



Article

The Dynamics of Soil Mesofauna Communities in a Tropical Urban Coastal Wetland: Responses to Spatiotemporal Fluctuations in Phreatic Level and Salinity

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Abstract: Coastal wetlands, vital for ecological diversity, have been significantly altered by anthropogenic activities, particularly in the Caribbean. These changes have created a complex mosaic of habitats and physicochemical conditions, further stressed by climate variability and sea-level rise. This study, conducted in Las Cucharillas Natural Reserve, a tropical urban coastal wetland in Puerto Rico, aimed to determine the effects of spatiotemporal variations in phreatic levels and salinity on soil mesofauna assemblages, crucial bio-indicators of environmental change. In 2020 and 2021, soil samples were collected from five diverse habitat types during different hydroperiods. Each sample was taken under four randomly selected plant types and processed using lighted Tullgren–Berlese extractors. Phreatic level and salinity were also measured. A total of 43 families were quantified, underscoring distinct habitat differences, similarities, and overall ecosystem diversity. Moderate correlations between phreatic levels, salinity, and mesofauna richness and abundance were determined. Peak richness and abundance were quantified at shallow (−0.03 to −0.07 m) and slightly moderate (−0.12 to −0.17 m) phreatic levels where oligohaline salinity (>0.5 to 5.0 ppt) prevails. The study highlights the adaptability of mesofauna to environmental shifts and their potential as biosensors for effective coastal wetland management amid climatic and anthropogenic pressures.

Keywords: urban wetland; coastal wetlands; Puerto Rico; hydroperiods; phreatic level; salinity conditions; soil mesofauna; biodiversity



Citation: Ortiz-Ramírez, G.; Hernández, E.; Pinto-Pacheco, S.; Cuevas, E. The Dynamics of Soil Mesofauna Communities in a Tropical Urban Coastal Wetland: Responses to Spatiotemporal Fluctuations in Phreatic Level and Salinity. *Arthropoda* **2024**, *2*, 1–27. <https://doi.org/10.3390/arthropoda2010001>

Academic Editor: Tetsuo Gotoh

Received: 22 September 2023

Revised: 18 December 2023

Accepted: 2 January 2024

Published: 9 January 2024



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1. Introduction

Wetlands provide heterogeneous ecological niches for unique soil arthropod assemblages, with mesofauna communities being the most abundant and diverse [1–3]. Among these, Acari (mites) and Collembola (springtails) are the most prevalent groups, consisting of microarthropods that range in size from 0.1 to 2 mm. They are present in different soil types, with most of their assemblages concentrated in hot spot zones or resource patches within the litter system, which consists of the loose litter layer and the upper 1–5 cm of the soil [4–6]. In the ecosystem, mites and springtails significantly influence decomposition processes and nutrient mobilization, serving as plant litter transformers through (a) fragmentation and comminution, (b) the ingestion of plant debris, and (c) the deposition of feces, which enhances mineralization by soil microflora (fungi and bacteria) [7–9]. They also foster the growth and dispersal of microbial populations and interact at different trophic levels through the litter decomposition process [10–13]. These microarthropods are sentinel species due to their inherent sensitivity to environmental modulations, thus facilitating the rapid detection and comprehension of the

ecological alterations occurring within a given habitat [14,15]. Their responsive dynamics to environmental fluctuations offer a rich repository of data, critical for interpreting the health and operational dynamics of ecosystems [4].

Soil mites are predominantly represented by three taxa at varying taxonomic levels: the suborder Oribatida (fungivores and detritivores), the order Mesostigmata (free-living soil predators), and the suborder Prostigmata (predators and fungal feeders) [16–18]. Springtails (order: Collembola), which are also fungivores and detritivores, are classified into two main groups: suborder Arthropleona and suborder Symphypleona [18–20]. The distribution patterns and interactions of these organisms occur at different spatiotemporal dynamics [4,8,10,11], which are in turn regulated by scale-dependent variables such as climate (temperature and precipitation), edaphic properties (including porosity, structure, nutrients, humidity, pH, and salinity), vegetation (the quality and quantity of resources), microtopography, and species-specific intra- and interspecific interactions [11]. For example, higher soil temperatures and lower humidity may result in decreased population densities of Mesostigmata mites [21]. Prostigmata mites tend to dominate in soils characterized by low nutrient content and low humidity, whereas Oribatid mites and Collembola (springtails) are typically found in nutrient-rich, humid environments [8,22,23]. The distribution of springtails is associated with soil pore size, relative humidity, and the availability of food [24]. Soil food web structure and mesofauna assemblages are directly and indirectly affected by plant species, as is the case of the legume *Lotus corniculatus* and the non-leguminous forb *Plantago lanceolata* [25]. A trophic cascade effect is observed whereby the microtopography alters the soil environment and thus the diversity and composition of soil fungal communities [26], which may subsequently influence the food resources and habitat quality for Collembola and Oribatida [23].

In coastal wetlands, spatiotemporal variations in the abundance and diversity of soil mesofauna are influenced by the effects of drying and wetting cycles or hydro-patterns on soil bio-physicochemical conditions [26]. General hydro-patterns, which are typically seasonal in water level variation (early dry, dry, early wet, and wet conditions), exhibit significant variability across and within different wetland types and climate conditions. Wetting cycles in wetlands include waterlogging or flooding time, frequency, duration, rate of water rise, and depth [26,27]. These cycles are modified by different water sources, including in-situ precipitation, freshwater inputs, and seawater flows [28]. The hydrological regime (wetting cycles) determines the degree of soil salinity, which subsequently shapes the spatiotemporal patterns of vegetation cover, in addition to the quality and quantity of the litter. The interplay among these factors is pivotal in shaping the spatiotemporal distribution and community dynamics of soil mesofauna [20,21]. For example, in the floodplains of the Netherlands, groundwater levels affect the distribution of Collembola, with a shift in community composition observable along elevation gradients from regularly inundated areas to dry, seldom-flooded zones [15,29,30]. A laboratory study examining the impact of salinity on soil species of Acari (mites) and Collembola (springtails) found that their reproductive cycles were differentially impacted by increasing salinity levels, with mites showing less sensitivity and maintaining their reproductive cycle, while reproduction in springtails significantly decreased [31]. In peatlands from Canada, China, Minnesota (USA), and northern England, variations in hydro patterns induced spatial and temporal fluctuations in bio-physicochemical factors that influenced the diversity and abundance of Acari and Collembola [32].

Although mesofauna communities play an essential role in wetlands' biological processes, there is still a gap in knowledge about how coastal wetlands' spatio-temporal dynamics influence mesofauna diversity, especially in the Caribbean. More research is needed to understand wetland marine–terrestrial–marine connectivity, bio-physicochemical components, and future climate change scenarios and their effects on mesofauna assemblages. Climate change projections for the Caribbean anticipate more frequent extreme precipitation, rising temperatures, and increased sea levels due to shifts in global and regional climate patterns, which are expected to have significant impacts on the region's

coastal wetland ecosystems [33]. Because Caribbean coastal wetlands have been anthropogenically modified since colonial times, a mosaic of physicochemical conditions, habitats, and vegetation cover characterizes these ecosystems; with global and regional climate variability, sea-level rise, land use, and land cover changes acting as additional stressors.

The combined effect between these anthropogenic stressors and the predominant wetland mosaic environment influences the hydrological regime, bio-physicochemical components, and soil mesofauna diversity, abundance, and functional relationships among taxa [33–36]. For instance, sea-level rise impacts coastal soil processes and modifies ecosystems' net primary production due to variations in salinity, which has direct and indirect effects on soil mesofauna diversity and function [37]. In a field experiment in the Zhanjiang Plain wetland, simulated variations in the phreatic level due to precipitation changes demonstrated that mesofauna communities were significantly affected by changes in water level. Slight increases in total abundance were documented under natural water level dynamics, with significant reductions under constant high water level conditions [38].

Given that mesofauna play an essential role in coastal wetland biological processes and have specific environmental requirements, determining how weather variability, shifts in the hydrological regime (wetting cycles), and soil salinity influence their composition becomes an important tool to understand ecosystem responses to global and regional climate change, sea-level rise, and increased anthropic use of the region. An in-depth analysis of their biodiversity serves a dual purpose: elucidating the present ecological state of the wetland and underwriting adaptive management strategies anchored in a robust understanding of ecosystem dynamics [39]. Our aim is to determine the effects of spatiotemporal fluctuations in phreatic levels and salinity on the assemblages of soil mesofauna in a tropical urban coastal wetland. We hypothesize that spatiotemporal variability in phreatic levels and salinity significantly modulates the diversity and abundance of soil mesofauna. This, in turn, has consequential impacts on the structure and dynamics of the mesofauna community, altering their interactions within the soil system and thus changing how they impact their surrounding ecosystem [14].

2. Materials and Methods

2.1. Study Area

The study took place over 2.2 ha (research area) within Ciénaga Las Cucharillas Natural Reserve, a palustrine–estuarine coastal urban wetland on the northern coast of the Caribbean Island of Puerto Rico. The reserve is in the municipality of Cataño (18°26′25.27″ N, 66°08′08.39″ W). The wetland comprises the western side of the San Juan Bay (Figure 1A).



Figure 1. (A) Ciénaga las Cucharillas located on the northern coast of the Caribbean Island of Puerto Rico, at the western side of the San Juan Bay, (B) study area (2.2 ha), and (C) study plots 3, 5, 10, and 6.

The average monthly temperature ranges from 31 °C to 25 °C from May to October and from 22 °C to 28 °C from December to March. The area has a humid climate with an average annual precipitation of 1920 mm. The rainfall distribution is bimodal, with lower precipitation occurring from December to April–May and two peak periods from May to June, and September to November [40]. The study was carried out from 2020 to 2021 (Figure 2). In 2020, the wettest month was July, with monthly mean precipitation of 9.64 mm and 24 rainy days. The driest month was May, with monthly mean precipitation of 0.51 mm and 6 rainy days. In 2021, the wettest month was September, with monthly mean precipitation of 8.63 mm and 18 rainy days. The driest month was May, with monthly mean precipitation of 1.78 mm and 13 rainy days.

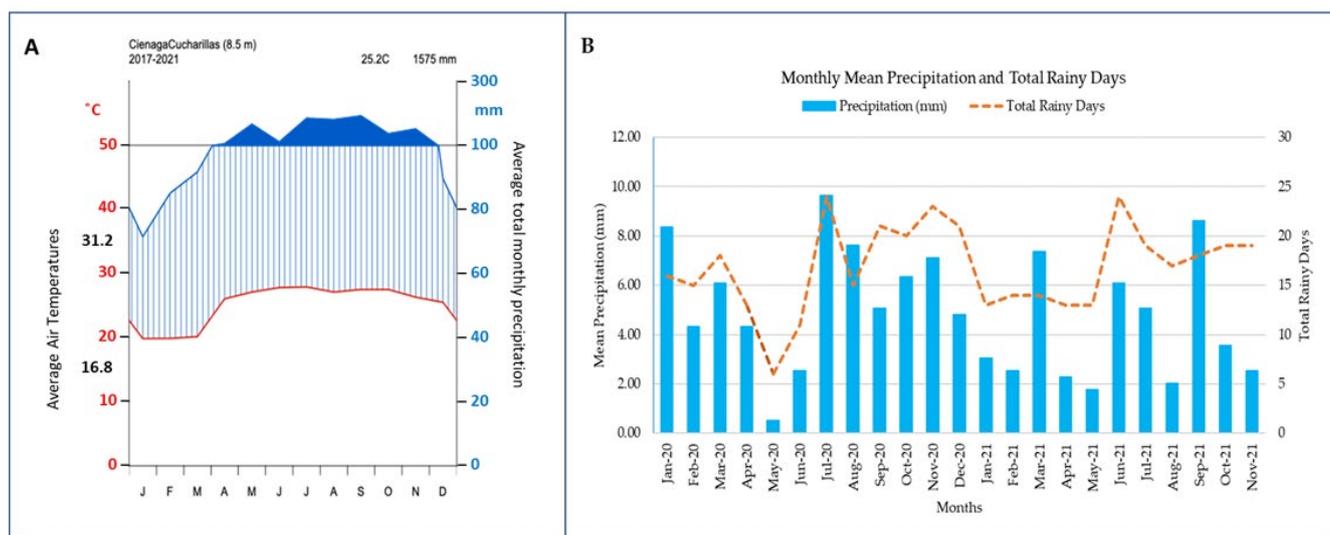


Figure 2. (A) The climate diagram illustrates monthly average air temperatures in °C (left y-axis, in red) and average total monthly precipitation in mm (right y-axis, in blue) from January 2017 to December 2021 (months are represented by letters) at Ciénaga Las Cucharillas Natural Reserve [28]. (B) The graph presents the mean monthly precipitation and the total number of rainy days, using climatological data from January 2020 to November 2021, sourced from the Toa Baja Levittown, PR Meteorological Station [40].

