ECOLOGIA BALKANICA

2022, Vol. 14, Issue 2 December 2022 pp. 113-121

Effect of the Urban Heat Island in Plovdiv City (Bulgaria) on the Species Composition and Distribution of the Dragonflies (Insecta: Odonata)

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Abstract. The current paper researches the impact of the urban heat island effect on the species composition and distribution of dragonflies (Insecta: Odonata) along the Maritsa River in the city of Plovdiv, Bulgaria. The study was conducted on imaginal and larval forms of the species, and the studied area was divided into 3 sub-areas (urban, suburban and rural) according to the proximity to the city center. Along the urban gradient from the rural to the urban zone, an increase in air, water and soil temperature by ≈1-2ºC was observed. Differences were found also in the dissolved oxygen in the water, which had the highest values in the rural area (10.70 mg/l) and decreased towards the urban area, where it was 9.03 mg/l. Four dragonfly species were confirmed for the study area, and 2 new species were recorded. The most species were found in the urban zone, probably due to the higher temperatures compared to the other two areas, while at the same time, no larvae were found there, due to the lower amount of dissolved oxygen in the water. The current paper gives a better understanding of the impact that the urban heat island effect has on dragonflies in cities and aims to contribute for timely measures and decisions for the management of wetlands around urban areas.

Key words: temperature, dissolved oxygen, Odonata, dragonflies, Plovdiv City, urban area.

Introduction

One of the biggest problems of the XXI century are climate anomalies, which lead to major changes in wetland regimes and changes in environmental conditions and affect all organisms in these ecosystems. Indeed, wetlands are most vulnerable in and around cities due to the presence of the "heat island effect". Urban heat islands are formed when the natural landscape is gradually replaced by asphalt, concrete and gravel used to build roads, buildings and other structures that retain heat, and this causes the temperature in cities to rise several degrees compared to the surroundings them (Oke, 1982).

Dragonflies (Odonata) are good indicators in aquatic ecosystems (Kalkman et al., 2008), since they are closely related to habitat quality, and their life cycle is directly affected by climate change. The changes in the climate are also clearly noticeable in the city of Plovdiv (Bulgaria), and Maritsa River is extremely important water basin for the dragonflies in the area. Proper management of green spaces and especially wetlands in cities would ensure stability in urban systems (Lovejoy & Hannah, 2005). A better understanding of the impact that the urban heat island effect has on dragonflies in cities will contribute to timely measures and decisions for the management of wetlands around urban areas, which determines the relevance of the present work, which aims to investigate the impact of the urban heat island effect on the species composition and distribution of dragonflies (Insecta: Odonata) along the Maritsa River in the city of Plovdiv.

Material and Methods

Study area. The study period was from May to August 2022, when the dragonflies are most active. The studied area was divided into 3 sub-areas (Fig. 1.) according to the proximity to the city center. The first site is located directly in the central part of the city of Plovdiv and covers the territory from the "Vasil Aprilov" bridge to the point of confluence of the Parvenetska River with Maritsa River (Site 1 - urban zone). The second site covers the point of confluence of Parvenetska River to the bridge at the 6th kilometer west of the city (Site 2 - suburban zone) and the third site is the farthest from the urban part and covers the bridge at the 6th kilometer to a small dam before the village of Orizari (Site 3 - rural zone).

