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DRAGONFLY FAUNA (INSECTA: ODONATA) OF PAPUK NATURE PARK, CROATIA

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Odonata is an amphibious insect order constituting an important link between aquatic and terrestrial habitats. Members of the group are widely used as bioindicators of freshwater habitat health. The Odonata fauna of a total of 44 freshwater habitats in the wider area of Papuk Nature Park was investigated in the spring and summer of 2017 and 2019. Twenty-three lotic and 21 lentic habitats were included in the study. We recorded 39 Odonata species, witha higher species richness (i.e. 35) documented at lentic than at lotic habitats (i.e. 16 species). *Calopteryx virgo* was the most widespread species in the area, while *Aeshna affinis, Epitheca bimaculata,* and *Sympetrum meridionale* were the rarest. The most frequently recorded species at lentic sites were *Platycnemis pennipes*, *Coenagrion puella,* and *Ischnura elegans*, while *Calopteryx virgo*, *Onychogomphus forcipatus,* and *Cordulegaster bidenatata* were the most common species in lotic habitats. Although we recorded numerous anthropogenic pressures in freshwater habitats in the Park, 11 recorded species are of conservation concern, which highlights the conservation value of aquatic habitats in the study area. Our results represent the first Odonata checklist of Papuk Nature Park, and as such, they are an important contribution to our knowledge of the Odonata fauna and species distribution in Croatia.

Key words: freshwater habitats, protected area, anthropogenic pressures, threatened species, Odonata

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Odonata (vretenca) su amfibijski red kukaca koji čini važnu poveznicu između vodenih i kopnenih staništa. Vretenca se često koriste kao bioindikatori zdravlja slatkovodnih staništa. Tijekom proljeća i ljeta 2017. i 2019. istraživana je fauna vretenaca na ukupno 44 slatkovodna staništa na širem području Parka prirode Papuk. U istraživanje su uključena 23 lotička i 21 lentičko stanište. Zabilježili smo 29 vrsta vretenaca, s većom brojnošću vrsta na lentičkim (35) nego na lotičkim staništima (16). Najraširenija vrsta na cijelom istraživanom području bila je *Calopteryx virgo*, dok su *Aeshna affinis, Epitheca bimaculata* i *Sympetrum meridionale* bile najrjeđe. Najčešće zabilježene vrste na lentičkim staništima bile su *Platycnemis pennipes*, *Coenagrion puella* i *Ischnura elegans*, a na lotičkim staništima bile su to vrste *Calopteryx virgo*, *Onychogomphus forcipatus* i *Cordulegaster bidenatata*. Iako su na slatkovodnim staništima na širem području Parka zabilježeni brojni antropogeni pritisci, čak 11 zabilježenih vrsta u nekoj je od kategorija ugroženosti, što naglašava konzervacijsku vrijednost vodenih staništa na istraživanom području. Naši rezultati predstavljaju prvi prvi popis vrsta vretenaca Parka prirode Papuk, i stoga su važan doprinos našem poznavanju faune vretenaca i rasprostranjenosti njihovih vrsta na području Hrvatske.

Ključne riječi: slatkovodna staništa, zaštićeno područje, antropogeni pritisci, ugrožene vrste, Odonata

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INTRODUCTION

Dragonflies (Odonata) are amphibious insects, which spend most of their life in the nymphal stage inhabiting various freshwater habitats, both lotic and lentic. The adult part of Odonata life is spent in a terrestrial environment around water bodies. Hence, they represent a very important link between aquatic and terrestrial ecosystems (Askew, 2004; Corbet & Brooks, 2008). Odonata species often have specific requirements for habitat conditions, such as habitat morphology, structure, and physical and chemical water parameters (Askew, 2004; Corbet & Brooks, 2008; Vidaković Maoduš *et al.*, 2022; Vilenica, 2017; Vilenica *et al.*, 2022a). The presence and structure of riparian, submerged, emergent, and floating aquatic vegetation provide a range of microhabitats for oviposition, nymphal survival, hiding from predators, perching, and hunting (Askew, 2004; Dijkstra & Lewington, 2006). As the composition and structure of Odonata assemblages reflect the condition of freshwater habitats, they are widely used as bioindicators of aquatic ecosystems' health and as a tool to assess the conservation value of lotic and lentic habitats (Corbet & Brooks, 2008; Vilenica *et al.*, 2020, 2022b).