Ciénaga Las Cucharillas Natural Reserve is representative of how coastal wetlands in the Tropics, especially in the Caribbean, have been hydrologically modified from colonial times to the present. The hydrological modifications include (a) drainage channels for agricultural use from the 17th century until the mid-20th century [41,42]; (b) the construction of a flood control channel (La Malaria channel) in the late 1940s, bringing a direct flow of fresh water to the wetland from the upper and middle parts of the basin; and (c) restricted seawater exchange due to the dike effect of an outflow water pump structure at the mouth of the channel [43] (Figure 3). As a result, tidal interaction in this wetland occurs via deep subsurface flow [44]. Historical and present hydrological modifications bring about a mosaic of physicochemical conditions, habitats, and vegetation cover.

The reserve is affected by the interplay of marine-terrestrial subsurface connectivity, local weather conditions, and regional climate variability, impacting water source inputs, including in situ precipitation, freshwater inputs, and seawater flows. These factors markedly influence the spatial and temporal patterns of wetting and drying periods, culminating in a unique regime characterized by variations in the frequency, duration, and timing of inundation. At the study site, flooding occurs due to the combined effect of regional/local precipitation and tidal fluctuations. The duration of flooding varies, persisting for either several months or just a few days, depending on the interplay of climate dynamics.



Figure 3. La Malaria flood control channel (represented by blue lines) positioned northwest of the delineated research area (highlighted with a yellow line) at Ciénaga Las Cucharillas Natural Reserve (outlined with a red line). The location of the outflow water pump structure is indicated by a yellow square at the channel's downstream point of discharge.

2.2. Research Area

Four study plots (3, 5, 6, and 10), each encompassing 100 square meters, were established in a research area within the natural reserve, with each plot featuring distinct physicochemical factors and habitat types. The naming of the plots as 3, 5, 6, and 10 refers to their corresponding pre-established monitoring wells (Figure 4), which have been in place since 2017. This approach was chosen to maintain consistency with the long-term phreatic level and salinity monitoring data available from these wells.

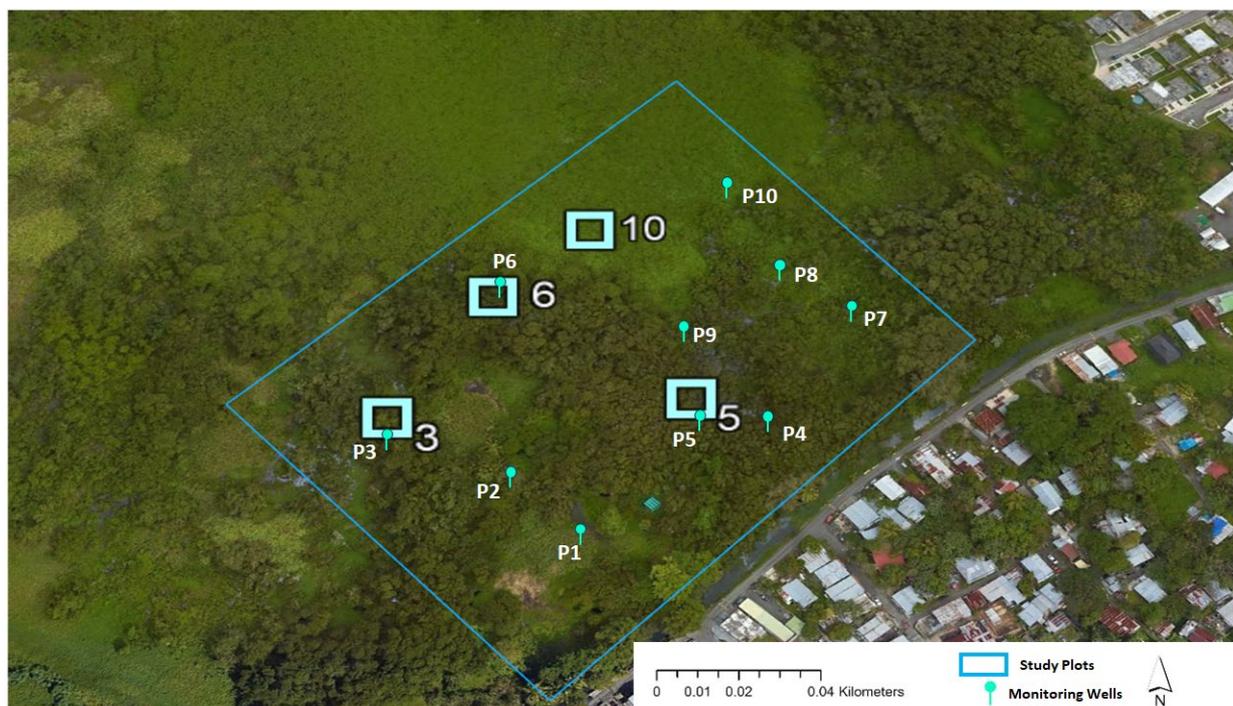


Figure 4. Aerial view of the study plots in the Las Cucharillas wetland research area. The naming of the plots as 3, 5, 6, and 10 refers to their corresponding pre-established monitoring wells (labeled P1 to P10), which have been in place since 2017.

The plot locations were selected based on geospatial analysis, the presence of predominant plant functional types, and onsite measurements of soil abiotic factors [28]. Each habitat has a predominant plant assemblage and variations in micro elevations, vegetation cover, soil type, and salinity (Table 1). Category-4 Hurricane Maria (19–20 September 2017) caused significant damage and defoliation in the study area. Twenty-seven percent (27%) of the area was flooded for nearly six months [45].

Table 1. Physicochemical factors and plots/habitat characteristics at the study site. Source [28].

Plot	3	5	6	10		
Micro-elevation	−0.79	−0.72	−0.86	0.1		
Habitat Type	Mangrove woodland (MMW)	Rehabilitated mangrove woodland (RMW)	Mangrove woodland (MWR)	>50 years Shrub (SM)	6 years grass & ferns (GF)	
Stage	Mature	Rehabilitated; damaged by Hurricane Maria	Natural recolonization damaged by Hurricane Maria	Mature	Early successional	
% Cover Plants Species	92.6% <i>L. racemosa</i> 3.2% <i>Acrostichum</i> sp. 4.2% grasses of the Poaceae family	59.9% young and seedlings <i>L. racemosa</i> , 33.8% herbs and vines 4.2% grasses of the Poaceae family 2.0% <i>Acrostichum</i> sp.	46.0% young and seedlings <i>L. racemosa</i> , 7.9% <i>Acrostichum</i> sp., 13.3% <i>D. ecastaphyllum</i> , 32.8% grasses of Poaceae family	40.4% <i>D. ecastaphyllum</i>	2.2% <i>L. racemosa</i> (young trees), 0.4% <i>Acrostichum</i> sp., 56.9% <i>Echinochloa</i> sp.	
Plant Type	Woody, fern, and grass	Woody, fern, herbs, and grass	Woody, fern, shrubs and grass	Shrubs	Woody, fern, and grass	
Soil Type	Mineral allochthonous embedded in an organic matrix (Martín Peña)			Organic (peat) Autochthonous (Saladar muck)		
Mean Salinity *	Wet Period	3.4 ± 2 O	2.8 ± 1 O	2.4 ± 2 O	2.1 ± 2 O	2.1 ± 2 O
	Dry Period	4 ± 0.4 O	12 ± 2 M	11 ± 5 M	7 ± 1 M	7 ± 1 M

* Salinity values: O—oligohaline refers to salinity levels between >0.5 ppt to 5.0 ppt; M—mesohaline refers to salinity levels between >5.0 ppt to 18.0 ppt.

Plot 3 represents a mature mangrove woodland habitat (MMW), predominantly populated by *Laguncularia racemosa* C.F.Gaertn. In contrast, plot 5 is a 25-year-old restoration mangrove woodland (RMW) with a primary cover of *L. racemosa*, interspersed with herbaceous species from the Cyperaceae, Vitaceae, and Polygonaceae families, as well as grassy patches from the Poaceae family. Plot 6 features a transitioning mangrove woodland (MWR) characterized by natural recolonization with young *L. racemosa* trees and seedlings, along with Poaceae grasses. Lastly, plot 10 comprises a mature 50-year-old shrub habitat (SM) dominated by *Dalbergia ecastaphyllum* (L.) Taub and an adjacent 6-year-old grassland succession area (GF) primarily consisting of *Echinochloa polystachya* (Kunth) Hitchc.

The research area is characterized by two soil types: Saladar muck (Sm) series and Martín Peña (Mp) series [46]. The Saladar muck (Sm) series consists of black, highly decomposed (peat) autochthonous vegetation materials that reach down to the bedrock

depth in the soil (Table 1). The Martin Peña (Mp) series contains deposits of organic material close to the surface (0–20 cm), over mineral sediments, which includes silty clay loam embedded in the peat down to the bedrock depth (20–45 cm). At the study site, the layers of mineral sediments found in the soil are the result of anthropogenic allochthonous infills from upper terrestrial sources, which were deposited during land preparation for shanty town establishment. The MWR, GF, and S habitats are situated on the Saladar muck (Sm) soil series, whereas the MMW and RMW habitats are situated on the Martin Peña (Mp) soil series.

2.3. Data Collection

Sampling in this study was conducted based on hydroperiod conditions to encompass a wide range of phreatic levels and weather conditions, as depicted in Figure 5 [26,27]. Soil samples, including litter layers, were collected on five dates, each chosen to represent distinct hydroperiod conditions: moderate dry (18–25 June 2020), flood (23 October 2020), moist/between floods (19 March 2021), and wet (9 June 2021). This methodology was designed to provide a comprehensive understanding of soil mesofauna responses under diverse environmental stresses.

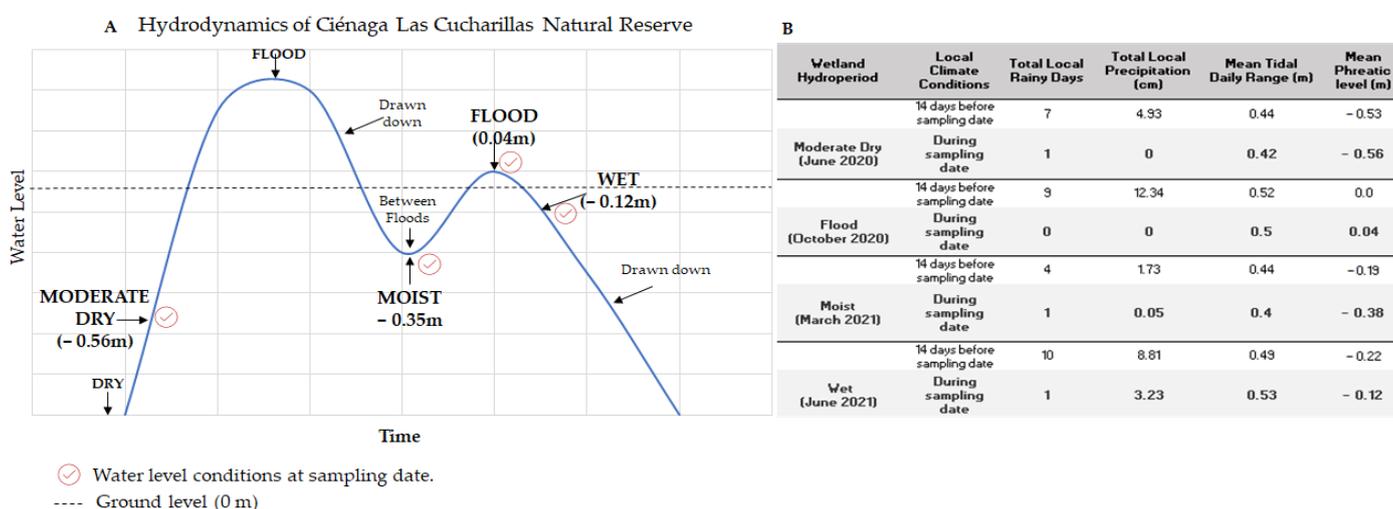


Figure 5. (A) Schematic diagram of the wetland hydrodynamics showing the phreatic level (m) on the date of sampling, adapted from [26]. (B) Overview of local total rainy days, precipitation (cm), mean tidal daily range, and mean phreatic level (m) for the 14-day period leading up to and including the sampling date [27]. These conditions have an influence on the wetland’s hydrodynamics at the time of sampling.