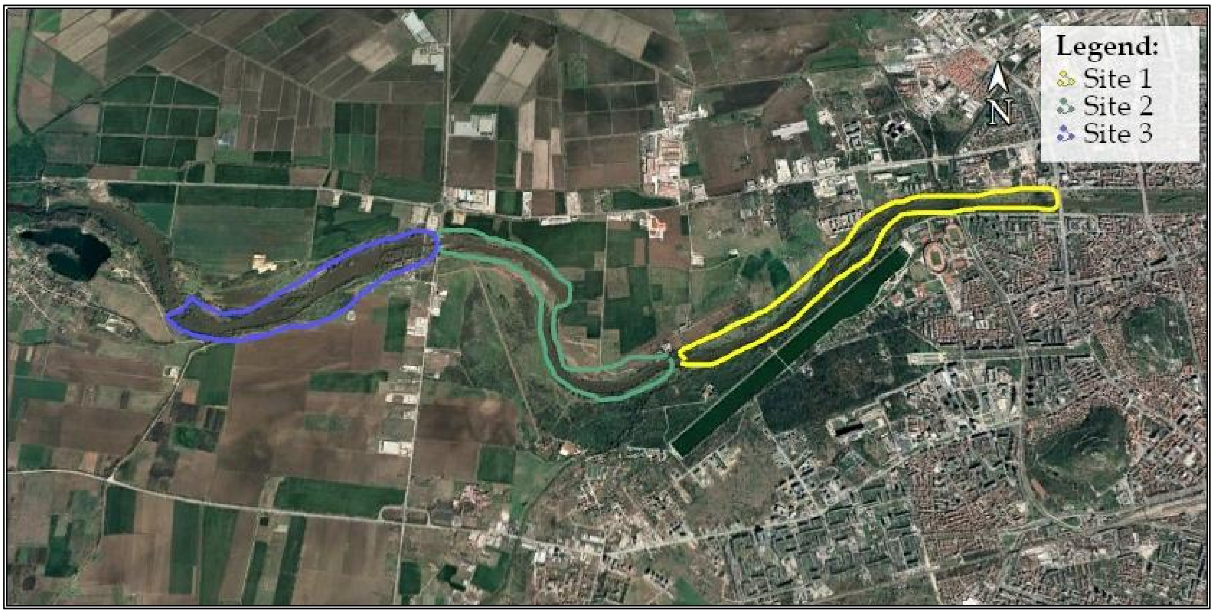

Fig. 1. Map of the study area with the boundaries of the studied sites.

Field surveys

The study was conducted on imaginal and larval forms of the order Odonata. The species composition of the imaginal individuals was established by means of transects (Gregory et al., 2004) at the north bank of Maritsa River. Where possible, the individuals were captured via entomological net, identified in the field and immediately released afterwards. Otherwise, a photographic technique with macro mode (Sony Alpha 58) was used for detailed photography of the registered species. The determination by photographic material was carried out later in laboratory conditions.

Larval material was collected using underwater live traps (Bock et al., 2009). Traps were placed at pre-selected points with similar characteristics in the three studied sites for comparability in data analysis. Traps were set monthly during the study period. After placing the traps, they are checked every 24 hours.

For the determination of the registered dragonflies (imago and larvae), we used specialized field guides by Beshovski (1994), Marinov (2000) and Smallshire & Swash

(2020), paying attention to the most taxonomically important features: size and shape of the eyes, shape and coloration of the prothorax, shape and coloration of legs, wing venation, coloration and shape of abdominal segments and copulatory apparatus of male and female specimens. For each captured larval individual, the determination was made by morphological marks with the help of a monocular magnifying glass. Valid species names are according to the "World Odonata Checklist" (Paulson et al., 2022).

At the points where the traps are placed, several abiotic factors (water, air and soil temperature, pH and dissolved oxygen in the water) are measured. The dissolved oxygen was measured using oximeter “Oxi 3205”; for measuring pH - an electronic pH meter “Lovibond SensoDirect 150”, and for measuring the temperature of air, water and soil, a mercury thermometer was used, with accuracy to 0.1ºC.

The data of the measured abiotic factors from the three zones were processed with descriptive statistics and compared using the Kruskal-Wallis test for independent samples, since the data did not have a normal distribution. In order to establish similarity between the three investigated areas (urban, suburban and rural), a cluster analysis was performed based on the quantitative data (number) (unweighted per-group average, Bray-Curtis similarity index), and for the distribution of the relationships of the species in the three areas, again, on the basis of the quantitative data, a corresponding analysis was made. Statistical package "PAST" v.4.11 was used for the statistical processing of the data. (Hammer et al., 2001).

Results and Discussion

Analysis of abiotic factors in the studied areas

The values of air, water and soil temperature, dissolved oxygen and water reaction (pH) in the studied parts of the Maritsa River in the city of Plovdiv during the whole period of study are presented in Fig. 2.

