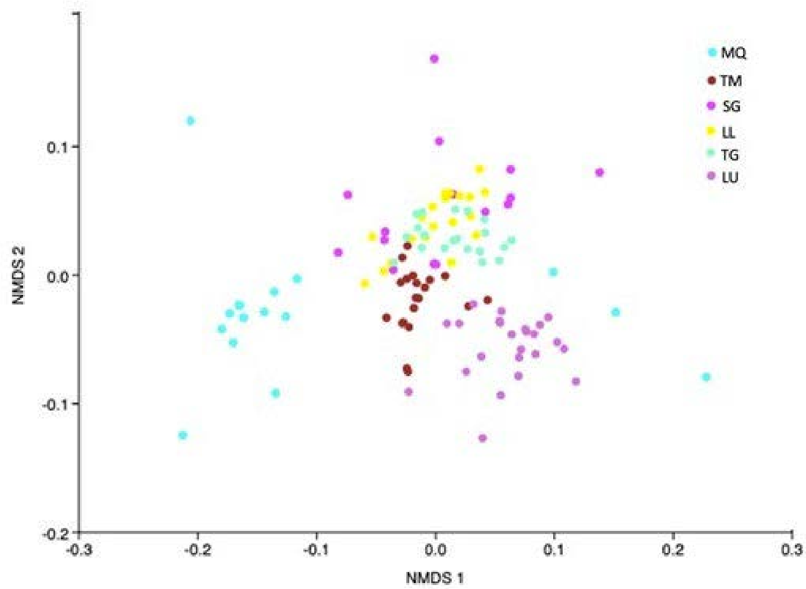

Fig. 5: Non-metric multidimensional scaling (NMDS) based on Bray-Curtis distance. Ordination plot illustrating differences in macroinvertebrate abundance between wetlands

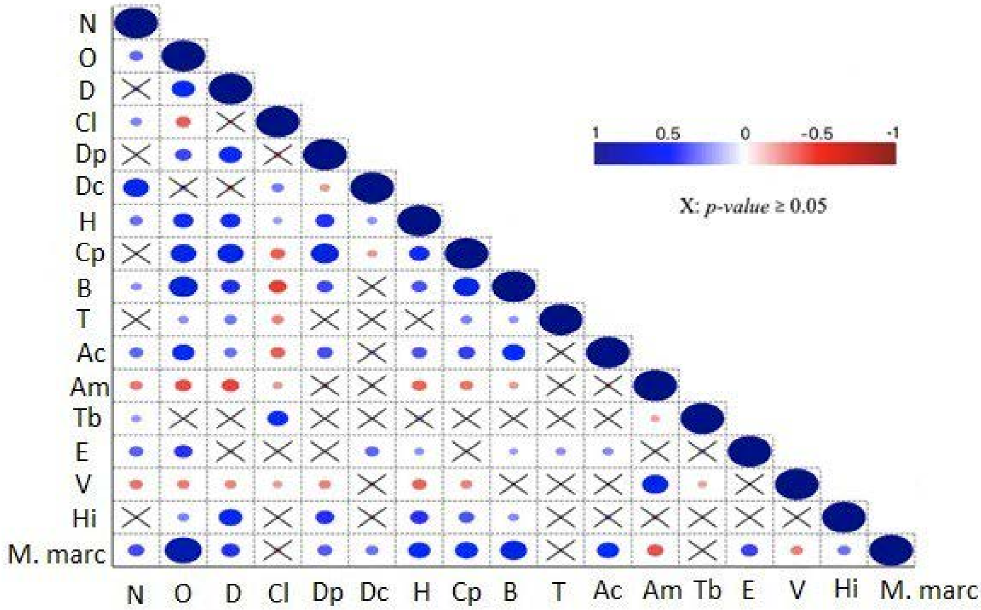

Fig. 6: Spearman correlation matrix between abundances of macroinvertebrate orders and *M. marcella* (p-value ≤ 0.05 blank). N: Neo-taenioglossa. O: Odonata. D: Diptera. Cl: Calanoida. Dp: Diplostraca. Dc: Decapoda. H: Hemiptera. Cp: Coleoptera. B: Basommatophora. T: Tubificida. Ac: Architaenioglossa. Am: Amphipoda, Tb: Trombidiformes. E: Ephemeroptera. V: Veneroida. Hi: Hirudinida. M.marc: *M. marcella*.

Tonkin *et al.* (2017) and Guellaf *et al.* (2021) found seasonal changes in macroinvertebrate community composition and structure due to environmental fluctuations including precipitation and caudal regime.

Relationship between macroinvertebrate abundance and Miathyria marcella

Spearman correlation values indicated statistically significant correlations between some analyzed variables (p-value ≤ 0.05). A high positive correlation was found between M. marcella and the orders Odonata (R^2 = 0.84, p-value ≤ 0.05), Coleoptera (R^2 = 0.52, p-value ≤ 0.05), Basommatophora (R^2 = 0.60, p-value ≤ 0.05), and Hemiptera (R^2 = 0.50, p-value ≤ 0.05) (Fig. 6).