The hydroperiod classification utilized in this study was predominantly predicated on the phreatic level values recorded at the sampling time. This approach was adopted due to the direct influence of these values on the soil environment (reflecting soil antecedent patterns of drying/wetting cycles) [38,47]. Additionally, local rainy day conditions and the mean tidal daily range in the 14 days preceding the sampling date were also considered. These factors are pertinent as they significantly affect the dry and wet cycles of the wetland, as well as the site’s phreatic level at the sampling time. For instance, during prolonged dry periods, bimodal high tide reaches the study site in 20 min, whereas it takes up to 2 h during wet periods [48].

The conditions were categorized as “moderate dry” and “moist” at phreatic levels of -0.56 m and -0.38 m, respectively. Furthermore, “wet” and “flood” conditions were identified at phreatic levels of -0.12 m and at or above the ground level (0 m). It is noteworthy that the moist sampling period, which took place on 19 March 2021, occurred amidst flooding events. Specifically, the site experienced flooding both a week before and after the sampling date, although the week of the sampling itself was dry. The sampling for this period was conducted immediately following the first flood event. Additionally,

the Flood sampling date, which was on 23 October 2020, coincided with the receding of floodwaters. Prior to this date, the wetland had been subjected to significant climatic events, including tropical storms Isaias and Laura, followed by a prolonged rainy period that lasted until the end of October 2020. This resulted in approximately three months of flooding at the site, spanning from August 2020 to October 2020 [49,50].

Sampling was carried out from 7:00 a.m. to 10:00 a.m. to ensure consistent conditions across habitats in terms of soil temperature, water content, and tidal influence (as this timeframe corresponds to the transition from high to low tide; see Table 2). Five plant species were chosen based on their functional type and presence in all habitats [18]: *D. ecastaphyllum* (shrub), *E. polystachya* (grass), Poaceae family (grass), *A. danaeifolium* (woody herb), and *L. racemosa* (tree). *D. ecastaphyllum* was present in two plots (6 and 10), and *E. polystachya* was present in plot 10, while the three other species were present in plots 3, 5, and 6. In each habitat type, three plants per functional type were chosen. Three soil samples, including litter layers, per plant were collected on every sampling date. Each sample measuring 7.62 cm diameter \times 5 cm depth was separated into a loose litter (relatively undecomposed) and an old litter (partly to fully decomposed). The phreatic level was measured on site. The samples were taken to the laboratory, their fresh weight was determined, and they were placed in lighted Tullgren–Berlese extractors for one week. The extracted arthropods were preserved in 70% ethanol solution and placed under each extractor. The collected micro-arthropods were taxonomically identified to the lowest category possible, either class, subclass, order or suborder, and family [51,52]. For each sample, they were identified and counted using an Amscope SF2TRA stereoscopic binocular microscope or a Nikon Eclipse 80i microscope. After extraction, the samples were oven-dried at 60 °C for a period of seven days. A subsample was mixed with distilled water (1:1) and homogenized to determine salinity using an EcoSense[®] conductivity meter [52].

Table 2. Description of tide conditions at the time of sampling, detailing the tidal phase (low or high) corresponding to the sampling events. Data were obtained from [53].

Sampling Date	Sampling Time *	Tide (m)	Tide Description
18 June 2020	7:00	0.22	High
	10:00	0.05	Low
25 June 2020	7:00	0.48	High
	10:00	0.23	Low
23 October 2020	7:00	0.31	High
	10:00	0.14	Low
19 March 2021	7:00	0.29	High
	10:00	0.15	Low
9 June 2021	7:00	0.22	High
	10:00	0.10	Low

* Sampling occurred in the morning, between 7:00 a.m. and 10:00 a.m.

2.4. Data Analysis

Non-parametric statistical methods, including the Wilcoxon/Kruskal–Wallis test followed by post hoc Dunn tests, were employed to discern habitat variations and analyze the impact of phreatic levels and salinity on the diversity and abundance of mesofauna. We meticulously evaluated these environmental factors to elucidate their influence on the distribution and composition of mesofauna. Our analysis focused on the data collected for the primary taxa of mites (the suborder Oribatida, the order Mesostigmata, and the suborder Prostigmata) and two suborders of springtails (Arthropleona and Symphyleona), which are predominant in mesofauna communities and serve as bioindicators of ecosystem changes. The assessment extended to examining the distribution patterns and occurrence of mesofauna families along the gradients of phreatic levels and salinity to gain insights into the adaptive mechanisms and preferred habitats of these soil-dwelling microarthropods.

Normalized abundance values [54], representing the number of individuals per square meter (m^2), and categorized phreatic and salinity levels provided a structured approach to our analysis. These categories were defined as follows:

Phreatic Level Categories:

- High: 0.09 to 0.11 m
- Shallow/near surface: -0.03 to -0.07 m
- Slightly moderate: -0.12 to -0.17 m
- Moderate: -0.36 to -0.43 m
- Deep: -0.51 to -0.64 m

Salinity Categories [55]:

- Freshwater: 0 to 0.5 ppt
- Oligohaline: >0.5 to 5.0 ppt
- Mesohaline: >5.0 to 18.0 ppt
- Polyhaline: >18.0 to 33.0 ppt

Taxonomic families of mesofauna were classified as “dominant”, “common”, or “rare” based on their relative abundance, enabling us to compare community structures across habitats using the Bray–Curtis similarity index and non-metric multidimensional scaling (NMDS) [56–59]. The dominant taxa were defined as those with a relative abundance of 10% or greater, common taxa had a relative abundance between 1% and 10%, and rare taxa were characterized by a relative abundance of less than 1% [55].

Spearman’s Rho correlation analysis delineated the significant correlations between these factors and the mesofauna composition. Furthermore, a general regression model was employed to elucidate the relationships and to determine the significance and intensity of the effects of the phreatic level and salinity variables. All statistical analyses were conducted through the utilization of SAS JMP® Pro 16 and R Studio 4.3.1® (R Core Team, 2023) statistical software.

3. Results

3.1. Variations in Habitat Phreatic Level and Salinity

Overall, significant variations in phreatic levels were observed among the different hydroperiods ($p < 0.05$). These hydroperiods can be ranked based on phreatic level measurements as follows: flood $>$ wet $>$ moist $>$ moderate dry (Table 3). From a habitat perspective (Table 4), substantial differences in phreatic levels were identified. During the flood period, the water level was above the soil surface for mature mangrove woodland (MMW) and natural recolonization mangrove woodland (MWR), whereas it remained near the soil surface for rehabilitated mangrove woodland (RMW), early successional grass and ferns (GF), and the mature shrub habitat (SM). In the moist period, the RMW exhibited the lowest phreatic levels, while GF, the MWR, and the SM displayed higher values, which were significantly different from the phreatic levels in other habitats ($p < 0.0001$). However, during the moderate dry period, no significant differences in phreatic levels were observed between the MMW and the MWR, as well as between the SM and GF. Similarly, no significant differences were noted among GF, the MWR, and the SM during the wet period.

Table 3. Phreatic level (m) (mean \pm std) between habitats and hydroperiods. Values not connected by the same letter indicate significant differences ($p < 0.05$).

Hydroperiod Phreatic Level (m)			
Moderate Dry	Flood	Moist	Wet
-0.49 ± 0.06^D	-0.01 ± 0.07^A	-0.44 ± 0.12^C	-0.12 ± 0.03^B

Table 4. Phreatic level (m) between habitats among hydroperiods. Values not connected by the same letter indicate significant differences ($p < 0.05$).

Hydroperiod Phreatic Level (m)				
Habitats	Moderate Dry	Flood	Moist	Wet
GF	−0.51 ^B	−0.05 ^D	−0.36 ^A	−0.12 ^B
MMW	−0.41 ^A	0.11 ^A	−0.43 ^B	−0.07 ^A
MWR	−0.41 ^A	0.09 ^B	−0.36 ^A	0.12 ^B
RMW	−0.54 ^C	−0.03 ^C	−0.64 ^C	−0.17 ^C
SM	−0.51 ^B	−0.05 ^D	−0.36 ^A	−0.12 ^B

Furthermore, significant negative correlations between phreatic levels with salinity within habitats were identified, as illustrated in Table 5 and Figure 6. Specifically, when the phreatic level was near the surface (with mean values of -0.03 ± 0.10 m and -0.11 ± 0.10 m), freshwater and oligohaline conditions tended to prevail. Conversely, when the phreatic level was lower, at approximately -0.44 ± 0.10 m and -0.57 ± 0.08 m (mean values), mesohaline and polyhaline conditions became more dominant.

Table 5. Spearman’s Rho correlation analysis showing significant correlations between the phreatic level and salinity within the habitats.

Phreatic Level by Salinity		
Habitats	Spearman ρ	Prob > $ \rho $
GFM	−0.5	<0.0001
MMW	−0.8	<0.0001
MWR	−0.8	<0.0001
RMW	−0.6	<0.0001
SM	−0.7	<0.0001

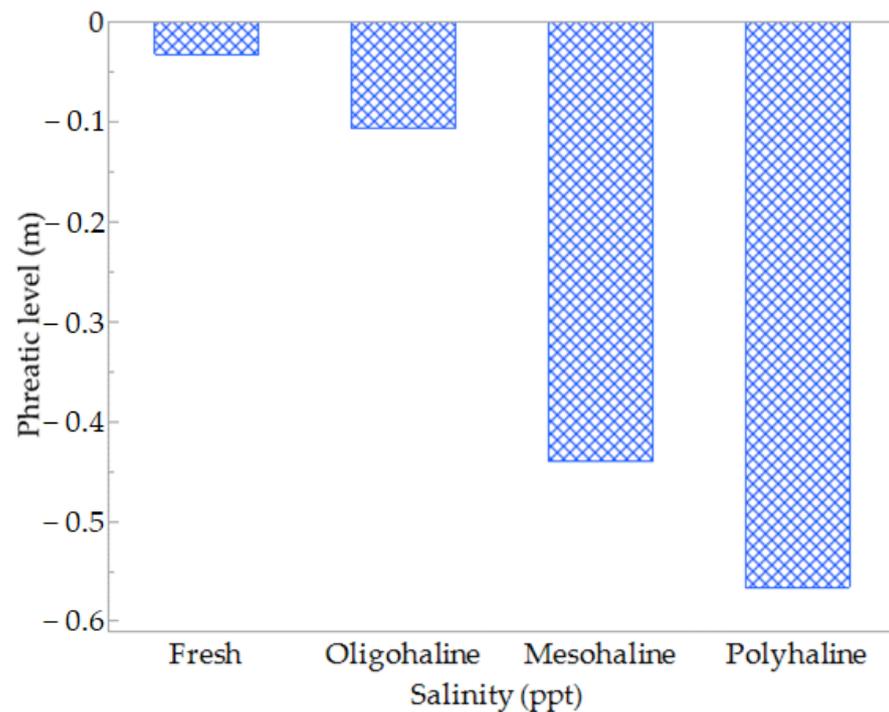


Figure 6. Variations in salinity conditions correlated with phreatic level.

The salinity conditions varied across the habitats throughout the different hydroperiods. During the moist and moderately dry periods, mesohaline (salinity ranging from >5.0 to 18.0 ppt) and polyhaline (salinity ranging from >18.0 to 30.0 ppt) conditions were prevalent, with significantly higher salinity levels observed across all habitats (see Figure 7). The MWR, MMW, and RMW exhibited the highest mean salinity levels during the moist period. In contrast, during the wet and flood periods, the salinity levels predominantly ranged from oligohaline (salinity >0.5 to 5.0 ppt) to freshwater (salinity ranging from 0 to 0.5 ppt) for all habitats.