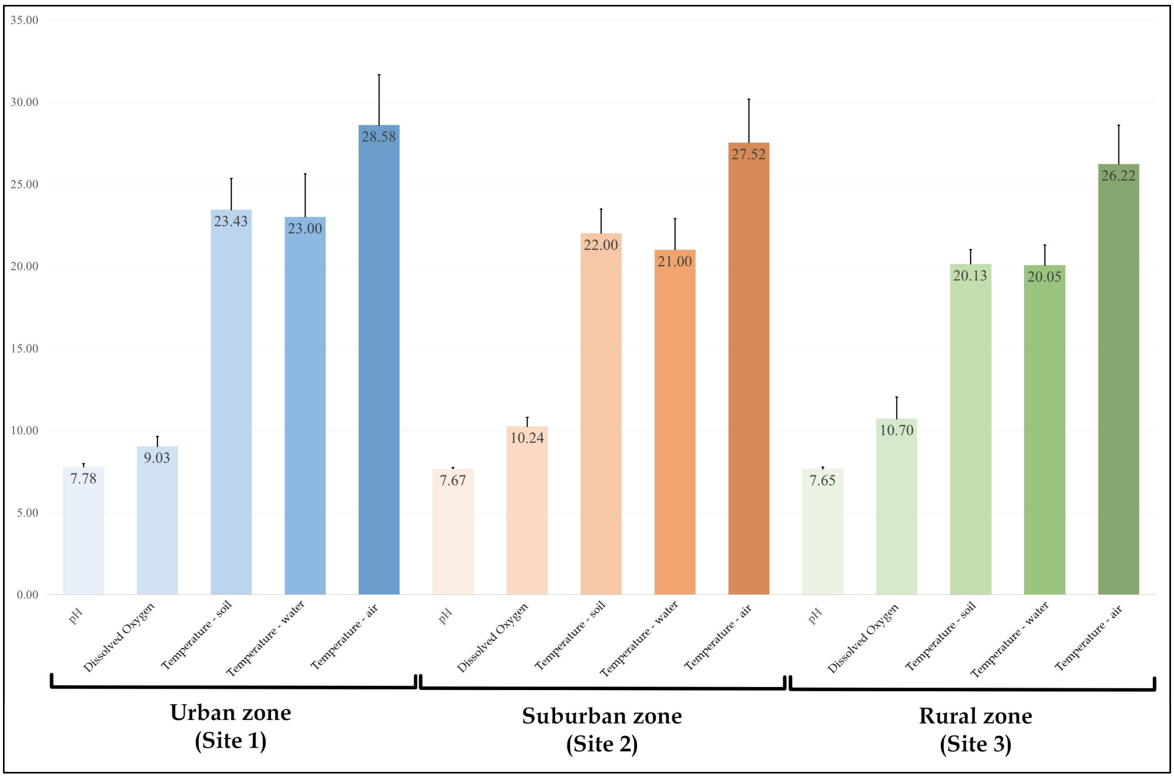

Fig. 2. Abiotic factors (mean values and standard deviations), measured along the urban gradient along the Maritsa River in the city of Plovdiv (total for 2022).

As it can be seen from the figure - along the urban gradient from the rural to the urban zone, an increase in air, water and soil temperature by ≈1-2°C is observed. The Kruskal-Wallis test based on the pooled data for the whole period shows statistically significant differences when comparing the air temperature of the three zones (H=9.803, p=0.00742), as well as the water temperature (H=21.43, p=0.0189) and the soil temperature (H=40.75, p=0.046). In the studied area for the period May-August 2022, we can talk about the presence of a "urban heat island effect" along the urban gradient along the Maritsa River in the city of Plovdiv.

Statistically significant differences were also registered regarding the dissolved oxygen in the water (H=23.71, p=0.00000854), which has the highest values in the rural area (10.70 mg/l) and decreases towards the urban area, where it is 9.03 mg/l . The only indicator that did not show statistically significant differences when comparing the three zones is pH (H=2.213, p=0.33), which ranges between 7.65-7.78 (Fig. 2).

