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Short-Term Responses of Aquatic Ecosystem and Macroinvertebrate Assemblages to Rehabilitation Actions in Martil River (North-Western Morocco)

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Abstract: This study aimed to evaluate the effects of the Martil River rehabilitation project and recently constructed dam infrastructures to reduce flood risks and to promote local socio-economic development on the ecological integrity of the river. The assessment focused on changes in fluvial landforms over time and the evaluation of aquatic ecosystems based on six physicochemical parameters (temperature, pH, electrical conductivity, dissolved oxygen, biochemical oxygen demand, and chemical oxygen demand), morpho-hydrological variables (stream width, water depth, and current speed), habitat indices (QBR, IHF, and MQI), and macroinvertebrate assemblages of EPT, OCH, and *Chironomidae* (*Diptera*) at five stations from autumn 2015 to spring 2018 (prior to and during the rehabilitation actions). The results showed that the river rehabilitation project led to profound changes in Martil River's ecosystem and water quality over time. Physicochemical and habitat measurements at the rehabilitated sites revealed a major change in macroinvertebrate communities due to changes in fluvial landforms in relation to flow-sediment regimes. As a result, some typical species of lentic habitats disappeared, while alien, opportunistic, and lotic species appeared.

Keywords: biomonitoring; ecological integrity rehabilitation; macroinvertebrates

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1. Introduction

Hydrological and morphological characteristics are crucial factors in maintaining the biological organization, richness, and complexity of river ecosystems. These characteristics are also responsible for the provision of numerous ecological goods and ecosystem services [1]. In essence, watercourses are dynamic and intricate systems that require a delicate balance between their physical and biological components to thrive. Without proper management of hydrological and morphological characteristics, river ecosystems can become degraded and lose their ecological functions, including the provision of clean water, nutrient cycling, and habitat for aquatic life [2]. Therefore, it is vital to maintain the natural hydrological and morphological regimes of rivers to support the continued health and sustainability of river ecosystems [3]. Urban lowland rivers are at the epicenter of human activities, which has resulted in a multitude of anthropogenic pressures. These pressures have led to dramatic ecological changes, such as alterations in the hydrological parameters, urbanization, water pollution, and habitat degradation [1,4,5]. Consequently, there is an urgent need for managers to develop innovative methods to better understand and assess the ecological status of these types of ecosystems [6,7].

Urban river rehabilitation is a global approach that seeks to integrate human society with its river systems for mutual benefit [8,9]. However, river rehabilitation projects themselves can cause disturbance through the modification of physical, geomorphological, and hydrological characteristics, leading to disconnections between the main river channel and the floodplain [10,11]. Research has shown that channelization of river channels has a significant impact on physical habitats and aquatic species assemblages [5,12–16]. Therefore, understanding the physical, chemical, biological, and hydro-morphological processes of river systems is essential to gain knowledge of the functional connectivity between ecosystem dynamics and human activities, and to increase the likelihood of successful rehabilitation [11,17]. To achieve successful urban river rehabilitation, it is essential to adopt a holistic approach that considers the complex interactions between the physical environment, ecosystem processes, and human activities [18]. By understanding the interdependence of these factors, it is possible to design rehabilitation strategies that not only improve ecological conditions but also enhance the socio-economic benefits that urban rivers provide. Therefore, it is vital to promote interdisciplinary collaboration between researchers, managers, and stakeholders to develop and implement effective and sustainable rehabilitation plans [19]. Maintaining eco-hydrological conditions is crucial in rehabilitation schemes to recreate an environment similar to the pre-rehabilitation conditions, enhancing the recovery of habitat heterogeneity and diversity of aquatic species adapted to lowland rivers [5,10,20,21]. Ecological responses of aquatic macroinvertebrates are of great interest in rehabilitation programs as they serve as biotic indicators to evaluate the environmental conditions and the success of rehabilitation [7,22,23]. Therefore, establishing ecological bioindicators should be a priority action in the implementation of rehabilitation programs to achieve good ecological status and conserve local native species [20,24].

Most of the rivers that run through urban areas in Morocco are severely degraded, limiting urban development. Recently, many river rehabilitation projects have been implemented in Morocco. The challenge for urban policies in Morocco generally and for Martil River in particular is to adopt new approaches that focus on the construction of sustainable cities to reduce flood risks, overcome urban dysfunctions, and create public spaces that promote local socio-economic development [25]. Unfortunately, when integrating damaged ecosystems into the urban landscape, the ecological dimension is often neglected, and restoration projects focus mainly on the aesthetic and visual aspects, disregarding the recovery of ecological functions. Martil River provides a good opportunity to evaluate the effects of the rehabilitation project on ecological status during and after significant changes. In order to assess the short-term impacts of the rehabilitation project on the ecological integrity of the Martil River, the main goals of this study are (1) to evaluate the seasonal variation of physicochemical properties, (2) to characterize its ecological status using different river habitat indices and (3) to examine responses of macroinvertebres communities according to land use change, seasonal variation of physico-chemical and hydrogeological characteristics that Martil River had undergone.

2. Materials and Methods

2.1. Study Area and Sampling Approach

Martil River, with a total length of 22 km, is located in the northwest of Morocco and flows through Tangier, Tetouan, and El Hoceima Province. Our study focuses on the downstream part of the Martil Basin, which appropriates the same name as the watershed. The river originates from the confluence of three main tributaries, namely Oueds Mhajrat, Khemis, and Chekkoûr, and crosses the eastern side of Tetouan City before discharging into the Mediterranean Sea at the level of Martil City [26]. The climate in the area is mainly Mediterranean, with rainy and wet winters and hot and dry summers. The mean annual precipitation is 651 mm, and the mean annual temperature ranges from 12.87–22.74 °C [27,28]. Due to its location along Tetouan City, which is the second largest city in Northern Morocco with approximately 398,000 inhabitants [29], the Martil River has become a reservoir of socio-economic activities and one of most impacted hydrosystems in the region. The rapid urbanization of the river's borders due to population growth over the past few decades, along with intensive agricultural activities, and the proliferation of quarries and industrial units, including ceramic and marble factories, cement plants, tanneries, and brickworks, have all contributed to the release of large quantities of mineral, organic, and nutrient discharges of untreated wastewater. This has led to a rapid deterioration in water quality. In addition, the presence of four dams (Nakhla, Moulay El Hassan Ben El Mahdi, Ajras, and Martil), particularly the recently implemented Martil dam, has probably affected the flow and sedimentation regime of the river, possibly affecting the structure and functions of the river and floodplain habitats, and consequently disturbing the aquatic ecosystem. In order to addresses our study objectives, we compared ecological conditions in different sections of the channel before and after rehabilitation. Therefore, five sites were selected based on their location within the city, accessibility, sources of pollution, and implementation of the rehabilitation project (see Figure 1). Sampling was carried out from autumn 2015 to spring 2018, before and after the rehabilitation process. Two sites (M1, M2) are located in the upstream part of Martil River in semi-urban areas, two others (M3, M4) are situated in urban areas that were greatly influenced by the rehabilitation activities, and the last one (M5) is located in an urban area at the center of Tetouan City.