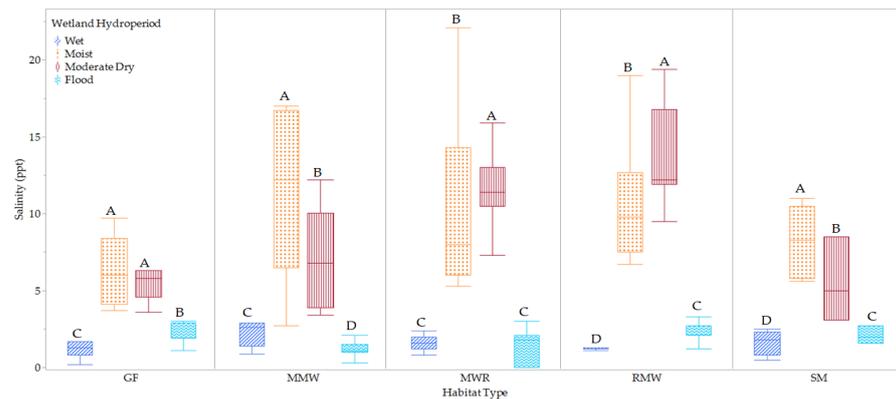


Figure 7. Significant differences in habitat salinity among the hydroperiods. Values not connected by the same letter indicate significant differences ($p < 0.05$).

Salinity variations between habitats across different hydroperiods were also assessed and quantified (Figure 8). The salinity differences between the MMW, MWR, and RMW during the moist period, ranging from high mesohaline to polyhaline levels, were found to be statistically insignificant. However, when considered collectively, they exhibited a notable contrast with GF and the SM, which had significantly lower mesohaline salinity levels. In contrast, during the moderate dry period, the SM and GF presented a range of salinity from oligohaline to low mesohaline, which was notably different from the mesohaline and polyhaline conditions found in the MWR and RMW. During the flood period, the MMW and MWR exhibited freshwater salinity significantly different from the oligohaline conditions observed in the other habitats. During this period, the phreatic level in both habitats was above the soil surface. In the wet period, the predominantly low mesohaline salinity in the MMW was also significantly distinct from the oligohaline conditions found in the other areas.

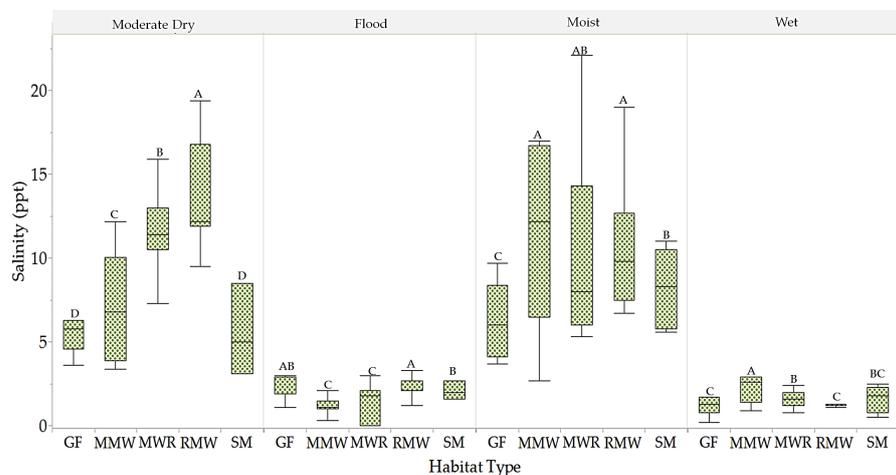


Figure 8. Significant differences between habitat salinity per hydroperiods. Values not connected by the same letter indicate significant differences ($p < 0.05$).

3.2. Mesofauna Diversity and Abundance between Habitat Types

A total of 7478 microarthropods representing 43 families were identified. The microfauna was characterized by 21 families of oribatid mites (suborder Oribatida), 10 families of prostigmatid mites (suborder Prostigmata), 8 families of mesostigmatid mites (order Mesostigmata), and 4 families of springtails (order Collembola). Overall, the suborder Oribatida had the highest number of families. The order Collembola, specifically the suborder Symphypleona (with 1 family), had the fewest families represented (Figure 9).

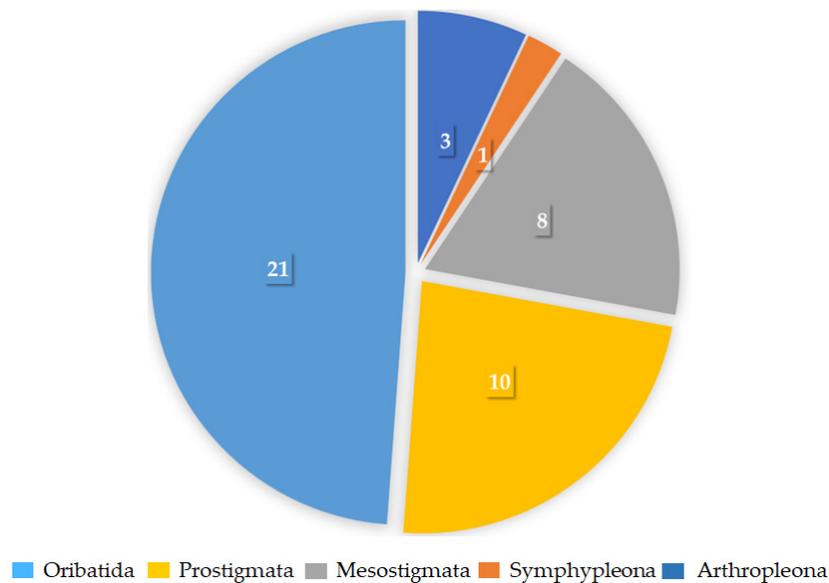


Figure 9. Total number of families identified by taxa (represented by number in captions). Within these categories, 43 families comprising 7478 organisms were documented.

The analyses revealed significant variations in both mesofauna richness and abundance among the different habitats, as illustrated in Figure 10. Among the habitats, the SM and the RMW exhibited the highest mesofauna richness, while GF displayed the highest mesofauna abundance. Both findings were statistically distinct from the other habitats. Conversely, no statistically significant differences in mesofauna richness were observed between GF, the MMW, and the MWR, as well as between the MMW and the MWR, when considering taxa abundance.

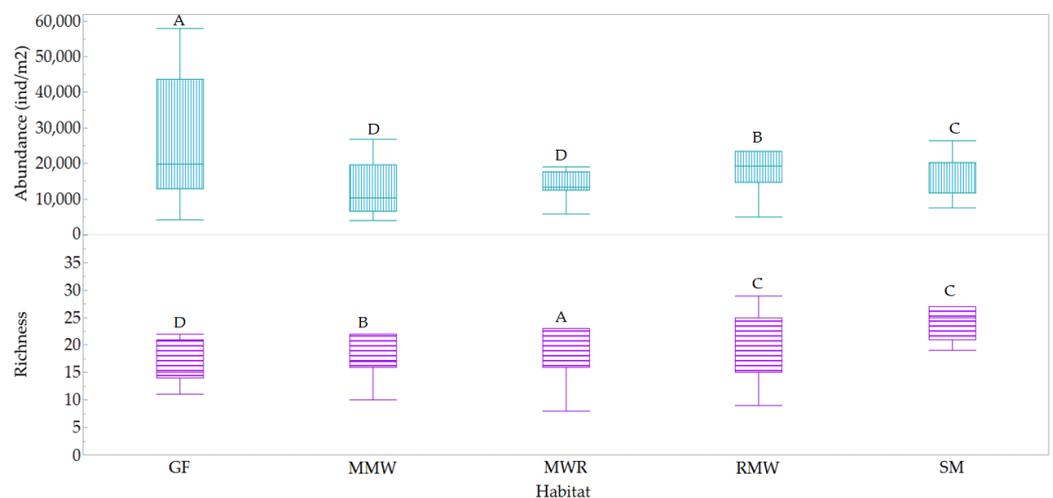


Figure 10. Significant differences in mesofauna richness and abundance between habitats. Values not connected by the same letter indicate significant differences ($p < 0.05$).

In total, the studied habitats shared 27 common families, as depicted in Figure 11, with an estimated similarity of approximately 64%. The remaining 36% of the families, which were not shared, contributed to the distinctions between the habitats. These non-shared groups included Acaridae, Cryptognathidae, Eniochthoniidae, Haplozetidae, Nothridae, and Sclerobatidae (suborder Oribatida); Bdellidae, Cheyletidae, Erythraeidae, Rhagidiidae, Scutacaridae, and Stigmaeidae (suborder Prostigmata); and Veigaiidae, Sejidae, and Trhypochthoniidae (order Mesostigmata).

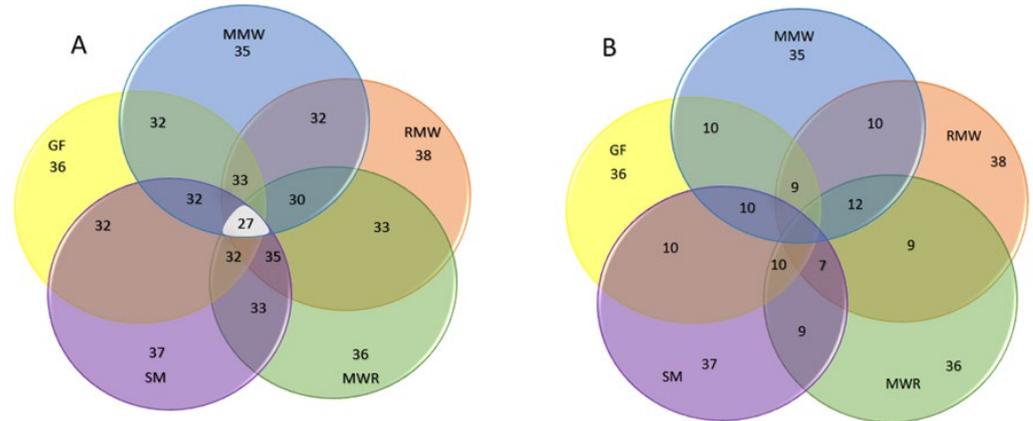


Figure 11. Venn diagram showing the number of (A) shared and (B) non-shared taxa among the habitat types.

The Bray–Curtis index and non-metric multidimensional scaling (NMDS) analyses revealed that three habitats, the MMW, MWR, and SM, are highly similar to one another. In contrast, the RMW and GF habitats show less similarity to these habitats as well as to each other, as detailed in Figure 12.

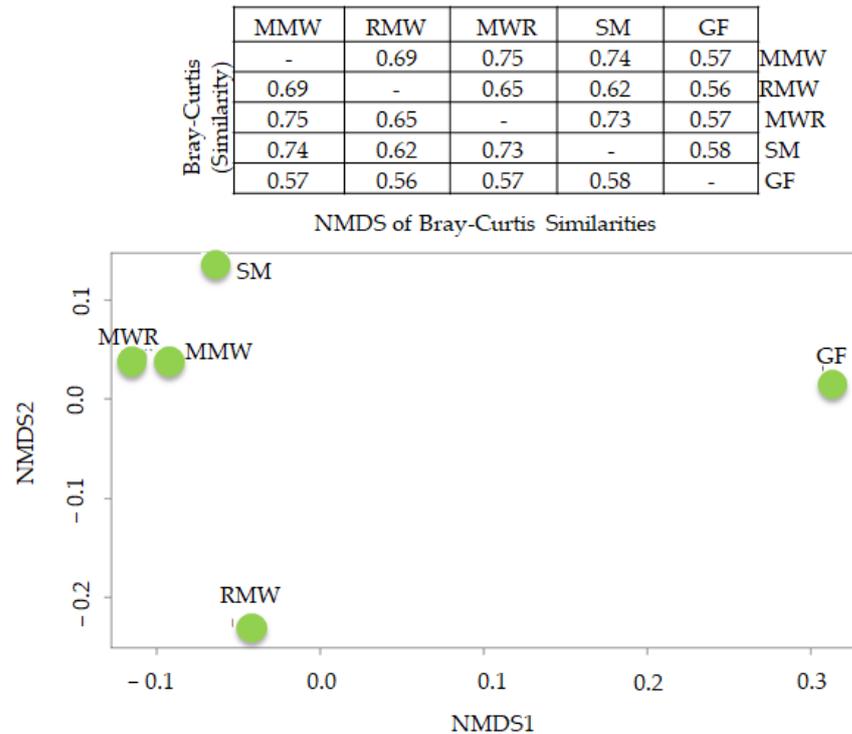


Figure 12. Bray–Curtis index matrix and non-metric multidimensional scaling results (NMDS) showing similarities between habitat types.