Although the interest in Odonata of Croatian freshwater habitats increased during the last several decades (Belančić *et al.*, 2008; Bogdanović *et al.*, 2008; Perović & Perović, 2006; Štih *et al.*, 2015; Vilenica *et al.*, 2011; Vilenica & Vinko, 2013; Vilenica & Dijkstra, 2014; Vilenica *et al.*, 2016, Vilenica, 2017, Vilenica *et al.*, 2020), there are still many gaps in our knowledge about species richness and distribution in Croatia. Many areas have remained understudied, or else data have not been published, which limits the protection of species and their habitats as well as the management of important areas. Such is the case with most nature parks and national parks in the country, with some rare exemptions (Štih *et al.*, 2020; Štih Koren & Koren, 2022). Before our study, there were only two published records regarding the occurrence of Odonata in Papuk Nature Park: *Sympecma fusca* Vander Linden, 1820 and *Sympetrum striolatum* (Charpentier, 1840) were recorded almost a century ago at Jankovac Lake (Koča, 1925). Therefore, here we aim to present Odonata species richness and distribution in Papuk Nature Park as well as the anthropogenic pressures on their habitats.

MATERIAL AND METHODS

Study area

Papuk Nature Park is located in the continental eastern part of the Republic of Croatia, in the Slavonian mountains, Papuk, and partially Krndija (Fig. 1). Due to the exceptional biological and geological diversity and valuable cultural and historical heritage, a large part of the area of the Slavonian highlands was protected by law on April 23 1999 as Papuk Nature Park. The Park covers an area of 336 km^2. It is mostly covered with mixed forests of beech, oak, and fir (Pamić *et al.*, 2010) with other flora and fauna being extremely rich (Tomašević & Samardžić, 2000; Pandža, 2010; Radović & Tepić, 2009). However, it is very important to mention the areas of non-forest vegetation, which occupy only about 4% of the Park's territory but are of crucial importance for the Park's biodiversity. Numerous and diverse surface terrestrial waters (springs, rivers, streams, ponds) and associated wetlands provide habitats for numerous aquatic and terrestrial organisms (Augustinović, 2009; Barišić & Bogdanović, 2011; Petrović, 1969; Kožić *et al.*, 2015; Kuhta & Brkić, 2003; Previšić *et al.*, 2013), including dragonflies (Bogdanović, 2007).

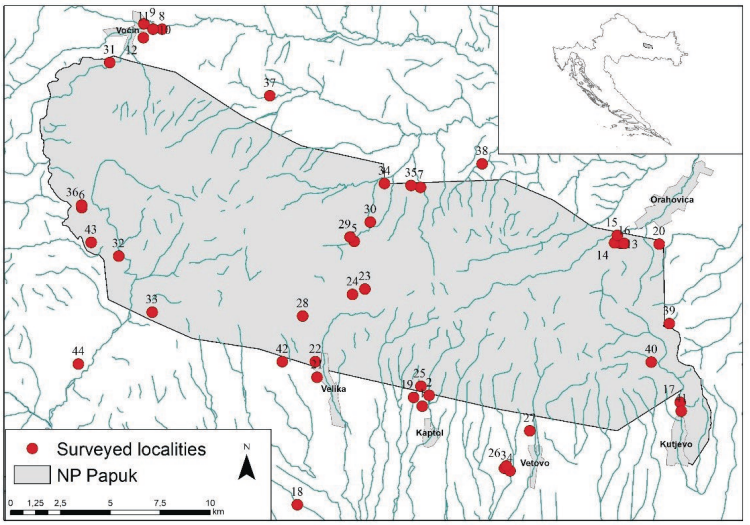

Fig. 1. Map of the study area located in the wider area of Papuk Nature Park, Croatia. Site numbers correspond to the ones given in Tabs 1 and 2.