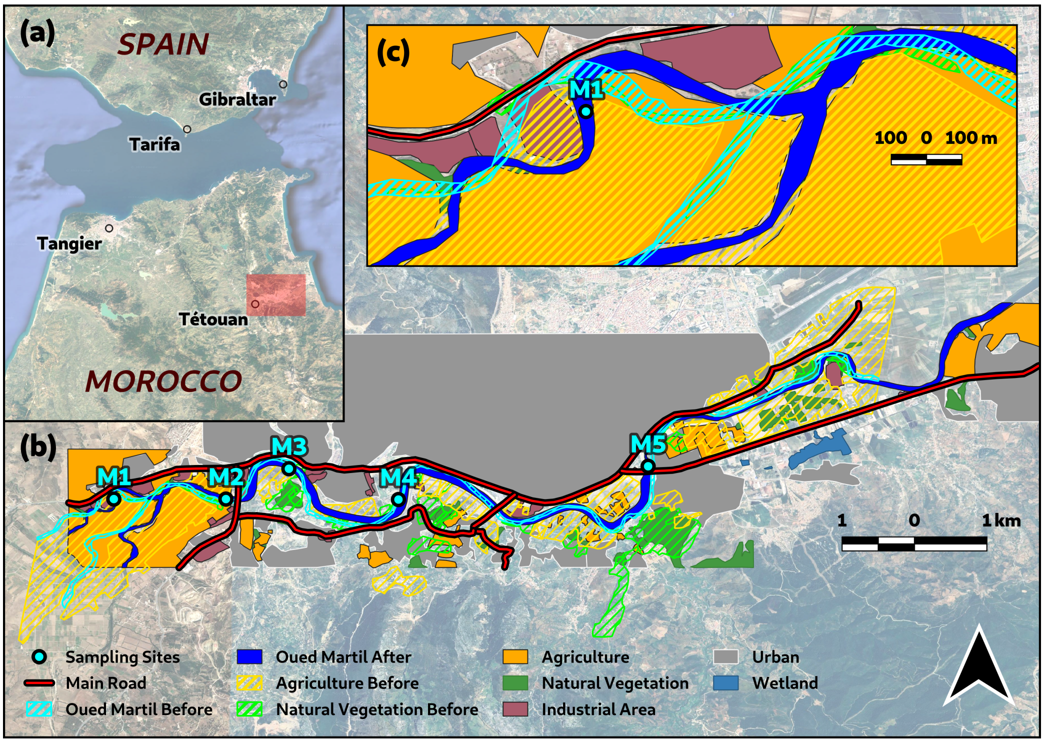

Figure 1. The situation of Martil River before and after the start of rehabilitation actions and the location of sampling sites. (**a**) Framing of investigated area represented in (**b**) where territorial transformations are compared. (**c**) Detail of Martil River bifurcation before and after the start of the river reahabilitation project.

2.2. Methods

2.2.1. Physicochemical Parameters

Physicochemical analyses were conducted seasonally in the Martil Basin from winter 2016 to spring 2018. Water temperature (T), pH, electrical conductivity (CE), and dissolved oxygen (DO) were measured in situ using a specialized portable device (EUTECH Cyber-Scan PCD 650) immediately before sampling macroinvertebrate taxa. Biochemical Oxygen Demand in 5 Days (BOD5) and Chemical Oxygen Demand (COD) were analyzed in the laboratory of the Loukkos Hydraulic Basin Agency (ABHL, Tetouan) using a Pastel UV portable UV analyzer. The physicochemical parameters were determined according to the recommendations of Rodier [30].

2.2.2. Hydromorphological Measures

To evaluate the impacts of the rehabilitation project on the hydrological and habitat conditions of Martil River, we conducted a 11 campaign study from autumn 2015 to spring 2018. Three hydrological variables, including current velocity (m/s), channel depth (cm), and streambed width (m), were measured at each of the five sites to determine spatio-temporal fluctuations and the loss of fluvial and parafluvial habitats. This study focused on three habitat indices: the Riparian Quality Index (QBR) [31], the River Habitat Index (IHF) [32], and the Morphological Quality Index (MQI) [33]. The QBR assesses riparian habitat quality based on four components, including total riparian vegetation cover, cover structure, cover quality, and river channel alterations. The IHF measures in-channel habitat heterogeneity based on six components, including the inclusion of riffles and pools, frequencies of riffles, substrate diversity, depth/velocity regime, percentage of shade in the riverbed, and aquatic vegetation coverage. The MQI evaluates hydro-morphological quality based on geomorphological functionality (morphology, continuity, and vegetation), artificiality (alterations of longitudinal, longitudinal and lateral continuities), and channel adjustments. The total score is obtained from the analyzed components of each index to indicate the ecological quality according to the quality classes described in (Appendix A Table A1).

2.2.3. Sampling and Identification of Macroinvertebrates

Standard hand nets (25 × 25 cm) and Surber nets (20 × 20 cm) were used to collect macroinvertebrate samples seasonally from autumn 2015 to spring 2018. The sampling effort lasted 30 to 60 minutes at each site to obtain representative samples from all habitat types. Samples were initially separated from rocks, debris, and leaves and then preserved in a plastic box in 90% alcohol. In the laboratory, all specimens were sorted and identified to the family level under a binocular microscope using taxonomic keys [34,35] and subsequently identified to the lowest possible taxonomic level (usually to species level). A total of 3117 macroinvertebrates were collected and identified.