Species composition and distribution

Up to date, a total of 24 species from 8 families have been reported for the studied areas, which, out of a total of 71 species in Bulgaria, makes 33.8% of the species composition in the country (Gainzarain, 2017): *Aeshna affinis, Aeshna mixta, Anax ephippiger, Anax parthenope, Calopteryx splendens, Crocothemis erythraea, Coenagrion puella, Gomphus vulgatissimus, Ischnura elegans, Ischnura pumilio, Lestes barbarous, Lestes dryas, Libellula fulva, Ophiogomphus cecilia, Onychogomphus forcipatus, Ophiogomphus serpentinus, Orthetrum albistylum, Orthetrum brunneum, Platycnemis pennipes, Sympetrum meridionale, Stylurus flavipes, Sympetrum depressiusculum, Sympecma fusca, Sympetrum fonscolombii* (Klapalek, 1894; Petkov, 1914; 1921; Urbanski, 1947; Angelov, 1960; Beshovski, 1964; Rusev, 1966; Dumont, 1977; Uzunov et al., 1981; Marinov, 2001).

From the 24 species reported in the literature, only 4 species were confirmed in the field studies. Another 2 species are new to the studied area: *Calopteryx virgo* (Linnaeus, 1758) and *Orthetrum cancellatum* (Linnaeus, 1758) - Fig. 3-4.

Fig. 3. *Orthetrum cancellatum.*

Fig. 4. *Calopteryx virgo.*

Calopteryx virgo was found in the urban zone among coastal vegetation. A male was observed among a group of *Calopteryx splendens* and *Platycnemis pennipes. C. virgo* is a rheophilic species and inhabits more often the upper reaches of rivers at altitudes above 400 m (Marinov, 2000). *Orthetrum cancellatum* was found again in the central urban area with 2 males. The species is limnophilous but is found in water bodies throughout the country (Marinov, 2000).

The most numerous is *Calopteryx splendens*. Both single specimens and groups of about 20 or more individuals have been found in the three studied sites. Such groups have been observed near the banks of the river with the presence of coastal and submerged aquatic vegetation.

This indicates that macrophyte habitat cover is an important factor for dragonfly populations (Pereira et al., 2019). To avoid overheating, some species may seek shady locations (May, 1976; Mazzacano et al., 2014). Junior et al. (2015) observed high species richness of Anisoptera in habitats that were ecologically characterized between built-up and well-preserved areas, while Zygoptera showed specificity for preserved habitats. They have greater richness in protected areas than in degraded habitats (de Carvalho et al., 2013).

In larval stage, only 3 species were found from the suburban and rural zones: *Calopteryx splendens* (Harris, 1782), *Platycnemis pennipes* (Pallas, 1771) and *Libellula fulva* Muller, 1764, as well as one individual determined only to the family level (Libellulidae).

Table 1 presents the species composition and numbers of the recorded species and their distribution in the three sites (rural, suburban and rural).

Table 1. Distribution and abundance (N) of Odonata (imago et larvae) in the three zones along the urban gradient along the Maritsa River in the city of Plovdiv.

Site 1 (urban zone)				**Site 2 (suburban zone)**				**Site 3 (rural zone)**			
Species	N	Males	Females	Species	N	Males	Females	Species	N	Males	Females
Larvae											
				Platycnemis pennipes	5			*Calopterix splendens*	8		
				Calopterix splendens	11			Libellulidae	1		
								Libellula fulva	1		
Imago											
Platycnemis pennipes	2		2	*Libellula fulva*	1	1		*Calopterix splendens*	27	23	4
Calopterix splendens	7	4	3	*Calopterix splendens*	32	3	29	*Orthetrum albistylum*	1	1	
Calopterix virgo	1	1									
Libellula fulva	3	2	1								
Orthetrum cancellatum	2	2									

It can be seen from the table that no larvae were detected in the urban zone, which may be due to the relatively lower content of dissolved oxygen in the water. Larvae are entirely aquatic organisms that directly depend on oxygen levels, dissolved in the water (Beshovski, 1994). Most of the individuals found are from the suborder Zygoptera, whose larvae possess gill plates. These species prefer waters with higher dissolved oxygen content. Dragonfly larvae are affected by many physical and biological factors, some of which may be limiting to their distribution (Vannote et al., 1980; Power, 2006). Although there are many observations in this area, almost no experimental tests have been conducted (Leipelt, 2005). The most numerous species is *Calopteryx splendens*. Willigalla & Fartmann (2012) indicate that species richness increases along the urban gradient from the city center to the outskirts of the city.