Among the studied habitats, mesofauna populations distributed between litter and soil organic layers exhibited significant variations in richness for GF and the RMW, as well as in abundance for the SM. Overall, acarine Oribatida and springtails Symphypleona were the dominant groups in terms of abundance and richness in the loose litter layer, with them showing significant differences in abundance compared to acarine Mesostigmata and Prostigmata. In the old litter layer, the abundance was predominated by Symphypleona, with them showing significant differences compared to acarine taxa (Figure 13).

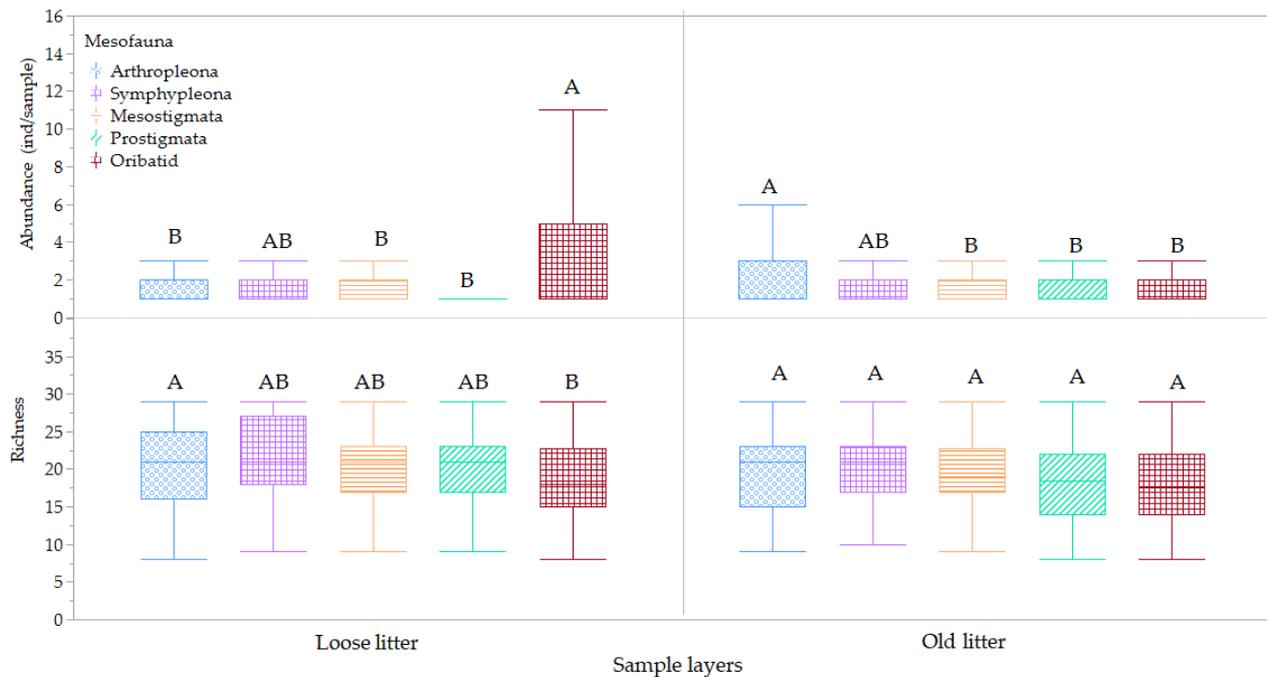


Figure 13. Statistical differences of mesofauna richness and abundance within loose litter and old litter layers. Values not connected by the same letter indicate significant differences ($p < 0.05$).

Biodiversity variations, classified into dominant, common, and rare taxa, were quantified across the different habitats (see Figure 14). In the GF habitat, a total of three dominant, ten common, and twenty-two rare taxa were identified. The dominant groups in this habitat were Collembola–Arthropleona (including Brachystomellidae and Isotomidae), which made up 42.8% of the mesofauna composition, along with Oribatida (Malaconothridae) at 14.4%. The MMW habitat comprised three dominant, fourteen common, and twenty rare taxa. In this habitat, Oribatida (including Damaeidae and Tegeribatidae) held dominance at 22.7%, together with Collembola–Arthropleona (Isotomidae) that accounted for 12.7% of the mesofauna composition. The MWR habitat contained three dominant taxa, mainly characterized by Oribatida (Ceratozetidae, Malaconothridae, and Tegeribatidae) at 43.2%, along with twelve common and twenty-one rare taxa. The RMW habitat had one dominant taxon, Oribatida–Ceratozetidae at 23%, along with seventeen common and twenty rare taxa. In the SM habitat, there were three dominant taxa, with Oribatida (Malaconothridae and Damaeidae) making up 31.1% of the composition, while Collembola–Arthropleona (Isotomidae) contributed 10.5% to the dominant groups. There were also fourteen common and twenty rare taxa identified in this habitat. In summary, Oribatida families, Malaconothridae, Ceratozetidae, Tegeribatidae, and Damaeidae were the dominant taxa among the habitats. In addition, the uniqueness of the mesofauna taxa among the habitats can be ranked as follows: GF > MWR > MMW = SM = RMW.

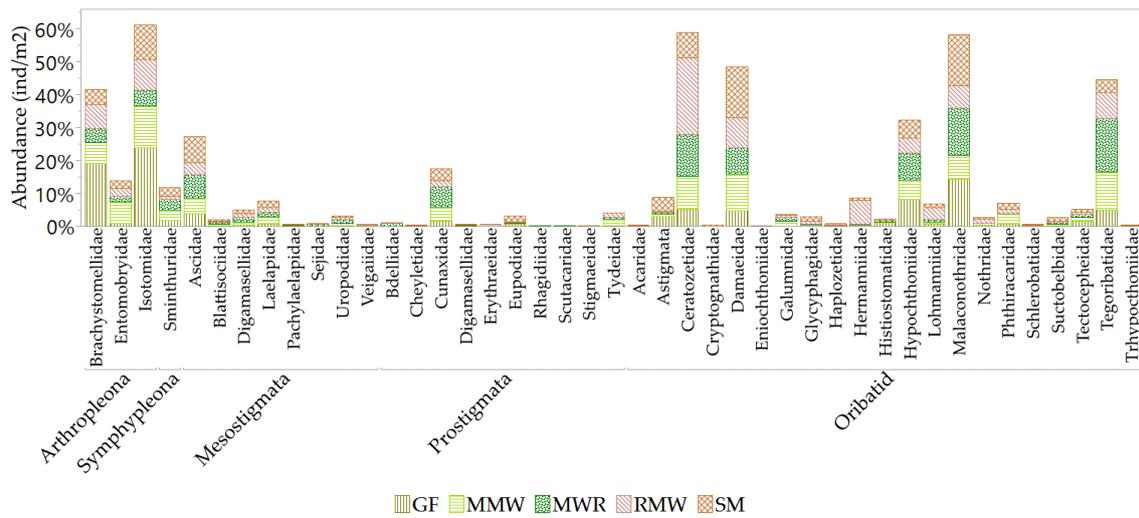


Figure 14. Mesofauna and dominant, common, and rare taxa composition by habitat [43].

3.3. Influence of Hydroperiod Phreatic Level and Salinity on Mesofauna Diversity and Abundance

Moderate correlations were estimated between the hydroperiod phreatic level and mesofauna richness and abundance (Table 6). The relationship assessed was positive with richness, indicating that as the phreatic level increased, mesofauna richness tended to increase as well. Conversely, the relationship with abundance was negative, suggesting that as the phreatic level increased, mesofauna abundance tended to decrease. Additionally, a moderate negative correlation was identified between salinity and mesofauna abundance, indicating that higher salinity levels were associated with lower mesofauna abundance.

Table 6. Spearman’s Rho correlation analysis showing correlations between the mesofauna richness index (Menhinick’s index) and the total abundance with the study site physicochemical factors.

Variable	By Variable	Spearman p	Prob > p
Richness	Phreatic Level	−0.5	<0.0001
	Salinity (ppt)	0.3	<0.0001
Abundance (ind/m ²)	Salinity (ppt)	−0.5	<0.0001
	Phreatic Level	0.5	<0.0001

The generalized regression model indicated that habitat type, phreatic level, and salinity together accounted for 45% (r-square = 0.45) of the variability in mesofauna richness and 40% (r-square = 0.40) of the variability in mesofauna abundance, as detailed in Table 7. The analysis of the effects suggests that habitat type and phreatic level were the most influential predictors in explaining these variations. These two factors exerted the strongest impact on mesofauna richness and abundance within the model. It can be inferred that the remaining 60% of the variability in mesofauna richness and abundance could be attributed to other soil constituents (soil texture, organic matter quality, and pH), biological processes (like reproduction and mortality), and biotic interactions (such as predation, competition, and facilitation) not measured in this study, either acting independently or in combination.

Table 7. Generalized regression model effect report providing information about the magnitude of the effect of each predictor on mesofauna richness index and total abundance (ind/m²).

Mesofauna Richness	Wald Chi-Squared	Prob > Chi-Squared	Mesofauna Total Abundance	Wald Chi-Squared	Prob > Chi-Squared
Habitat type	658	<0.0001	Habitat Type	568	<0.0001
Phreatic level	472	<0.0001	Phreatic level	260	<0.0001
Salinity	57	<0.0001	Salinity	12	0.0005

3.3.1. Hydroperiods

Variations in habitat richness and abundance across the hydroperiods were observed, as illustrated in Figures 15 and 16, highlighting the dynamic nature of mesofauna richness and abundance in each and between the different habitats in response to changes in hydroperiods' phreatic levels and salinity.

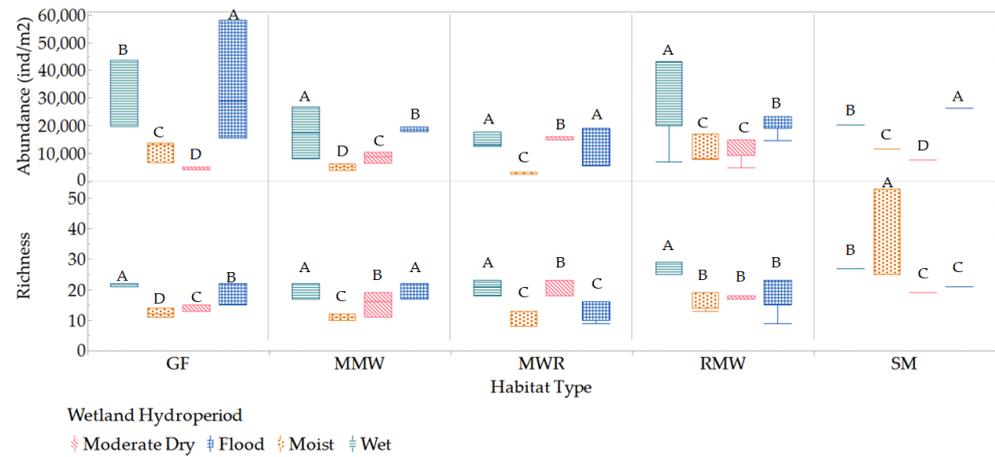


Figure 15. Statistical differences in mesofauna richness and abundance within habitats among the hydroperiods. Values not connected by the same letter indicate significant differences ($p < 0.05$).

Habitat-specific variations in mesofauna richness across the different hydroperiods were quantified (Figure 15). In the GF habitat, significant differences in richness were observed among all periods. The wet period had the highest richness value, while the moist period had the lowest. In contrast, in the MMW habitat, richness during the flood and wet periods showed no significant differences, but both were significantly different from the moderate dry and moist periods. MWR exhibited significantly higher richness during the wet and moderate dry periods, with no significant differences between the flood and moist periods (between floods). For the RMW, there were no significant differences between the moist, moderate dry, and flood periods, which were all different from the wet period. SM displayed significantly higher richness during the moist period, which was twice as high as that of the other periods. Regarding abundance, high values were quantified for all habitats during the flood and wet periods.