2.2.4. DPSIR Model

The DPSIR model (Driving Force, Pressure, State, Impacts, Response) was developed by the European Environmental Agency (EEA) in 1999 [36] and is an effective tool for describing the chain of cause-and-effect links between socio-economic and environmental systems. This socio-ecological approach facilitates the understanding of human-ecosystem interactions and helps to evaluate and manage environmental problems [37–39]. The model is based on:

- Driving forces (D): refers to natural and anthropogenic factors that impact the environment
- Pressures (P): refers to how these drivers are produced and expressed at the local
- State (S): refers to the current state of the environment under the pressures exerted
- Impact (I): refers to the changes resulting from the combined impact of natural and anthropogenic pressures on environmental state, human health, and socio-economic aspects.
- Response (R): refers to the measures and practices undertaken to improve the current environmental status.

2.3. Data Analysis

Descriptive statistics, such as mean and standard deviation, were calculated to explore variation in the measured variables obtained from different sites. To assess the effects of spatiotemporal variability on sampling sites before and during Martil River rehabilitation project, we conducted a principal component analysis (PCA) to examine the relationships between physicochemical and hydrological factors, habitat indices, and macroinvertebrate assemblages [40]. The analysis was performed using the R software, Version 4.2.3 [41]. Principal component analysis (PCA) is a useful multivariate method for analyzing the studied variables (e.g., phytochemical and hydrological variables) covariations. As an efficient dimensionality reduction technique, PCA transfers primary correlated variables into a series of uncorrelated variables [40] that are then used to extract the main change trends from the variable covariations.

3. Results

3.1. Environmental and Biotic Variables

The mean and standard deviation of the environmental factors, habitat indices, and biological metrics recorded before and during the river restoration process at the five study sites throughout the sampling period (autumn 2015–spring 2018) are summarized in Table 1. Despite the significant changes in the physical structure of the river due to the restoration project, the temporal fluctuations of the physicochemical variables showed insignificant differences before and after the project's beginning. Thus, the average water temperature values of the total selected stations in Martil River ranged from 21.1 °C to 20.9 °C before and during the river restoration project, respectively. The average values of pH along the studied sites varied from 7.75 to 7.57, both before and after the beginning of the restoration project. The mean levels of Electrical Conductivity from the total sampled sites oscillated between 668.052 and 749.572 µS/cm before and following the start of the restoration project, respectively. Those of dissolved oxygen ranged from 2.77 mg/L to 3.85 mg/L during the two periods, respectively. BOD and COD trends were similar before and following the start of restoration activities, ranging from 36.4 mg/L to 32.2 mg/L and 84.1 mg/L to 71.8 mg/L, respectively. Significant differences were observed between the two periods in QBR and MQI, which proved to be highly sensitive to rehabilitation actions. The average values of QBR and MQI were significantly higher after the rehabilitation project (QBR: 40.73, indicating bad quality; MQI: 0.42, indicating poor quality) compared to before the rehabilitation project (QBR: 19.59, indicating very bad quality; MQI: 0.29, indicating very poor quality). However, the average IHF values before and during the rehabilitation actions ranged from 41.12 to 40.46, indicating moderate quality. The percentage abundance of EPT and chironomids increased from 18% and 29% to 21% and 37%, respectively, before and after the rehabilitation project, while the abundance of OCH decreased to 53% and 42%, respectively, during the two periods (refer to Table 1). The effect of seasonal variation was less pronounced than the impact of the modifications implemented in Martil River during both periods. However, there was a slight but significant difference between the seasons marked by reduced flows during summer and autumn. This led to a decrease in EPT taxa.

The Principal Component Analysis (PCA) was used to explore the relationships among physico-chemical and hydrological characteristics, habitat indices, and macroinvertebrate assemblages, which allowed us to identify spatio-temporal differences between sampling sites before and after the start of rehabilitation actions in Martil River (Figure 2). The first axis, which explained 36% of the total variability, was positively correlated with temperature, pH, DO, QBR, MQI, and IHF (Figure 2). In contrast, the second axis, which explained 30.9% of the total variability, was positively correlated with all hydrological variables, BOD5, and COD, and negatively correlated with electrical conductivity and *Chironomidae* taxa (Figure 2). According to the PCA analysis, the sampling sites were clustered based on the period of sampling (i.e., before and during the rehabilitation actions). For example, most of the sampling sites before restoration were clustered in the positive and upper part of PCA1. In the second period, the less affected stations (M1a, M2a) were positioned in the negative part of PCA1. Conversely, M3a and M4a were located in the positive part of PCA2, while M5a was clustered in the negative part of PCA2.

Table 1. Environmental characteristics and macroinvertebrate assemblages (Mean ± SD) of the studied sites in Martil River during the survey period. The measures are summarized for every sampling site before and after the start of the rehabilitation project.