The Park area is located in climate zone Cfb: a moderately warm, humid climate with hot summers, during which the mean air temperature of the hottest month is below 22 °C (Köppen climate division, Šegota & Filipčić, 2003). The average annual precipitation is between 700 and 1000 mm (Zaninović *et al*., 2008).

Odonata survey

An Odonata survey in the wide area of Papuk Nature Park was conducted on three occasions: at the end of spring 2017 (May 26, 27, and 28), in mid-summer 2017 (July 31, August 1, and 2), and late spring and early summer 2019 (May 16 and 17, June 12 and 13, July 5) at a total of 43 sites: 23 lotic and 21 lentic habitats (Tabs 1 and 2, Fig. 1).

At each site, Odonata fauna was surveyed for 45 minutes, until no additional species were detected. Species flying or perching within ≈5 m of the survey route were documented and counted (high abundances of damselflies were estimated immediately). Dragonflies were observed visually and identified by eye or using close-focusing binoculars. Some species were captured with an entomological net (e.g., those from the genus *Sympetrum*), identified in the field, photographed, and released.

Additionally, at lotic habitats, nymphs were collected using a standard benthos net (25x25 cm, 500μm mesh size) at all available microhabitats. Individuals were identified in the field and released. The surveys were conducted on sunny days between 9 a.m. and 5 p.m.

RESULTS

Thirty nine Odonata species were recorded (Tab. 3). A higher number of species (i.e. 35) was recorded in lentic than in lotic habitats (i.e. 16 species) (Fig. 2). In lentic habitats, between zero and 22 species were recorded (Tab. 4), while in lotic habitats we recorded between one and seven species (Tab. 5). The lentic site with the highest number of

Tab. 1. Lentic habitat sites in Papuk Nature Park, Croatia, with study period, coordinates and observed anthropogenic pressures.

Site number	Lentic habitats	Study period	Coordinates		Anthropogenic pressures
			N	E	
1	Kaptol, Bistra reservoir	spring, summer 2017	45°26'41.87"	17°43'30.60"	Riparian vegetation removal, waste disposal
2	Kaptol, Bistra fishpond	spring, summer 2017	45°26'57.30"	17°43'31.43"	
3	Vetovo, fishpond 1	spring, summer 2017	45°24'56.39"	17°46'34.96"	Riparian and aquatic vegetation removal
4	Vetovo, fishpond 2	spring, summer 2017	45°24'57.32"	17°46'38.95"	Riparian vegetation removal, shore banks erosion
5	Jankovac lake	spring, summer 2017; spring 2019	45°31'13.76"	17°41'06.14"	
6	Novo Zvečevo, Zvečevo fishpond (reservoir on the Brzaja river)	spring, summer 2017	45°32'22.64"	17°30'40.31"	
7	Slatinski Drenovac, Ponds /wet meadow next to the Radetina river	spring, summer 2017	45°32'39.51"	17°43'24.74"	
8	Voćin, Voćinska lakes - lake 1	spring, summer 2017	45°37'08.00"	17°33'33.00"	Riparian vegetation removal
9	Voćin, Voćinska lakes - lake 2	spring, summer 2017	45°37'07.00"	17°33'36.00"	High level of eutrophication during the summer
10	Voćin, Voćinska lakes - lake 3	spring, summer 2017	45°37'06.00"	17°33'39.00"	Intensive succession
11	Voćin, Voćinska lakes - lake 4	spring, summer 2017	45°37'09.33"	17°33'37.63"	
12	Voćin, Voćinska lakes - lake 5	spring, summer 2017	45°36'55.90"	17°33'15.09"	Part of the shoreline covered with concrete
13	Orahovica (Duzluk), Orahovica gravel pit	spring, summer 2017	45°30'55.70"	17°51'19.94"	Absence of riparian vegetation, very low abundance of aquatic vegetation, gravel excavation
14	Orahovica (Duzluk), reservoir on the stream	spring, summer 2017	45°30'56.70"	17°51'06.73"	
15	Orahovica (Duzluk), canal near the Orahovica lake	spring, summer 2017	45°31'08.70"	17°51'13.97"	High inflow of the sediment from the Orahovica gravel pit
16	Orahovica (Duzluk), Orahovica lake	spring, summer 2017	45°30'55.19"	17°51'29.10"	Completely covered in concrete, used as a swimming pool
17	Kutjevo, fishpond/reservoir on the Kutjevo river	spring, summer 2017	45°26'33.60"	17°53'25.11"	
18	Trenkovo, Trenkovo fishpond	spring, summer 2017	45°24'08.66"	17°38'34.58"	Very reduced riparian vegetation
19	Kaptol, Kaptol fishpond	spring 2019	45°26'56.6"	17°43'21.7"	
20	Duzluk, fishpond	spring 2020	45°30'51.9"	17°52'49.4"	
21	Velika, small pond made by the adjacent stream	spring 2019	45°27'34.9"	17°39'29.8"	