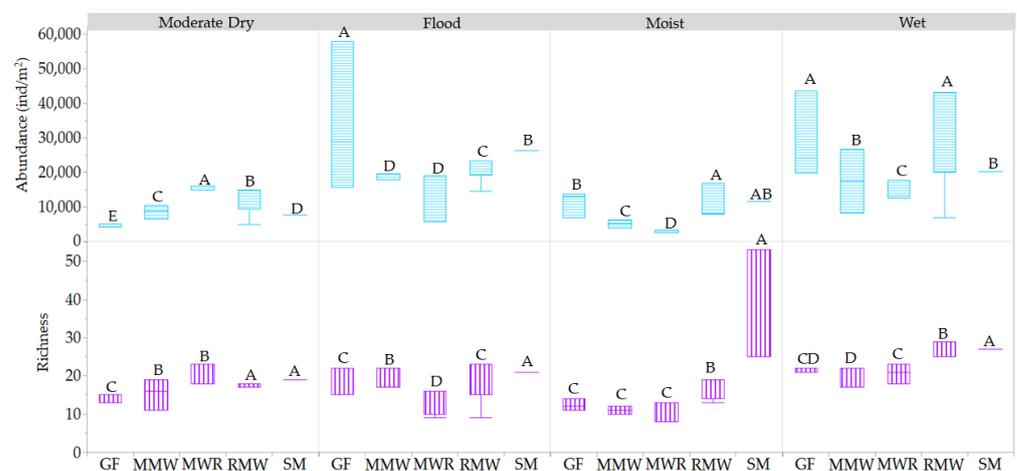


Figure 16. Statistical differences in mesofauna richness and abundance between habitats among the hydroperiods. Values not connected by the same letter indicate significant differences ($p < 0.05$).

Among the various habitats, the highest mesofauna richness was observed during the wet period, as shown in Figure 16. Notably, the SM consistently exhibited the highest richness across all periods, with significant differences from mean values in the other habitats. Specifically, the SM doubled its richness compared to other levels during moist periods, while GF, the MMW, and the MWR showed richness levels that were not significantly different from each other. The moderate dry period exhibited the lowest overall mesofauna richness. During this period, there were no significant differences in richness between the SM and the RMW, as well as between the MMW and the MWR, while GF had the lowest richness.

Mesofauna abundance was higher during the wet and flood periods and lower during the moderate dry and moist periods, with significant differences observed between habitats. This suggests that these hydroperiods had a substantial impact on mesofauna abundance across the different habitats (Figure 16). However, no significant differences in mesofauna abundance were found between the MMW and the MWR during the flood period, between the SM and the RMW during the moist period, and between GF and the RMW as well as between the MMW and the SM during the wet period. A notable observation from the study is that the GF habitat exhibited a two-fold increase in mesofauna abundance compared to the other habitats during the flood period.

3.3.2. Phreatic Level

Significant differences in mesofauna richness and abundance were correlated with phreatic levels, as illustrated in Figure 17. Overall, the highest richness was observed under slightly moderate conditions (−0.12 to −0.17 m). This richness significantly differed from that observed at other phreatic levels. For Mesostigmata and Oribatida, richness was notably lower at deeper levels (−0.51 to −0.64 m), while for Prostigmata, it decreased at moderate levels (−0.36 to −0.43 m). Mesofauna abundance was greater at shallow (−0.03 to −0.07 m) to slightly moderate phreatic levels but was lower at moderate and deep levels for both Mesostigmata and Oribatida. The abundance of Collembola, especially within the suborder Symphypleona, showed no significant difference across all phreatic levels.

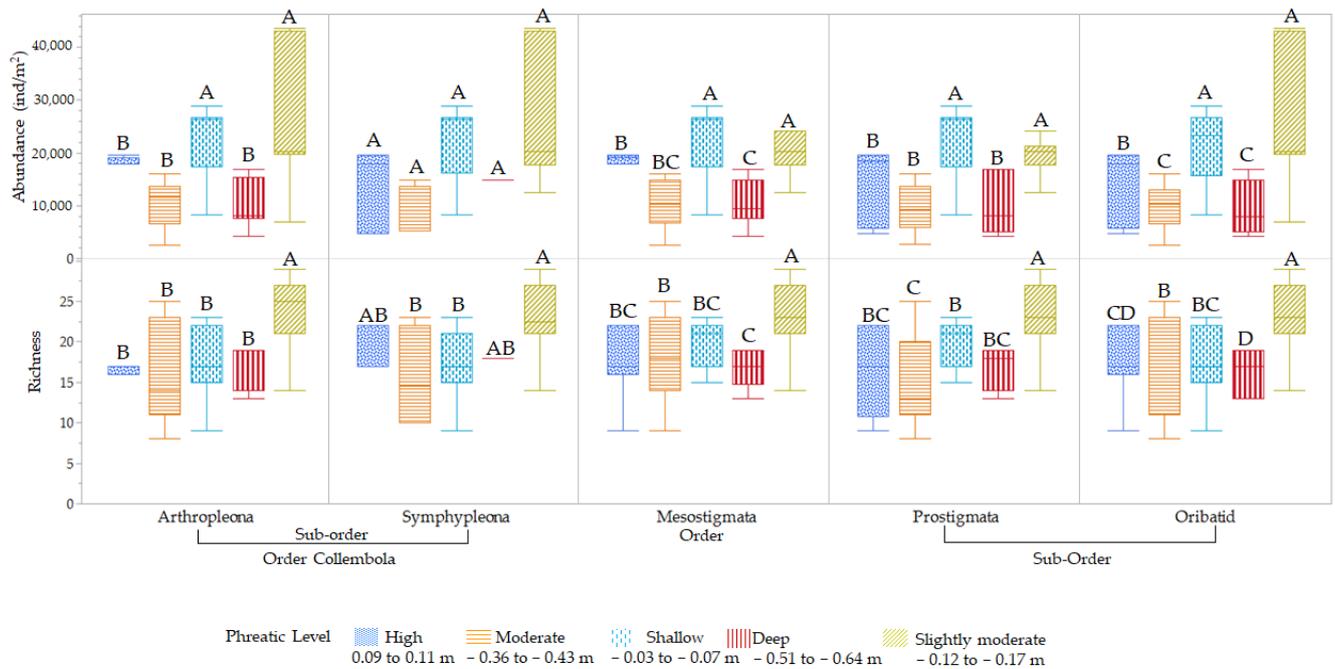


Figure 17. Statistical differences in mesofauna richness and abundance by taxa across the phreatic levels. Values not connected by the same letter indicate significant differences ($p < 0.05$).

Mesofauna populations distributed between the loose litter and old litter layers exhibited significant variations in richness at high, moderate, and slightly moderate phreatic levels (Figure 18). Higher richness was observed in the loose litter layer at moderate and slightly moderate phreatic levels and in the old litter layer at high phreatic levels. Abundance was significantly different under high, moderate, and shallow conditions, with more individuals located in the loose litter layer. No significant differences in richness and abundance were quantified at deep phreatic levels between the two layers.

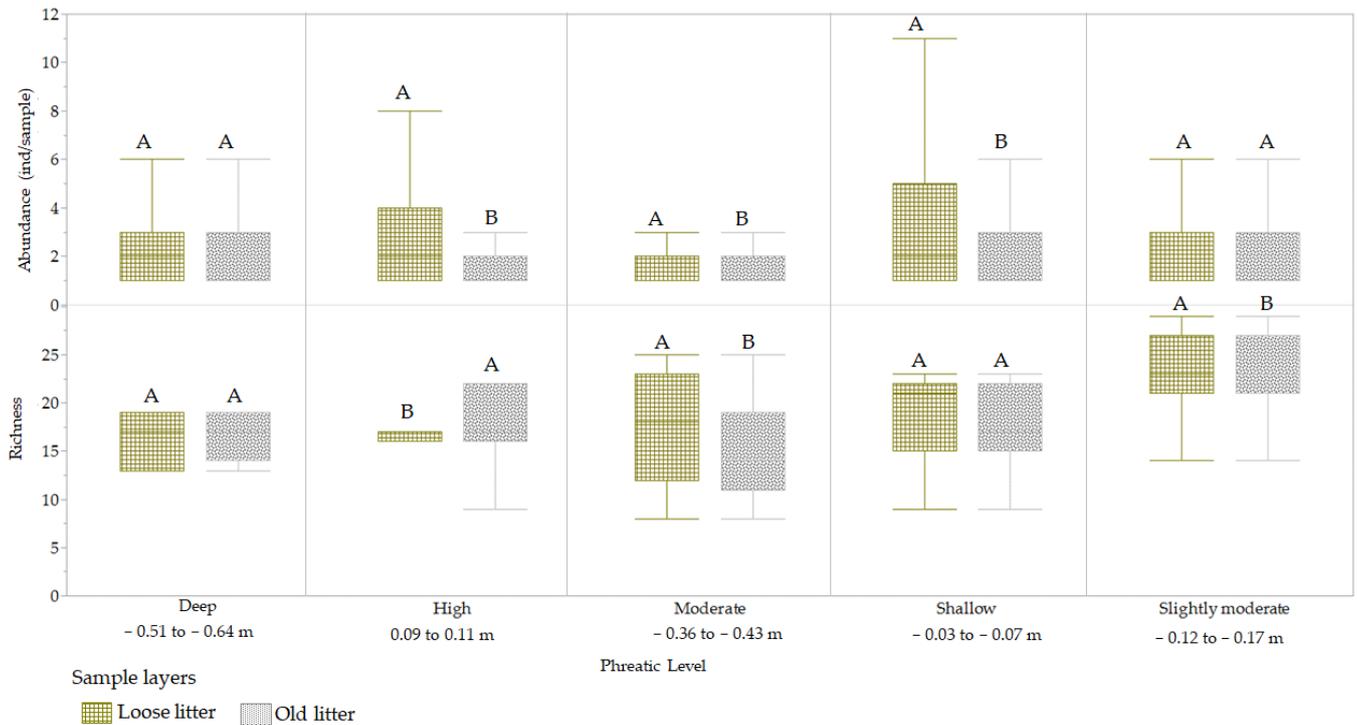


Figure 18. Statistical differences in mesofauna richness and abundance within the litter and soil organic layers across the phreatic levels. Values not connected by the same letter indicate significant differences ($p < 0.05$).

The distribution patterns and the presence or absence of various mesofauna families across distinct phreatic gradients, as delineated in Figure 19, offer a rich source of data for understanding the adaptive responses and habitat preferences of these species. Ninety-five percent (95%) of all families were prevalent during moderate and slightly moderate levels. In contrast, conditions characterized by high and shallow phreatic levels, which are locales prone to flooding or waterlogging, showed a notable absence of 28.6% of the families. This category includes a diverse range of families from the suborder Oribatida, such as Cryptognathidae, Haplozetidae, Eniochthoniidae, Lohmanniidae, Eupodidae, Schelorbitidae, Suctobelbidae, Glycyphagidae, and Nothridae. It also encompasses the suborder Prostigmata families Bdellidae and Hermanniidae, as well as the Mesostigmata families Pachylaelapidae and Veigaiidae. In deeper conditions, typically drier, there was an absence of 4.8% of the taxa, including families from the suborder Prostigmata such as Cheyletidae and Scutacaridae.

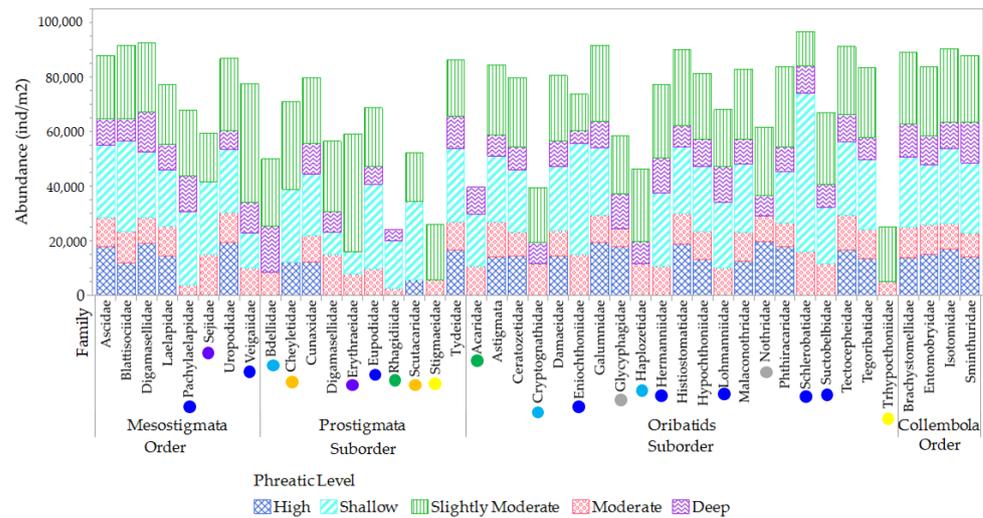


Figure 19. Distribution and habitat preferences of different mesofauna taxa in various phreatic environments. In this figure, different colored circles represent the presence or absence of various taxa at different phreatic levels: green circles: taxa absent in high and slightly moderate phreatic levels; yellow circles: taxa exclusively present in slightly moderate and moderate conditions; dark blue circles: taxa absent in high phreatic levels, characterized by flooded conditions; turquoise circles: taxa absent in high and near-surface phreatic levels, typically associated with flood or waterlogged conditions; orange circles: taxa absent in both moderate and significantly deep phreatic levels, which are known for drier conditions; purple circles: taxa absent in environments with high to significantly deep phreatic levels, indicative of extreme conditions; and grey circles: taxa absent in near-surface phreatic levels.