Factors	M1		M2		M3		M4		M5	
Physiochemical										
T (°C)	23.25 ± 1.24	20.72 ± 2.80	20.00 ± 0.50	20.10 ± 2.43	21.90 ± 0.30	21.37 ± 3.23	21.25 ± 0.55	21.65 ± 0.20	19.50 ± 2.45	21.30 ± 0.90
PH	7.96 ± 0.54	7.64 ± 0.70	7.75 ± 0.15	7.67 ± 0.73	7.77 ± 0.21	7.77 ± 0.81	7.65 ± 0.25	7.70 ± 0.32	7.62 ± 0.18	7.08 ± 0.12
EC (μS/cm)	577.1 ± 13.9	688.2 ± 53.0	636.7 ± 23.2	764.9 ± 260.0	645.7 ± 32.8	764.9 ± 204.1	672.3 ± 35.1	770.9 ± 296.1	808.4 ± 59.0	1352.1 ± 75.0
DO (mg/L)	4.80 ± 0.40	3.20 ± 0.72	3.65 ± 1.70	2.68 ± 0.85	3.60 ± 1.40	2.97 ± 0.86	3.35 ± 1.85	3.14 ± 0.99	2.85 ± 0.65	1.90 ± 0.74
BOD (mg/L)	34.0 ± 1.0	22.0 ± 4.5	36.0 ± 1.0	24.7 ± 4.8	34.5 ± 1.5	30.4 ± 2.9	41.5 ± 1.5	60.2 ± 19.8	36.0 ± 1.0	22.8 ± 2.2
COD (mg/L)	80.2 ± 1.0	51.6 ± 10.3	79.8 ± 0.3	48.9 ± 10.4	74.4 ± 1.8	60.7 ± 8.8	92.8 ± 4.2	136.6 ± 48.3	73.4 ± 2.9	51.7 ± 6.0
Hydrological										
Current Speed (m/s)	4.35 ± 0.25	4.07 ± 0.36	6.53 ± 0.31	4.65 ± 0.45	11.10 ± 0.94	9.84 ± 0.53	10.16 ± 0.66	9.21 ± 0.49	8.80 ± 1.24	7.72 ± 0.71
Water Depth (m)	0.44 ± 0.01	0.39 ± 0.32	0.62 ± 0.71	0.37 ± 0.23	0.58 ± 0.44	0.43 ± 0.17	0.59 ± 0.45	0.44 ± 0.35	0.63 ± 0.66	0.46 ± 0.61
Stream Width (m)	12.10 ± 0.10	10.19 ± 1.07	12.56 ± 0.34	12.90 ± 0.87	15.16 ± 0.16	41.85 ± 6.46	16.16 ± 0.83	40.42 ± 7.60	31.60 ± 0.88	31.10 ± 0.45
Habitat Indices										
QBR	64.33 ± 0.30	52.00 ± 2.42	60.66 ± 5.45	48.42 ± 4.70	52.66 ± 8.35	0.00 ± 0.00	21.00 ± 1.73	0.00 ± 0.00	5.00 ± 0.57	2.57 ± 0.97
IHF	65.66 ± 1.40	55.17 ± 1.37	34.66 ± 2.02	44.00 ± 2.69	29.66 ± 4.91	31.00 ± 3.79	33.33 ± 9.27	32.00 ± 3.10	42.33 ± 0.80	39.10 ± 0.89
MQI	0.57 ± 0.02	0.54 ± 0.19	0.56 ± 0.33	0.40 ± 0.30	0.36 ± 0.10	0.16 ± 0.12	0.32 ± 0.39	0.15 ± 0.12	0.30 ± 0.03	0.22 ± 0.06
Biological Metrics										
EPT (%)	18.50 ± 4.50	24.42 ± 7.40	24.71 ± 7.89	42.66 ± 29.40	3.66 ± 3.66	13.57 ± 7.57	6.66 ± 5.23	7.57 ± 5.24	20.30 ± 15.10	23.57 ± 7.40
OCH (%)	52.00 ± 15.00	35.00 ± 19.91	43.30 ± 21.78	46.57 ± 10.10	62.00 ± 27.00	43.42 ± 15.91	62.00 ± 26.76	34.14 ± 13.50	43.60 ± 22.50	43.66 ± 9.50
Chironomids (%)	29.50 ± 10.50	26.28 ± 11.80	15.00 ± 11.23	27.85 ± 9.00	34.33 ± 29.00	30.85 ± 10.27	31.33 ± 27.80	18.85 ± 7.78	36.00 ± 7.37	57.14 ± 13.00

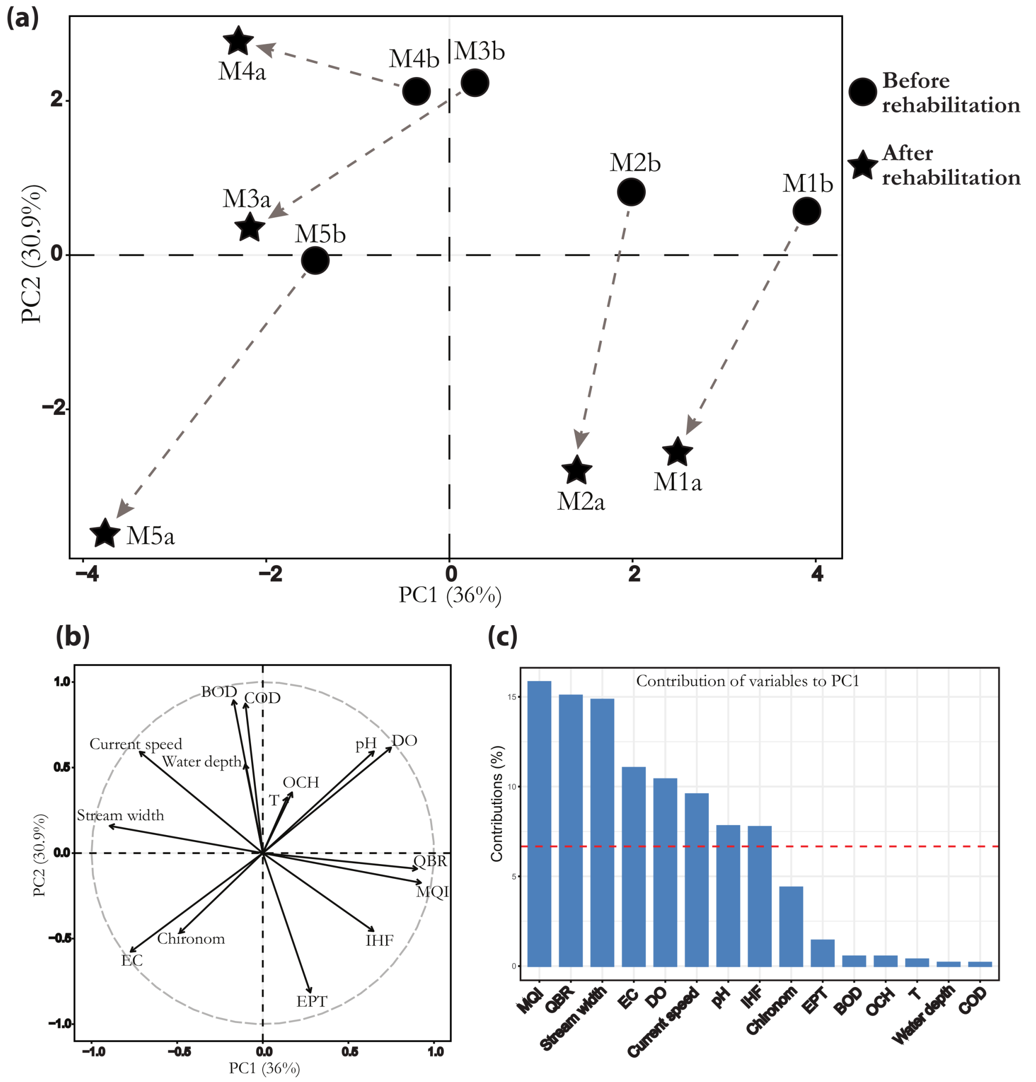

Figure 2. (**a**) Principal components analysis (PCA) of environmental characteristics and macroinvertebrate assemblages among Martil River sites before and after rehabilitation, (**b**) variables loading on the two first axes of PCA and (**c**) contribution of variables to PC1. The red dashed line in (**c**) indicates the expected average contribution to PC1.