Tab. 2. Lotic habitat sites in Papuk Nature Park, Croatia, with study period, coordinates and observed anthropogenic pressures.

Site number	Lotic habitats	Study period	Coordinates		Anthropogenic pressures
			N	E	
22	Velika, Dubočanka stream 1	spring, summer 2017	45°28'00.11"	17°39'27.24"	Hydro-morphological alterations, construction waste disposal
23	Velika, Dubočanka stream 2	summer 2019	45°29'55.4"	17°41'27.0"	Large dams and reservoir construction
24	Velika, Dubočanka stream 3	spring 2019	45°29'47.4"	17°40'58.0"	
25	Kaptol, Bistra stream	spring, summer 2017	45°27'14.55"	17°43'29.11"	
26	Vetovo, Vetovka stream	spring, summer 2017	45°25'00.26"	17°46'39.26"	Construction and domestic waste disposal, shore banks erosion, small dams' construction
27	Vetovo, Vetovo stream	spring 2019	45°25'56.0"	17°47'36.3"	
28	Veličanka stream	spring, summer 2017	45°29'15.16"	17°39'01.45"	
29	Kovačica stream	spring, summer 2017	45°31'20.82"	17°40'56.93"	
30	Jankovac stream	spring, summer 2017	45°31'44.14"	17°41'44.51"	
31	Djedovica stream	spring, summer 2017	45°36'17.05"	17°31'54.99"	
32	Novo Zvečevo, Brzaja stream	spring, summer 2017	45°31'02.13"	17°32'01.64"	
33	Vranovo stream	spring, summer 2017	45°29'29.07"	17°33'14.76"	
34	Slatinski Drenovac, Marin stream	spring, summer 2017	45°32'46.10"	17°42'20.33"	Hydro-morphological alterations, streambed covered with concrete
35	Slatinski Drenovac, Radetina river	spring, summer 2017	45°32'41.50"	17°43'22.26"	
36	Novo Zvečevo, stream near fishpond Zvečevo	spring, summer 2017	45°32'26.62"	17°30'39.89"	
37	Sekulinci, Ćeralinica stream	spring, summer 2017	45°35'14.85"	17°38'02.73"	
38	Pušine, Pušine stream	spring, summer 2017	45°33'12.43"	17°46'07.74"	Hydro-morphological alterations, streambed covered with concrete
39	Kutjevo, Kutjevačka river 1	spring, summer 2017	45°28'42.37"	17°53'06.33"	
40	Kutjevo, Kutjevačka river 2	spring 2019	45.461309	17.872678	
41	Kutjevo, Javornik stream	spring, summer 2017	45°26'19.17"	17°53'26.87"	
42	Kamenac, stream by the road	spring 2019	45°28'02.0"	17°38'10.9"	
43	Novo Zvečevo, Kraljičino Brdo, stream by the road	spring 2019	45°31'25.8"	17°30'59.3"	
44	Striježevica, Čamanovica stream	spring 2019	45°28'08.7"	17°30'20.9"	

Tab. 3. Odonata species recorded in Papuk Nature Park, Croatia, with national and international conservation concern categories. Legend: NT = near threatened, VU = vulnerable, EN = endangered, DD = data deficient (according to Belančić et al. (2008) and Kalkman et al. (2010)).