3.3.3. Salinity Conditions

Significant differences in mesofauna richness and abundance were correlated with the salinity conditions (Figure 20). The highest richness and abundance for all groups were observed under oligohaline conditions (>0.5 to 5.0 ppt). For Mesostigmata and Arthropleona, richness was significantly lower at fresh salinity levels (0.0 to 0.5 ppt), whereas for Oribatida, it was lower at both fresh and polyhaline levels (>18.0 to 30.0 ppt). No significant differences were observed in Symphypleona abundance across fresh, oligohaline, and mesohaline conditions.

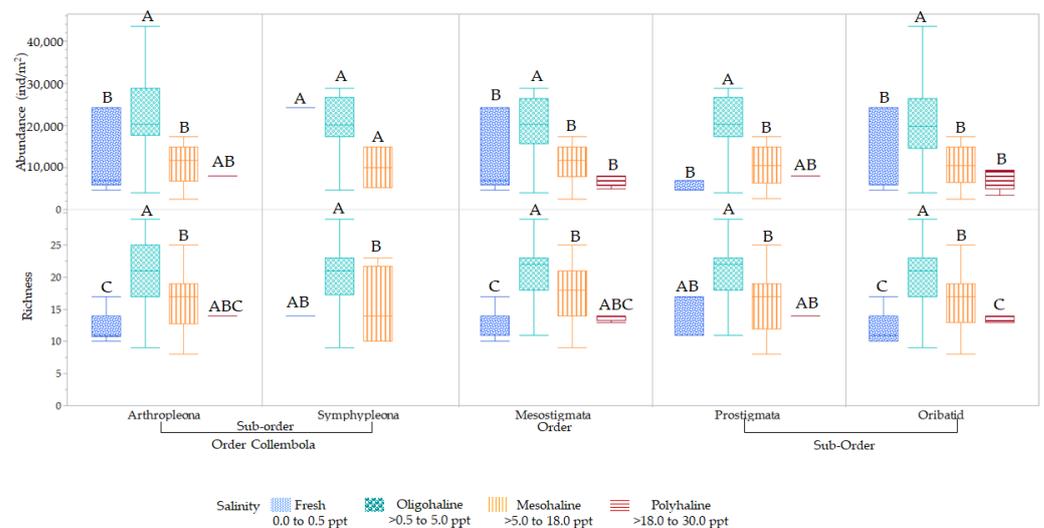


Figure 20. Statistical differences in mesofauna richness and abundance by taxa across the salinity conditions. Values not connected by the same letter indicate significant differences ($p < 0.05$).

Mesofauna populations distributed between the loose litter and old litter layers exhibited significant variations in richness at oligohaline levels (Figure 21), with higher values observed in the loose litter layer. Abundance differed significantly under fresh and oligohaline conditions, showing a greater number of individuals in the loose litter layer. No significant differences in richness or abundance were observed between the two layers at mesohaline and polyhaline salinities.

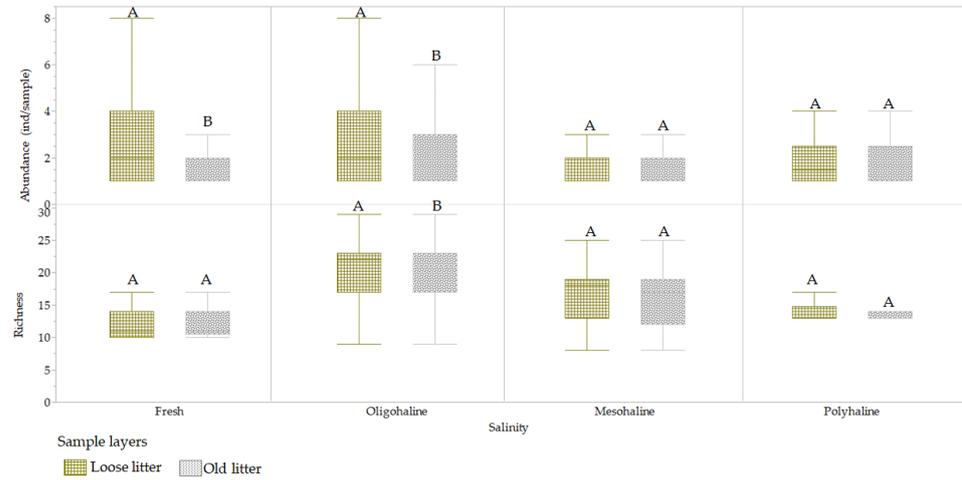


Figure 21. Statistical differences in mesofauna richness and abundance within the litter and soil organic layers across the salinity conditions. Values with different letters indicate means with significant differences ($p < 0.05$).

Quantifying the prevalence and absence of mesofauna families across various salinity levels provided valuable insights into how mesofauna species distribute and acclimate in response to varying salinity conditions, as illustrated in Figure 22. Ninety-five percent (95%) of mesofauna taxa are predominant in oligohaline and mesohaline salinities. In contrast, Prostigmata Scutacaridae and Cheyletidae are exclusive to oligohaline salinities. Additionally, twenty-four percent (24%) of the taxa can acclimate to both freshwater and polyhaline salinities. Meanwhile, twenty-five percent (25%) of the families were found in freshwater conditions, and seventeen percent (17%) were observed in polyhaline salinity.

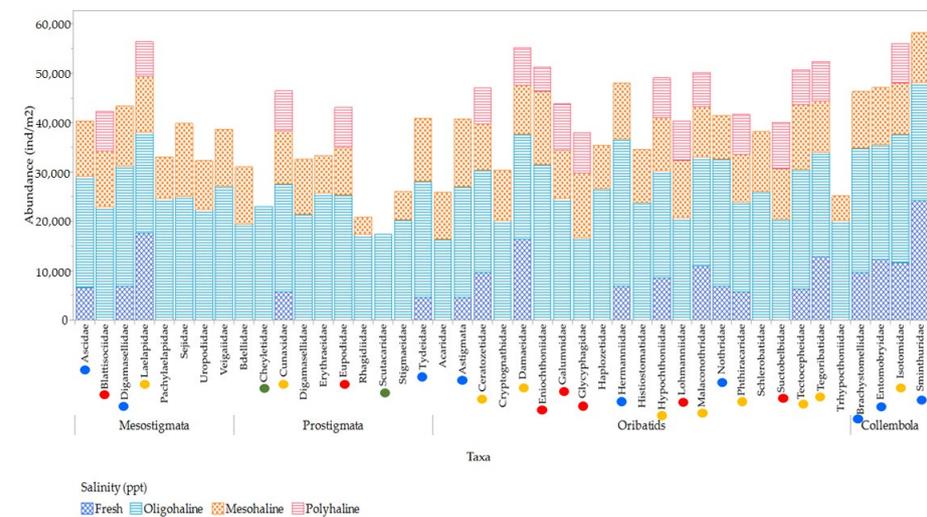


Figure 22. Variations of mesofauna taxa among the different salinity conditions. Green circles represent taxa exclusive to oligohaline salinities. Yellow circles indicate taxa tolerant of freshwater and polyhaline conditions. Blue circles correspond to taxa found at freshwater salinities. Red circles are taxa present in polyhaline salinities.

4. Discussion

In this study, we have explored the intricate dynamics of soil mesofauna assemblages within a tropical urban coastal wetland, specifically focusing on how spatiotemporal fluctuations in phreatic levels and salinity influence their diversity and abundance. Our findings offer insights into the complex interplay between environmental factors and mesofauna communities, shedding light on the implications of our initial hypothesis regarding the significant modulation of these assemblages by varying phreatic levels and salinity.

Ciénaga Las Cucharillas Natural Reserve has undergone hydrological modifications since colonial times, altering its marine–terrestrial–marine connectivity and bio-physicochemical components. Consequently, a mosaic of physicochemical conditions and habitat types characterizes these ecosystems, with global and regional climate variability, sea-level rise, land use, and land cover changes acting as additional stressors (Figure 23).

The observed variations in phreatic levels and salinity conditions across different hydroperiods and habitats underscore the complex interplay between hydrological processes and habitat characteristics. The significant negative correlations between phreatic levels and salinity further elucidate the pivotal role these factors play in shaping the habitat conditions. It is important to recognize that these environmental factors are influenced by various water sources that enter the wetland, including in situ precipitation, freshwater inputs, and seawater flows [28].

Marine - Terrestrial – Marine Connectivity (Sea level rise, Freshwater inputs)

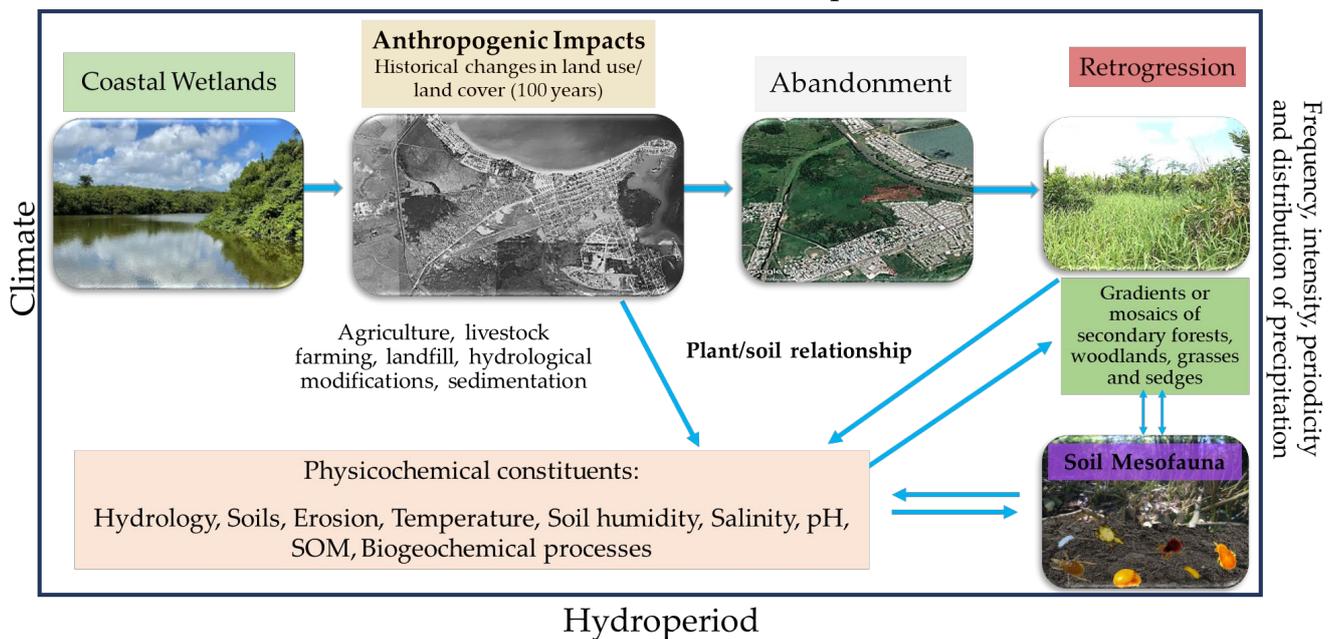


Figure 23. Historical changes in the land cover of coastal wetlands since colonial times, exemplified by the Ciénaga Las Cucharillas Natural Reserve, along with subsequent abandonment, have altered its hydrology and marine–terrestrial connectivity (upper axis). These modifications have led to shifts in the soil’s physicochemical constituents, subsequently affecting plant–soil interactions and mesofauna communities. The ongoing global and regional climate variability (left and right axes), sea-level rise (upper axis), and land use and cover changes act as additional stressors in this process. The combined effect of these anthropogenic stressors and the predominant wetland mosaic environment significantly influences the hydrological regime (lower axis), biophysicochemical components, and soil mesofauna diversity and abundance in the ecosystem.