3.2. Macroinvertebrate Assemblages

A total of 3117 macroinvertebrates were collected and identified from the five studied sites, belonging to the EPT (*Ephemeroptera*, *Trichoptera*, and *Plecoptera*), OCH (*Odonata*, *Coleoptera*, and *Heteroptera*), and *Diptera* (*Chironomidae*) orders, comprising 32 families, 53 genera, and 74 species. *Chironomidae* (*Diptera*) was the most abundant group, with 20 species, followed by *Hemiptera* (17 species), *Coleoptera* (14 species), *Ephemeroptera* (13 species), *Odonata* (8 species), *Trichoptera* (3 species), and *Plecoptera* (2 species). *Chironomidae* also had the highest abundance, representing 43.8% of the total number of collected individuals (Figure 3).

The minimum and maximum taxa richness ranged from 27 species at Taboula (M3) and Roumana (M4) to 39 species at Coelma (M5). Our results indicated that macroinvertebrate assemblages were influenced by seasonality and rehabilitation actions. Prior to and during the project construction, as well as between the rehabilitated and reference sites, taxa richness showed significant differences. Table A2 provide a comprehensive list of EPT, OCH and Chironomids reported during our study period, supplemented by data from previous studies conducted in Martil River. Comparison of species previously reported in our study area with those collected during our recent surveys revealed significant effects of rehabilitation actions on the aquatic habitats for OCH taxa, which showed reduced occurrence and abundance compared to the pre-rehabilitation period (Table A2). Twenty-one species were previously recorded in Martil River, while twenty-four are currently reported, and twelve species were common to both periods. Therefore, ten species of OCH are newly recorded for Martil River (Table A2).

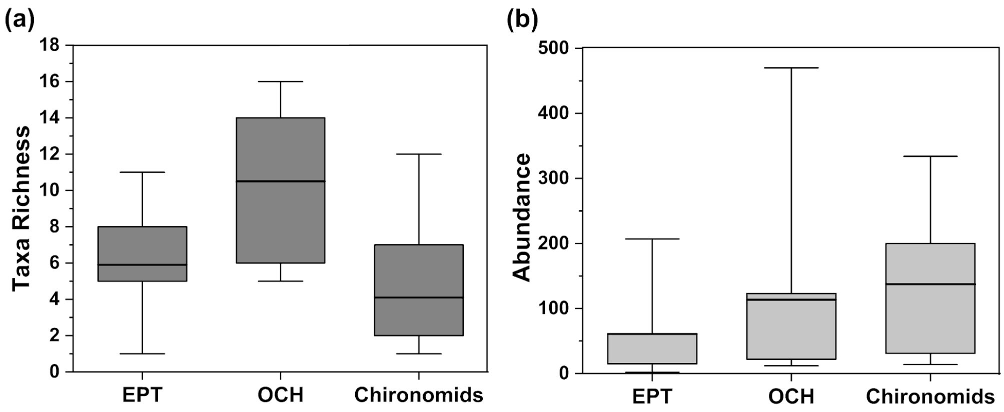

Figure 3. Box-plots (Mean, min-max) showing the variations of abundance (**a**) and taxa richness (**b**) and abundance of EPT, OCH and chironomid taxa sampled from Martil River during the study period.

On the other hand, the changes in environmental conditions have created favorable conditions that resulted in an increase in EPT taxa. Our investigation found eighteen species during the rehabilitation project, compared to only one species captured in the pre-rehabilitation period. However, the rehabilitation project may have led to the loss of twenty-two species of chironomids that were previously recorded or mentioned in the study area but not found in our recent samples. It is worth mentioning that sixteen species of chironomids have appeared for the first time in Martil River. Only four species were common between the two periods (Figure 4). It is important to note that these changes in macroinvertebrate assemblages are likely due to the improvement of the water quality and habitat conditions resulting from the rehabilitation actions.

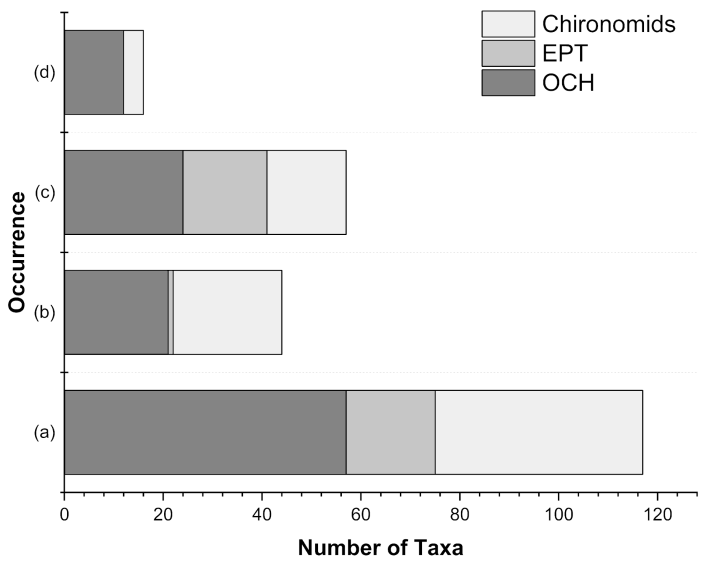

Figure 4. Number of (**a**) all mentioned taxa, (**b**) taxa previously reported, (**c**) taxa recently found during our investigation after the start of the rehabilitation project and (**d**) common taxa in Marti river.