Fig. 5 presents a dendrogram built on the basis of cluster analysis of the quantitative data (abundance) of Odonata species in the three studied areas. The dendrogram shows that the urban zone separates into a single cluster with only about 30% similarity to the other two zones, which form a second cluster with about 85% similarity between them. As already mentioned the urban zone is where the majority of species were found, some of which are not found in the other two areas. Dragonflies belong to the so-called warm-adapted animals (Marinov, 2000), accordingly, the high species diversity can probably be attributed to the higher average air temperature (Fig. 2). There is also evidence that species of the suborder Zygoptera are more sensitive to dynamics in environmental factors (Perez & Bautista, 2020; Sganzerla et al., 2021) and as it can be seen from Table. 1 in the urban zone, no large aggregations of species of the suborder Zygoptera were found. Another factor that may affect the distribution of dragonflies is the food resource. Higher temperatures may contribute to higher densities of other insects that represent a food base attracting dragonflies. Fig. 6. presents a graph from the correspondence analysis, which shows the distribution of species (based on the quantitative data) in relation to the three zones.

Some researchers believe that urbanization is having an adverse effect on dragonfly populations. One study shows that species richness increases from urban to rural areas (Willigalla & Fartmann, 2012). One of the reasons, according to the authors, is that in the center of the cities the number of water basins is much smaller and insignificant. The result of the studies conducted by Perez & Bautista (2020) and Sganzerla et al. (2021), proving that representatives of the suborder Zygoptera are more sensitive to changes in environmental factors compared to species of the suborder Anisoptera. Ambient relative humidity and temperature can affect the abundance of certain species in their populations, and vegetation in riparian habitats is critical for increasing dragonfly populations in highly urbanized areas (Chrislene et al., 2022).

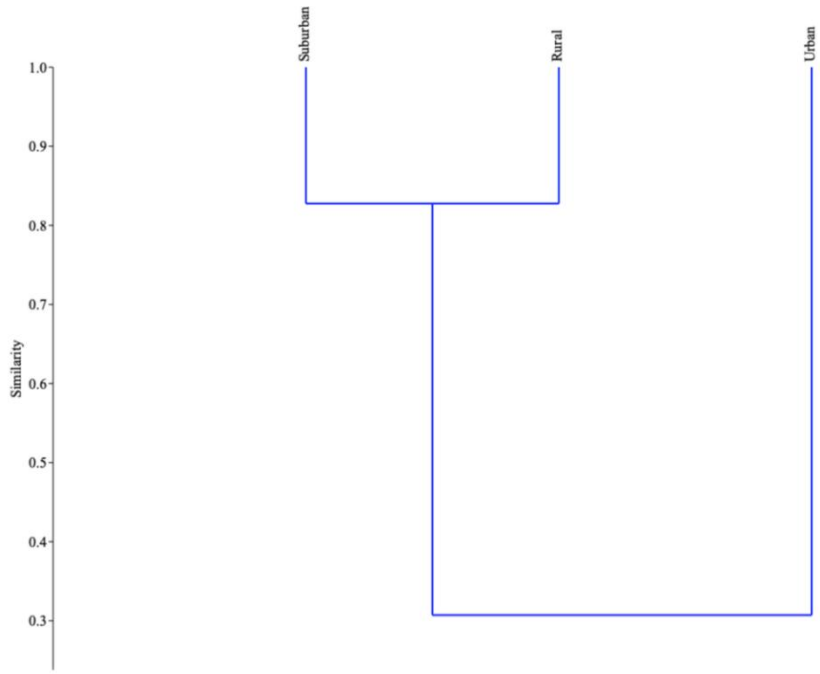

Fig. 5. Dendrogram (unweighted per-group average, Bray-Curtis similarity index) showing the similarity of dragonflies (based on quantitative data) in the three studied areas (urban, suburban and rural zones).