Mesohaline and polyhaline conditions are favored when the phreatic level is moderate and deep, as observed during the moist and moderate dry periods. During these periods, a bimodal high tide reaches the study site in just 20 min. Conversely, freshwater and oligohaline conditions occur mostly at higher and near-surface phreatic levels, particularly during the flood and wet periods, when it takes up to 2 h for the bimodal high tide to reach the study site [48]. This tidal interaction in this wetland occurs via deep subsurface flow and causes notable fluctuations in soil salinity concentrations within habitats. The moderate dry and moist periods are influenced by marine intrusion/tides and the flood and wet periods by freshwater input by precipitation and runoff. These periodic fluctuations in phreatic level and salinity influence mesofauna dynamics and distribution patterns within and between habitats, underscoring their sensitivity to changes in these environmental factors.

During both wet and flood periods, the peak in mesofauna richness and abundance was observed across various habitats, with these organisms predominantly inhabiting the loose litter layer. Sampling during both periods coincides with the receding of floodwaters. This prevalence suggests that habitat conditions during both hydroperiods, characterized mostly by shallow to moderately shallow phreatic levels (0.01 ± 0.07 m, -0.12 ± 0.03 m) and oligohaline salinities (1.61 ± 1.07 ppt, 1.97 ± 0.8 ppt), foster an optimal microenvironment for a diverse array of mesofauna families. A plausible explanation for this trend is the series of environmental changes preceding these periods. After enduring alternating flood and dry conditions for several months, factors such as soil moisture, salinity, and food availability undergo significant shifts across habitats [26,60,61]. In wetland ecosystems, terrestrial plant litter accumulates during dry spells and undergoes partial in-situ decomposition, enriching the humic material reservoir. The onset of flooding leads to the death of some terrestrial plants, while aquatic plants sprout, grow, and eventually decay, further augmenting the mixture and quantity of detrital accumulation. As floodwaters recede, transitioning into the wet period, the mixture and exposure of these organic materials create zones ripe for recolonization, enhancing the activity of microflora [57] and paving the way for a resurgence of mesofauna. This resurgence includes fungivorous entities such as Oribatida mites and Collembola, as well as their predators, including Mesostigmata and Prostigmata mites [21]. An exemplification of this recolonization is observed in the Oribatida family Hermanniidae, which exhibited a doubling in their population during the wet sampling period, coinciding with a slightly moderate phreatic level with the receding of floodwaters.

The lowest abundance of mesofauna observed during the moist and moderate dry hydroperiods indicates that the prevailing conditions across different habitats impact mesofauna dynamics. The moist period occurred between flooding events, with our sampling conducted immediately after the first flood. Conversely, the moderate dry period followed months of lower precipitation. During both periods, we observed deeper phreatic levels (-0.46 ± 0.60 m) and moderate mesohaline to polyhaline salinities (10.53 ± 2.97 ppt, 18.94 ± 0.48 ppt). Notably, ninety-five percent (95%) of mesofauna taxa tolerated mesohaline salinities, while thirty-nine percent (39%) of these families demonstrated additional tolerance to polyhaline conditions. One possible explanation for the lower abundance values could be the reduced adaptability of certain mesofauna taxa to the increased salinity and altered phreatic levels during these periods. This suggests a selective pressure exerted by changing hydrological conditions, potentially leading to a shift in community composition favoring more tolerant species.

Between habitat-specific variations in richness and abundance, the mature 50-year shrubland of *Dalbergia ecastaphyllum* (L.) (SM habitat) emerges as a distinctive environment, consistently showcasing the highest richness throughout all observed periods. This heightened richness is likely fostered by the unique characteristics of the SM habitat, including a moderate phreatic level (mean value = -0.22 ± 0.16 m), the presence of oligohaline to low mesohaline salinities, canopy closure providing shade to the understory and soil, and enhanced litter inputs. These factors collectively cultivate a microenvironment conducive to a diverse mesofauna community, instigating shifts in the population dynamics [62–64]. During the moist period, which occurs between flood events, the SM habitat exhibited a

richness that was twice that of other habitats. This period was characterized by a moderate phreatic level and a prevailing low mesohaline salinity of 8.32 ± 2.09 ppt. The elevated richness during this period can be attributed to the higher micro-elevation of the SM habitat, which acts as a buffer against the high phreatic levels typically experienced during flood disturbances, a protection not afforded to other habitats especially the MMW and MWR which had similar microenvironments. This distinctive microenvironment fosters conditions favorable to colonization by a variety of mesofauna taxa that are well adapted to predominantly mesohaline salinities [19,23]. Families such as Acaridae (Oribatida), Digamasellidae (Prostigmata), and Uropodidae (Mesostigmata) exemplify this trend, as they exhibited a doubling in their abundance in the SM habitat during the moist period. Furthermore, the presence of these families was predominantly observed in oligohaline and low mesohaline conditions, suggesting a strong ecological preference or adaptability to these specific salinity ranges.

Overall, significant variability exists in how different mesofauna taxa respond to phreatic levels and salinity conditions (Figure 24), suggesting distinct tolerances to these environmental factors. Empirical evidence from our Spearman's Rho correlation analysis and the generalized regression model confirms the significant impact of phreatic level and salinity on mesofauna richness and abundance. These diverse responses among taxa are likely due to factors such as life cycle variants, physiological specialization, and behavioral adaptations.

Oribatid mites are prevalent in most phreatic levels and salinity conditions. Notably, they were the only taxa present in polyhaline conditions at moderate phreatic levels. In both cases, they are more abundant in the loose litter layer. Anthropleona show increased richness and abundance in oligohaline salinities at moderate to shallow phreatic levels and in polyhaline salinities at deep levels, mainly located in the old litter layer. Conversely, Symphyleona are more abundant in freshwater conditions at slightly moderate phreatic levels, predominantly found in the old litter layer. Mesostigmata and Prostigmata exhibit an increased presence in oligohaline and mesohaline conditions at slightly moderate to high phreatic levels, with their abundance being greater in the loose litter layer.

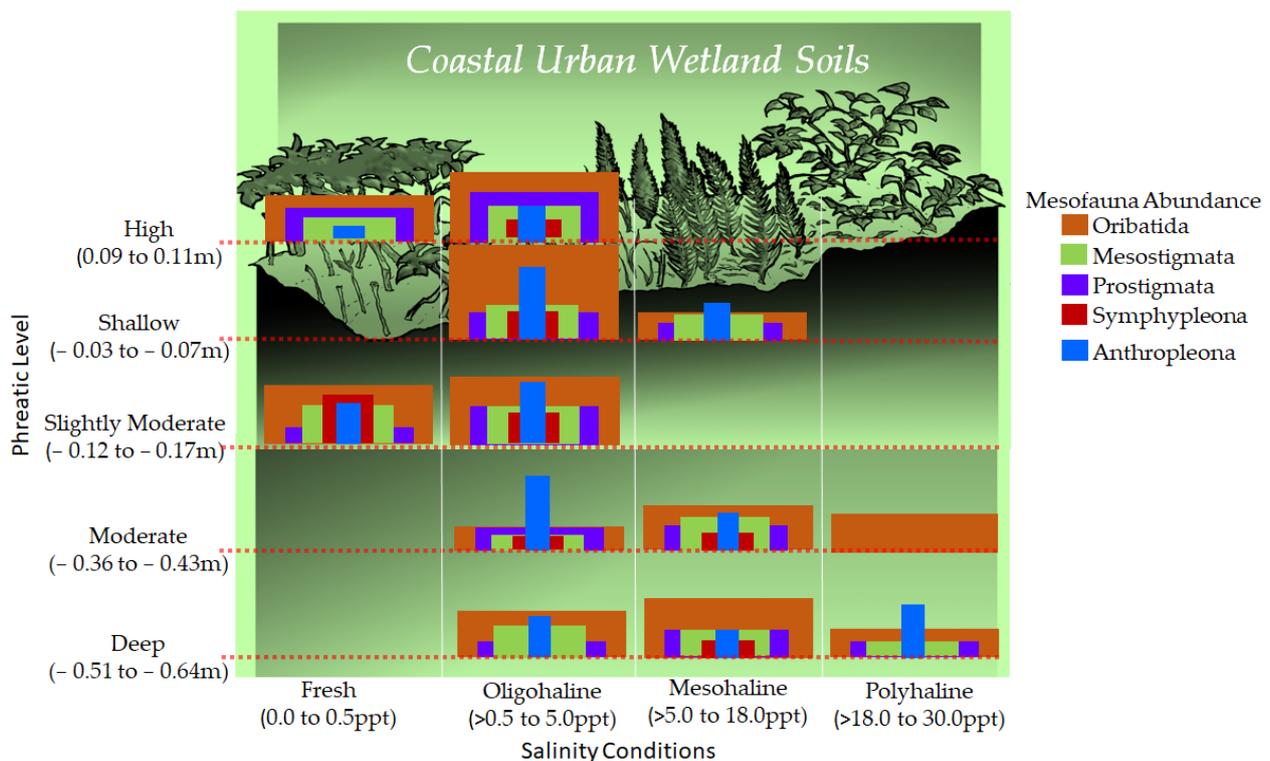


Figure 24. Mesofauna taxa variability compared to phreatic levels and salinity conditions.

Significantly, around thirty-six percent (36%) of the mesofauna families were absent during periods of marked shifts in phreatic levels, including the flood and subsequent post-flood (moist) phases. This absence underscores the sensitivity of a considerable portion of mesofauna families to such disturbances. A case in point is the oribatid family Trhypochthoniidae, which exhibited a pronounced sensitivity to extreme fluctuations in phreatic levels. This family was conspicuously absent not only during the moderate dry periods, characterized by deep phreatic levels but also during the flood periods where high phreatic levels prevailed. This pattern of absence across a spectrum of extreme phreatic conditions highlights the vulnerability of Oribatid Trhypochthoniidae to substantial variations in hydroperiods, pointing to a narrow ecological amplitude with regard to phreatic level tolerances.

Regarding salinity preferences, the majority of mesofauna families, ninety-five percent (95%), thrive in oligohaline and mesohaline salinities. This is exemplified by Prostigmata families such as Scutacaridae and Cheyletidae, which are exclusive to oligohaline salinities, indicating a specialization in this salinity range.

The findings delineated above unveil a complex interplay of inter- and intra-specific responses to the fluctuating phreatic levels and salinity conditions prevalent during the hydroperiods of wetland habitats. This underscores the intricate adaptations and ecological strategies that various mesofauna families have evolved to acclimate to the periodic landscape dynamics inherent to tropical urban coastal wetlands. Consequently, this research offers profound insights into the community structures and operational dynamics of mesofauna in these ecosystems, elucidating their resilience and adaptability in the face of environmental variations.

5. Conclusions

In conclusion, the study underscores the significance of understanding mesofauna's intricate inter- and intra-specific responses to fluctuations in wetland hydroperiod phreatic levels and salinity conditions. The diverse range of responses exhibited by the mesofauna community in this wetland emphasizes their varying degrees of adaptability and resilience to changes in their microenvironment. This insight into mesofauna community dynamics is invaluable for effective wetland management, particularly in the context of multiple stressors such as global and regional climate change, sea-level rise, and human activities. The bio-sensor capacity of soil mesofauna emerges as a crucial tool for monitoring and adaptive ecosystem management to ensure their long-term health and sustainability.

Author Contributions: G.O.-R. and E.C. conceived and designed the study, analyzed the data, and wrote the manuscript. G.O.-R., E.H. and S.P.-P. completed the field sampling and analysis. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the NSF CREST—Center for Innovation Research and Education in Environmental Nanotechnology (CIRE2N) HRD 1736093, NSF HRD 1806129, and the Center for Applied Tropical Ecology and Conservation (CATEC) of the University of Puerto Rico.

Data Availability Statement: The authors commit to making the raw data that support the conclusions of this article available without undue reservation.

Acknowledgments: The authors would like to acknowledge the technical assistance provided by the Center for Applied Tropical Ecology and Conservation (CATEC). Appreciation is also extended to the coordinator of the Process and Functions Ecosystem Lab, Larry Díaz, and the following undergraduate students—Diego E. Otero-Santiago, Cecilia M. Fadhel-Alvarez, Isabel Alayón, Jorge L. Gonzalez-Santana, Thalia M. Rosa-Agosto, Alexis Roque Sotomayor, and Alexander Cántres—for their substantial contributions to both the field and laboratory work.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analysis, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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