4. Discussion

The results of our study indicate that the rehabilitation actions did not have a significant impact on the physicochemical parameters during the study period, with few exceptions. It should be noted that until now, no concrete measures or actions have been taken to improve water quality in the urban section of Martil River, and organic and mineral pollutants remain the main cause of water quality deterioration, classifying Martil River as polluted. Our findings on water quality are consistent with previous studies conducted along Martil River [42,43]. However, observed results are consistent with other studies that have suggested that physicochemical parameters are not affected by changes occurring after river rehabilitation [44–46]. The major changes in rehabilitated sites, in terms of sediment movement, hydrological alterations, ecological connectivity and land cover modification, as a consequence of morphological adjustments, have strongly altered the distribution of habitats and the biological characteristics within river ecosystems [10,46]. Habitat indices have been applied to confirm these changes, and they have shown their lowest values after the beginning of rehabilitation operations, along with significant variations in hydrological factors between the two periods. The IHF has remained the most stable index, despite having decreased due to the components related to the "percentage of shade in the riverbed and aquatic vegetation coverage" after the rehabilitation actions. However, the score of this index increased due to the components of "frequencies of rifles" and "substrate diversity" caused by channel widening.

Hydrological and habitat variables have long been considered significant factors driving aquatic assemblages. They modify riparian areas, substrate types, microhabitats, and spatial physical features of the river mosaic, resulting in hydro-morphological adjustments that affect the taxa richness and abundance of macroinvertebrates [47,48]. In Martil River, a noticeable shift in macroinvertebrate groups was observed following rehabilitation operations, resulting in an increase in the proportion of *Chironomidae*, particularly in site M5, and EPT taxa, mainly in sites M1 and M2. This was accompanied by a decline in OCH taxa, which was consistent with the findings of previous studies [10,49,50]. Among the 74 species identified during our investigation, only 15 species were common between the two periods. According to our study, the degradation of woody banks, sediment mobilization, and deposition in restored sites have contributed to the establishment of OCH taxa in newly created habitats, especially lentic ones. This finding is consistent with previous research indicating that the degradation of habitat quality leads to the increase of OCH taxa [51–53]. On the other hand, our study revealed that some macroinvertebrate functional groups benefited from the restoration, showing positive responses to the changed abiotic conditions and the ability to colonize newly constructed or restored rivers. *Chironomidae*, *Hydropsychidae*, and *Baetidae* were among the groups that showed positive responses in our study area. These findings are in line with previous research [10,54–57]. Various studies have demonstrated that the response of aquatic assemblages to restoration projects may be due to changes in resource availability, sediment, and flow regimes [5,49,52]. These studies have also shown that restoration projects result in an increase in species adapted to lotic systems, and a decrease in lentic species [52,58–60]. Some studies suggest that large rivers are resilient and recover quickly after rehabilitation or disturbance [61–63]. However, short-term recolonization of the restored sections can result in the extinction of some native species or the appearance of resistant or new taxa with distinct affinities to the new conditions [20,55,59]. For example, in Martil River, new species such as *Chironomus barbarensis* and *Glyptotendipes barbatipes* were recorded for the first time in North Africa, *Cricotopus fuscus* and *Chironomus dorsalis* were newly recorded for Morocco, and *Helophorus atlantis* was newly mentioned from the whole Rif region. Additionally, the first record of *Hemimelaena flaviventris* and *Capnioneura sp.* in low altitudes (10 m) in Morocco was observed. Consequently, generalist or opportunistic species with specific functional traits that facilitate their dispersal and establishment in constructed environments or empty microhabitats can also appear [52,64]. This was observed in Martil River with the presence of *Anisops sardeus sardeus*, *Hydroglyphus geminus*, and alien species such as *Trichocorixa verticalis verticalis*.

Recognizing the significant importance of ecological integrity requires interdisciplinary expertise to develop ideas about how cities should interact with rivers and restore natural elements of landscapes and river corridors at different spatial scales [52,65,66]. In order to describe the environmental problems in the Martil Basin, we utilized the DPSIR framework to identify the cause-effect relationships between environmental indicators and various anthropogenic pressures (Table 2).

Martil River has been subject to strong pressure from various anthropogenic activities, including urbanization, industrialization, agriculture, and tourism. The construction of dams, changes in land use patterns, and the discharge of wastewater have caused alterations in surface water and flow regimes, leading to habitat loss, decreased ecological connectivity, and significant impacts on hydro-morphological regime, land cover, water quality, and biodiversity. As a result, the river and its floodplain have become obstacles to the socio-economic development of the city. In response to these challenges, rehabilitation projects for Martil River were established to mitigate natural and anthropogenic impacts and improve the environmental quality for sustainable socio-economic development in Tetouan City.

Table 2. The DPSIR framework proposed to evaluate the impact of the rehabilitation effects on the ecological state of Martil River.

Driving Forces	Population growth; Urbanization; Industry; Agriculture; Tourism
Pressure	Water resources use; Domestic water use; Chemical fertilizer use; Land use; Floodplain changes; Construction of dams
State	Water pollution; Habitat degradation; Hydrological control; Loss of wetland habitats; Ecological disturbances; Decline in species richness
Impacts	Water quality; Hydromorphology; Vegetation coverage; Ecosystem functions; Biodiversity
Responses	Martil River rehabilitation project
Work in progress:	Reduce Flood Risks; River re-meandering; Creation of leisure zone; Creation of attractive economic zones
Approaches to take into consideration:	Ecological integrity; Habitat and hydrological connectivity; Protection of biodiversity; Sensibilisation and law enforcement

Furthermore, we acknowledge the efforts made by managers to integrate Martil River into a socio-economic framework and mitigate the effects of flooding. However, the success of the rehabilitation project should also consider the socio-ecological dimension to maintain ecosystem functions in urban river systems [67]. After the significant modifications that Martil river underwent, it is essential to clarify the interlinks between habitat diversity, biotic communities, and urban land use to provide alternative measures for the recovery of damaged ecosystems [68]. Previous studies have demonstrated the effectiveness of such methods in restoring river ecosystems [20,65,69,70]. Additionally, more studies should be conducted to compare the efficiency of river modifications, to highlight the rehabilitation effects on the ecological integrity of rivers, and to analyze biotic responses to rehabilitation practices in order to assess the success of this operation [52,59].