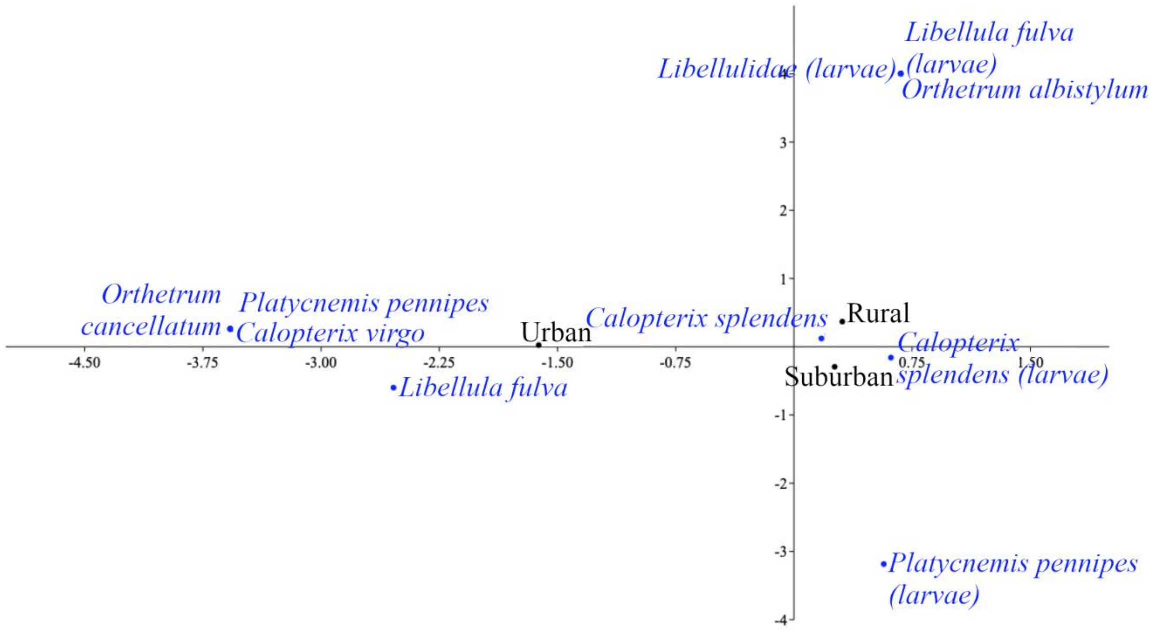

Fig. 6. Correspondence analysis showing the relationship of dragonfly species (based on quantitative data) in the three studied areas (urban, suburban and rural zones).

Another study conducted in Germany (Goertzen & Suhling, 2018) focused on examining the species richness of dragonflies in agricultural areas and in urban environments. The results show that the urban environment is characterized by the presence of more opportunistic and thermophilic species. The authors concluded that urban landscapes may have more diverse habitats and support greater species richness of dragonflies than agricultural areas. Another survey conducted in the Braunschweig area (northern Germany) from 1980 to 2009 recorded 51 species of dragonflies (Suhling et al., 2009). This research supports the proposition that cities have the potential to support a high species richness of dragonflies.

Conclusions

As a result of the research carried out and presented, we can summarize the following conclusions:

1. In the studied area during the sampling period (May-August 2022), we can talk about the presence of a "urban heat island effect" along the urban gradient along the Maritsa River in the city of Plovdiv. Air, water and soil temperatures rise by approximately 1-2ºC from the periphery to the city center.

2. A total of 4 species were confirmed and 2 new species of dragonflies were recorded for the study area (*Calopteryx virgo* and *Orthetrum cancellatum*), which increases the total number of Odonata species for the study are to 26.

3. The most species were found in the urban zone, which was probably due to the higher temperatures compared to the other two zones, while at the same time, no Odonata larvae were found in this area, due to the lower amount of dissolved oxygen in the water.

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Received: 01.10.2022
Accepted: 23.11.2022