Odonata species	Lotic habitats	Lentic habitats	Croatian Red list	European Red list	Habitat Directive
Calopteryx virgo (Linnaeus, 1758)	x	x			
Calopteryx splendens (Harris, 1782)	x	x			
Sympecma fusca (Vander Linden, 1820)		x			
Platycnemis pennipes (Pallas, 1771)	x	x			
Pyrrhosoma nymphula (Sulzer, 1776)		x			
Erythromma lindenii (Selys, 1840)		x			
Erythromma najas (Hansemann, 1823)		x	NT		
Erythromma viridulum (Charpentier, 1840)		x			
Coenagrion ornatum (Selys, 1850)		x	NT	NT	Annex II
Coenagrion puella (Linnaeus, 1758)		x			
Coenagrion pulchellum (Vander Linden, 1825)		x	NT		
Enallagma cyathigerum (Charpentier, 1840)		x			
Ischnura pumilio (Charpentier, 1825)		x			
Ischnura elegans (Vander Linden, 1820)	x	x			
Aeshna affinis Vander Linden, 1820	x				
Aeshna mixta Latreille, 1805	x	x			
Aeshna isoceles (Muller, 1767)	x	x	NT		
Anax imperator Leach, 1815	x	x			
Anax parthenope (Selys, 1839)		x	NT		
Hemianax epphipiger (Burmeister, 1839)		x	VU		
Brachytron pratense (Muller, 1764)		x			
Gomphus vulgatissimus (Linnaeus, 1758)	x				
Onychogomphus forcipatus (Linnaeus, 1758)	x	x			
Cordulegaster bidentata Selys, 1854	x	x			
Cordulegaster heros Theischinger, 1979	x			NT	Annex II, IV
Cordulia aenea (Linnaeus, 1758)		x			
Somatochlora meridionalis Nielsen, 1935	x	x			
Epitheca bimaculata (Charpentier, 1825)		x	EN		
Libellula depressa Linnaeus, 1758	x	x			
Libellula fulva Muller, 1764		x			
Orthetrum albistylum (Selys, 1848)		x			
Orthetrum brunneum (Fonscolombe, 1937)		x			
Orthetrum cancellatum (Linnaeus, 1758)	x	x			
Orthetrum coerulescens (Fabricius, 1798)		x	DD		
Crocothemis erythraea (Brulle, 1832)		x			
Sympetrum sanguineum (Muller, 1764)	x	x			
Sympetrum meridionale (Selys, 1841)		x	NT		
Sympetrum vulgatum (Linnaeus, 1758)		x	NT		
Number of species	16	35	10	2	2

Tab. 4. Odonata species recorded at lentic sites in Papuk Nature Park, Croatia. Site numbers correspond to those given in **Tab. 1**. Legend:♂ - male, ♀ - female.