5. Conclusions

Overall, the success of the Martil rehabilitation project is closely tied to the potential for enhancing ecosystem functions and promoting habitat heterogeneity, besides, it is crucial to understand the relationship between habitat diversity and biotic communities, and how they are affected by urban land use. This understanding will enable the development of effective strategies for the recovery of damaged ecosystems. As rivers continue to be increasingly modified by human activities, it is important to implement rehabilitation methods that recreate the diversity of habitats and the features of riverine landscapes that existed prior to anthropogenic impacts. One approach to achieve this goal is to increase meandering, natural barriers, and riparian vegetation, which can reduce flow velocity and sediment transport while improving geomorphological characteristics that provide suitable microhabitats for various biota. Therefore, it is our hope that managers will incorporate ecological approaches in the subsequent steps of rehabilitation efforts. While we acknowledge that short-term monitoring may not provide a complete understanding of the rehabilitation's success, given that the process of rehabilitating the Martil River will take much longer than the period studied, long-term assessments are necessary to detect more detailed ecological responses in the post-rehabilitation period.

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Abbreviations

The following abbreviations are used in this manuscript:

QBR	Riparian Quality Index
IHF	River Habitat Index
MQI	Morphological Quality Index
EPT	Ephemeroptera, Plecoptera, Tricoptera
OCH	Odonata, Coleoptera, Hemiptera
CE	Electrical Conductivity
DO	Dissolved Oxygen
BOD	Biochemical Oxygen Demand
BOD5	Biochemical Oxygen Demand in 5 Days
COD	Chemical Oxygen Demand
ABHL	Loukkos Hydraulic Basin Agency
UV	Ultra Violet
DPSIR	Driving forces, Pressure, State, Impact, Response
EEA	European Environmental Agency
PCA	Principal Component Analysis

Appendix A

Table A1. Grid of the physicochemical quality [71] QBR [31], IHF [32] and MQI [33] used for the classification of surface waters in Martil River.

Quality Class	T (°C)	pH	EC (µS/cm)	DO (%)	BOD5 (mg/L)	COD (mg/L)	QBR	IHF	MQI
Excellent	<20	6.5–8.5	<750	>7	<3	<30	<95	<60	0.85–1
Good	20–25	-	750–1300	7–5	3–5	30–35	90–75	40–60	0.7–0.85
Average	25–30	8.5–9.2	1300–2700	5–3	5–10	35–40	70–55	>40	0.5–0.7
Poor	30–35	<6.5 or >9.2	2700–3000	3–1	10–25	40–80	50–30	-	0.3–0.5
Very Poor	>35	-	>3000	<1	>25	>80	>30	-	<0.3

Table A2. List of OCH, EPT and Chironomidae (Diptera) of Martil River. Symbols used: species previously cited in the literature and not captured in our study (*), species cited and found (**), new citations for the study region (***).

Taxa	Previous Findings	CIT.	Stations
Odonata			
Lestes barbarus (Fabricius, 1798)	Benazzouz, 1988 [72]	*	M2
Lestes viridis (Vander Linden, 1825)		***	M5
Calopteryx sp.		***	M5
Calopteryx exul Selys, 1853	Benazzouz, 1988	*	M2
Erythromma lindenii (Selys, 1840)	El Haissoufi et al., 2015 [73]	*	M2
Ischnura graellsii (Rambur, 1842)	Benazzouz, 1988; El Haissoufi et al., 2015	**	M2, M3, M4, M5
Aeshna mixta Latreille, 1805	Benazzouz, 1988	**	M1, M2
Anax parthenope Selys, 1839	Benazzouz, 1988	*	M2
Anax sp.		***	M1, M2, M4, M5
Onychogomphus forcipatus unguiculatus (Vander Linden, 1823)	Benazzouz, 1988	**	M2, M3
Paragomphus genei (Selys, 1841)	Benazzouz, 1988	*	M2
Cordulegaster boltonii (Donovan, 1807) *algirica* Morton, 1916		***	M4
Crocothemis erythraea (Brullé, 1832)	Benazzouz, 1988; El Haissoufi et al., 2015	*	M2
Libellulidae		***	M3, M4
Sympetrum fonscolombii (Selys, 1840)	Benazzouz, 1988	*	M2
Trithemis annulata (Palisot de Bauvois, 1807)	El Haissoufi et al., 2015	*	M2
Coleoptera			
Aulonogyrus striatus (Fabricius, 1792)	Benamar, 2015 [74]	**	M1, M2, M3, M4, M5
Gyrinus dejeani Brullé, 1832	Benamar, 2015	**	M1, M2, M5
Gyrinus urinator Illiger, 1807		***	M1
Haliplus lineatocollis (Marsham, 1802)		***	M4
Noterus laevis Sturm, 1834		***	M4
Agabus brunneus (Fabricius, 1798)	Benamar, 2015	*	M2
Agabus conspersus (Marsham, 1802)		***	M5
Hydroglyphus geminus (Fabricius, 1792)		***	M5
Deronectes fairmairei (Leprieur, 1876)		***	M1, M2
Stictonectes optatus (Seidlitz, 1887)	Benamar, 2015	*	M2
Laccophilus minutus (Linnaeus, 1758)		***	M5
Hydroporus discretus discretus Fairmaire & Brisout, 1859	Benamar, 2015	*	M2
Helophorus atlantis Angus & Aouad, 2009		***	M5
Berosus affinis Brullé, 1835		***	M5
Berosus hispanicus Küster,1847		***	M2, M3, M4
Laccobius atrocephalus Reitter, 1872		***	M1, M2
Hydrochus aljibensis Castro & Delgado, 1999	Benamar, 2015	*	M2
Hydraena cordata Schaufuss, 1883	Benamar, 2015	*	M2
Ochthebius mediterraneus (Ienistea, 1988)	Bennas et al., 2001 [75]	*	M2
Elmis maugetii velutina (Reiche, 1879)		***	M5
Oulimnius troglodytes (Gyllenhal, 1827)	Benamar, 2015	*	M2
Dryops algiricus (Lucas, 1849)	Benamar, 2015	*	M2
Dryops sulcipennis (Costa, 1883)	Benamar, 2015	*	M2