The correlation found between *M. marcella* and the orders Odonata, Coleoptera, and Hemiptera can be explained by the high dispersal ability of these insect groups in a wide variety of aquatic environments. These groups inhabit all types of freshwater and brackish environments, from small ponds to lakes, wetlands, and streams (Guellaf *et al.*, 2021), tolerating a wide variety of environmental and anthropogenic stressors at different spatial and temporal scales (Abdul *et al.*, 2017). Similarly, the relationship between *M. marcella* and these orders may be caused by their tropic relationships, as they are potential dietary elements. Different authors have used correlation analysis to observe the relationships between dragonflies with different biotic and abiotic variables. González-Soriano *et al.* (2021) found relationships between Odonata in terms of monthly diversity, that is, taxonomic divergence with monthly precipitation values. Dou *et al.* (2022) evaluated relationships between species richness, diversity of macroinvertebrates, and biomass of macroinvertebrates. However, experimental observations have shown that Odonate larvae are cannibals, and also consume Coleopterans (Fulan and Anjos, 2015), Basommatophorans (Younes *et al.*, 2015), and Hemipterans (Kondo *et al.*, 2015). Adult and larval Odonates play an important role, both as predators and prey of other animals (Samanmali *et al.*, 2018). It is important to assess which macroinvertebrates serve as food for Odonates, as predation affects species abundance, population dynamics, and community structure (Mariani-Ríos *et al.*, 2022). Macroinvertebrates have long been used as proxies for environmental status, particularly in the context of water pollution and habitat perturbation (Buczynska and Buczynski, 2019). Among orders related to *M. marcella* abundance, there are different responses to environmental factors and perturbations. However, they are considered to be tolerant to water pollution (Silva *et al.,* 2020). Assessment approaches that focus on macroinvertebrate relationships are important conservation tools for evaluation of biodiversity. Assessment of *M. marcella* larvae is intended to provide information on distribution and abundance, in relationship to the accompanying fauna. Studies including estimates of *M. marcella* accompanying fauna will contribute to a better understanding and management of wetlands.

CONCLUSIONS

Abundance values for *M. marcella* larvae along with macroinvertebrate composition differed among sampled wetlands. A total of 12925 individual macroinvertebrates were collected. The most abundant orders were Neotaenioglossa, Odonata, Calanoida, and Diptera. Heatmap and scaling analysis indicated different macroinvertebrate compositions in the sampled wetlands. It was found a high positive correlation between *Miathyria marcella* and the orders Odonata, Coleoptera, Basommatophora, and Hemiptera. Hydrological influence has a significant effect on this distribution, as their abundance was greater in wetlands hydrologically influenced by the Magdalena River, followed by those hydrologically influenced by seasonal drainages, and with the lowest abundance in wetlands hydrologically influenced by the Caribbean Sea. *M. marcella* is a species that may adapt to different aquatic environments. It has been shown that Odonate abundance is directly related to environmental quality, due to the sensitivity of members of this order to environmental changes. Composition differences among wetlands, as indicated by heatmap and NMDS, are mediated by hydrology, aquatic vegetation, anthropogenic perturbations, and accompanying faunal elements, along with differences in wetland hydrological influence (Magdalena River, Caribbean Sea, or seasonal runoff). Due to their great diversity, easy identification, and high sensitivity, Odonate communities have been used as key bioindicators to verify the ecological integrity of ecosystems and assess environmental impacts. Results suggest that *M. marcella* abundances respond to accompanying invertebrate groups, particularly the orders Coleoptera, Basommatophora, and Hemiptera. This relationship may be associated with the importance of these orders for Odonate diets. Future research should consider physicochemical variables of water, as they may help to complement and understand macroinvertebrate distribution in wetlands. Without a proper knowledge of distribution for these invertebrate groups, it is not possible to advance conservation efforts. The results of this study will serve as a baseline to propose monitoring and follow-up strategies for the environmental sustainability of wetlands in the Colombian Caribbean. Composition and abundance of macroinvertebrates were assessed using simple techniques, which implies that this methodology can be replicated in other study areas.

AUTHOR CONTRIBUTIONS

M.I. Moreno Pallares performed literature review, experimental design, analyzed and interpreted the data, writing original draft, writing review and editing. M.A. Bonilla Gómez experimental design, writing original draft, writing review and editing. G.H. Guillot Monroy experimental design, writing original draft, writing review and editing. A.C. Torregroza-Espinosa performed literature review, analyzed and interpreted the data, writing review and editing.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

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ABBREVIATIONS

%	Percentage
°C	Degree centigrade
±	Plus–minus sign
>	Greater-than sign
≤	Less than or equal to
µS/cm	Conductivity unit
Ac	Architaenioglossa
Am	Amphipoda
B	Basommatophora
Cl	Calanoida
cm	Centimetre
Cp	Coleoptera
D	Diptera
Dc	Decapoda
Dp	Diplostraca
E	Ephemeroptera
Fig.	Figure
H	Hemiptera
H. ephippiger	*Hemianax ephippiger*
Hi	Hirudinida
km	Kilometer
LL	Larga-Luisa wetland
LU	Luruaco wetland
M. marc	*M. marcella*
M. Marcella	*Miathyria marcella*
m^2	Square meter
masl	Meters Above Sea Level
Max	Maximum
mm	Millimetre
MQ	Mallorquín wetland
N	Neotaenioglossa
NMDS	Non-metric multimensional scaling
O	Odonata
p-value	Statistical significance
R^2	R-squared
SD	Standard deviation
SG	Sabanagrande wetland
T	Tubificida
Tb	Trombidiformes
TG	Tocagua wetland
TM	Totumo wetland
V	Veneroida

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