Odonata species/ Lentic sites	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
C. virgo		4♂2♀			12♂3♀	20♂♀								2♂1♀					20♂5♀		
C. splendens	4♂				7♂	20♂♀			4♂		5♂	3♂							8♂5♀		
S. fusca					12♂				6♂3♀	4♂		20♂♀								8♂1♀	
P. pennipes	100♂♀	1000♂♀		50♂♀	200♂♀	1000♂♀		500♂♀	500♂♀	10♂♀	100♂♀	100♂♀	3♂	4♂			500♂♀	200♂♀	200♂♀		
P. nymphula	3♂				5♂2♀	10♂															
E. lindenii	50♂♀			7♂2♀								50♂♀									
E. najas					4♂	20♂♀		10♂♀	10♂♀												
E. viridulum	50♂♀			20♂♀				50♂♀	3♂		50♂♀	50♂♀							15♂5♀		
C. ornatum								1♂♀	1♂♀												2♂
C. puella	200♂♀	200♂♀		30♂♀	1000♂♀	100♂♀	20♂♀	500♂♀	500♂♀	20♂♀	1000♂♀	100♂♀		50♂♀	50♂♀		100♂♀				10♂3♀
C. pulchellum								200♂♀	100♂♀		50♂♀	50♂♀					100♂♀				
E. cyathigerum	100♂♀			5♂3♀	300♂♀			20♂♀	20♂♀			50♂♀	10♂♀	2♂1♀		1000♂♀	100♂♀				
I. pumilio				2♂3♀	4♂1♀																2♂1♀
I. elegans	500♂♀	200♂♀		30♂♀	100♂♀	50♂♀	6♂	20♂♀	20♂♀	20♂♀	100♂♀	50♂♀	1♂♀		20♂♀			100♂♀	200♂♀		
A. mixta					30♂♀																
A. isoceles					1	2		1	2♂										1♂		
A. imperator	6♂	1♂		2♂♀	4♂			2♂1♀	3♂		1	2							9♂		
A. parthenope	1♂				1♂			2				1									
H. epphipiger	1♂♀							1♂													
B. pratense		2♂			1♂			1♂													
O. forcipatus					8♂														1♂		
C. bidentata					3♂																
C. aenea		2♂				2												3			
S. meridionalis																1	20♂♀				
E. bimaculata																			5♂3♀		
L. depressa					2♂1♀	6♂2♀	3♂2♀	2♂♀	1♂		1♂1♀	2♂1♀		1♀					3♂		
L. fulva	1♂				1♂♀														5♂2♀		
O. albistylum	9♂	1♂♀		6♂	7♂2♀	6♂2♀		4♂	6♂2♀	2♀	10♂	6♂						5♂	2♂1♀		
O. brunneum				3♂										2♂	20♂♀				2♂		
O. cancellatum	4♂																	2♂	1♂		
O. coerulescens								2♂	3♂		1♂	5♂									
C. erythraea	3♂♀	2♂		1♂	2♂♀	1♀		1♂2♀	1♂	1♂	3♂	1♀		1♀				1♂			
S. sanguineum	12♂			6♂	10♂	50♂4♀		4♂2♀	12♂1♀	2♂	2♂	5♂			3♂		6♂	5♂2♀			
S. meridionale	1♂																				
S. vulgatum						6♂ 1♀											1♂	1♂			
Number of species	17	9	0	12	22	14	3	18	17	7	12	16	3	7	4	2	7	8	14	1	3

Tab. 5. Odonata species recorded at lotic sites in Papuk Nature Park, Croatia. Site numbers correspond to those given in Tab. 2. Legend: ♂ - male, ♀ - female, N – nymph.

Odonata species/ Lotic sites	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
C. virgo	15♂ 6♀2N	5♂	20 ♂♀	8N	10 ♂♀					16♂ 7♀4N	8♂ 9♀2N	4♂	15♂ 6♀2N	20♂ 10♀	5♂ 6♀	30♂♀	20♂ ♀3N	3♂4♀	3♂	30♂ ♀2N			5♂ 3♀
C. splendens					5♂									4♂								5♂ 3♀	
P. pennipes					20 ♂♀	8♂2♀														30♂♀			
I. elegans					10 ♂♀																		
A. affinis		10♂ 3♀																					
A. mixta																					3♂		
A. isoceles													1										
A. imperator						2♂																	
G. vulgatissimus		1♂	1♂																				
O. forcipatus	2N	4♂		5N			3N	4N	3♂ 2N	6♂1♀	1♂ 1♀4N	1♂2♀	3♂ 2♀2N	3N	3♂ 1♀	20♂♀	5N	1		4♂			
C. bidentata	4N		2♂	9N			2N	4N	1♂ 1N	6N		1N		5N		2N		2N		1♂			
C. heros	2N	3♂ 1♀	4♂	11N			3N	5N	2N	1N		5N				1N		20N					
S. meridionalis	1N	2♂	1♂	2♂							2N		3♂1N	1	1					3♂			
L. depressa			2♂																				
O. cancellatum						1♂													1♂				
S. sanguineum		5♂ 1♀																					
Number of species	**5**	**7**	**6**	**5**	**4**	**3**	**3**	**3**	**3**	**4**	**3**	**4**	**4**	**5**	**3**	**4**	**2**	**4**	**2**	**5**	**1**	**1**	**1**