Table A2. *Cont.*

Taxa	Previous Findings	CIT.	Stations
Hemiptera			
Aquarius cinereus (Puton, 1869)		***	M1
Aquarius najas (de Geer, 1773)		***	M1
Gerris gibbifer Schummel, 1832	L'Mohdi, 2015 [76]	**	M4, M5
Gerris thoracicus Schummel, 1832		***	M1, M4, M5
Hydrometra stagnorum (Linnaeus, 1758)	L'Mohdi, 2015	**	M1, M2, M3
Mesovelia vittigera Horváth, 1895		***	M5
Velia ioannis Tamanini, 1971	L'Mohdi, 2015	**	M2
Corixa affinis Leach, 1817	L'Mohdi, 2015	**	M2
Hesperocorixa furtiva (Horváth, 1907)	L'Mohdi, 2015	*	M2
Sigara lateralis (Leach, 1817)	L'Mohdi, 2015	**	M2
Micronecta scholtzi (Fieber, 1860)	L'Mohdi, 2015	**	M2
Naucoris maculatus Fabricius, 1798		**	M4
Nepa cinerea Linnaeus, 1758	L'Mohdi, 2015	*	M2
Anisops sardeus sardeus Henrrich-Schaeffer, 1849		***	M1, M2, M3, M4, M5
Notonecta maculata Fabricius, 1794		***	M5
Notonecta meridionalis Poisson, 1926	L'Mohdi, 2015	*	M2
Plea minutissima Leach, 1818		***	M4, M5
Ephemeroptera			
Acentrella almohades (Alba-Tercedor & El Alami, 1999)		***	M2
Baetis fuscatus (Linné, 1761)		***	M4
Baetis pavidus (Grandi, 1949)		***	M1, M2, M3, M4, M5
Baetis rhodani (Pictet, 1984)		***	M1, M2, M3, M4, M5
Cloeon dipterum (Linné, 1761)		***	M1, M2, M3, M4, M5
Cloeon simile (Eaton, 1870)		***	M1, M2, M4
Procloean concinnum (Eaton, 1885)		***	M1
Ecdyonurus rotschildi (Navás, 1929)		***	M4
Chroterpes volubilis (Thomas & Vitte, 1988)		***	M1, M2, M3, M5
Chroterpes atlas (Soldan & Thomas, 1983)		***	M1, M5
Ephoron virgo (Olivier, 1791)		***	M1
Serratella ignita (Poda, 1791)		***	M1
Caenis luctuosa (Burmeister, 1839)		***	M1, M2, M3, M4, M5
Plecoptera			
Capnioneura sp.		***	M1
Hemimelaena flaviventris (Pictet, 1841)		***	M1
Trichoptera			
Hydropsyche iberomaroccana (González & Malicky, 1999)		***	M1, M5
Hydropsyche lobata (McLachlan, 1884)		***	M2, M3
Hydropsyche pellucidula (Curtis, 1834)		***	M3
Chimarra marginata (Linnaeus, 1767)	Hajji, 2017 [77]	*	M2
Diptera (Chironomidae)			
Tanypus punctipennis (Maigen, 1818)		***	M2
Cricotopus bicintus (Meigen, 1818)	Kettani et al., 1995 [78]	*	M2
Cricotopus fuscus (Kieffer, 1909)		***	M3
Cricotopus pallidipes (Edwards, 1929)	Kettani et al., 1995	*	M2
Orthocladius ashei (Soponis, 1990)		***	M3
Orthocladius obumbratus (Johannsen, 1905)	Kettani et al., 1995	*	M3

Table A2. *Cont.*

Taxa	Previous Findings	CIT.	Stations
Diptera (Chironomidae)			
Orthocladius rubicundus (Meigen,1818)	Kettani et al., 1995	**	M2
Rheocricotopus atripes (Kieffer, 1913)	Kettani et al., 1996 [79]	**	M2, M3
Rheocricotopus chalybeatus (Edwards, 1929)	Kettani et al., 1995	*	M2
Rheocricotopus tirolus (Lehmann, 1969)		***	M3
Chironomus barbarensis (Theowald & Oosterbroek, 1980)		***	M2
Chironomus dorsalis (Meigen, 1818)		***	M4, M5
Chironomus luridus (Strenzke, 1959)	Kettani & Langton, 2011 [80]	*	M2
Chironomus nuditarsis (Keyl, 1961)		***	M5
Chironomus plumosus (Linnaeus)		***	M2, M3, M4, M5
Chironomus riparius (Meigen, 1804)		***	M5
Chironomus salinarius (Kieffer, 1915)		***	M2, M5
Chironomus Pe 3 (Langton, 1991)		***	M4
Cryptochironomus rostratus (Kieffer, 1921)		***	M2
Cryptochironomus Pe 5 (Langton, 1991)		***	M2
Dicrotendipes modestus (Say, 1823)	Kettani & Langton, 2011	*	M2
Dicrotendipes septemmaculatus (Becker, 1908)	Kettani et al., 1995	**	M2
Glyptotendipes barbatipes (Staeger, 1911)		***	M2
Glyptotendipes gripekoveni (Kieffer, 1913)		***	M2, M5
Glyptotendipes pallens (Meigen, 1804)		***	M2
Harnischia curtilamellata (Malloch, 1915)	Kettani et al., 1995	*	M2
Microtendipes britteni (Edwards, 1929)	Kettani et al., 1995	*	M2
Nubensia nubens (Edwards, 1929)	Kettani et al., 1995	*	M2
Parachironomus frequens (Johannsen, 1905)	Kettani et al., 1995	*	M2
Paracladopelma camptolabis (Kieffer, 1913)	Kettani et al., 1995	*	M2
Paratendipes albimanus (Meigen, 1818)	Kettani et al., 1995	*	M2
Polypedilum aegyptium (Kieffer, 1925)	Kettani et al., 1995	*	M2
Polypedilum separabilis (Brundin, 1947)	Kettani et al., 1995	*	M2
Polypedilum sordens (Van der Wulp, 1875))	Kettani & Langton, 2011	**	M2, M5
Polypedilum Pe 1 (Langton, 1991)	Kettani et al., 1995	*	M2
Stictochironomus maculipennis (Meigen, 1818)	Kettani et al., 1995	*	M2
Cladotanytarsus vanderwulpi (Edwards, 1929)	Kettani et al., 1995	*	M2
Paratanytarsus bituberculatus (Edwards, 1929)	Kettani et al., 1995	*	M2
Paratanytarsus inopertus (Walker, 1856)	Kettani & Langton 2011	*	M2
Rheotanytarsus reissi (Lehman, 1970)	Kettani et al., 1995	*	M2
Tanytarsus medius (Reiss & Fittkau, 1971)	Kettani et al., 1995	*	M2
Virgatanytarsus albisutus (Santos Abréu, 1918)	Kettani et al., 1995	*	M2

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