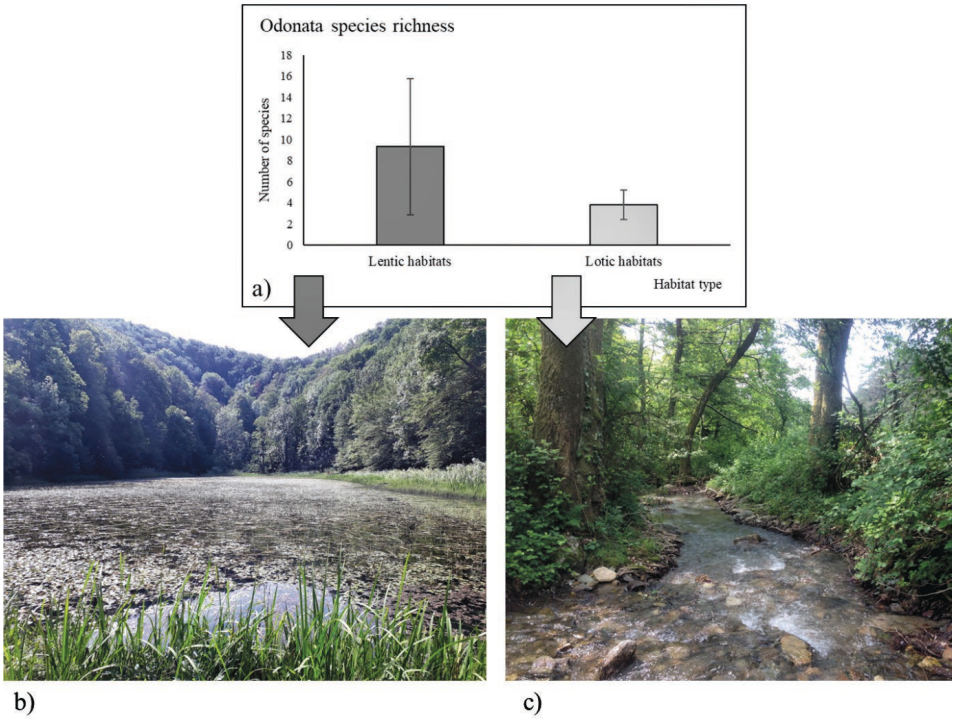

Fig. 2. a) Odonata species richness (shown as mean with standard deviation) in lentic and lotic habitats in Papuk Nature Park, Croatia, with examples of each habitat type characterized by highest number or Odonata species: b) the Jankovac lake, the Dubočanka stream.

Odonata species was the Jankovac lake (site 5), while no Odonata were recorded at the fishpond in Vetovo (site 3) (Tab. 4). The lotic site with the highest Odonata species richness was the Dubočanka stream (site 23), while at three streams only one species was recorded: Kamenac stream, stream in Kraljičino brdo, and the Čamanovica stream (sites 42, 43, 44) (Tab. 5).

Calopteryx virgo was the most widespread species in the area, recorded at 22 sites, while *Aeshna affinis, Epitheca bimaculata,* and *Sympetrum meridionale* were recorded at only one site (Tabs 4 and 5). The most frequently recorded species at lentic sites were *Platycnemis pennipes*, *Coenagrion puella,* and *Ischnura elegans* (Fig. 3), found at 15 sites, while the rarest were *Cordulegaster bidentata, Aeshna mixta, Epitheca bimaculata,* and *Sympetrum meridionale*, recorded at only one site (Tab. 4). *Calopteryx virgo*, *Onychogomphus forcipatus,* and *Cordulegaster bidentata* were the most common species in lotic habitats, recorded at 17, 16, and 12 sites, respectively (Fig. 3). Seven species were recorded at only one lotic site: *Ischnura elegans, Aeshna affinis, Aeshna mixta, Aeshna isoceles, Anax imperator, Libellula depressa,* and *Sympetrum sanguineum* (Tab. 5).

A total of 11 recorded species are of conservation concern: ten of them are in the Croatian and two in the European Red List of Odonata (Tab. 3), whereas the latter two species are also listed in the Habitat Directive's Annexes (Tab. 3, Fig. 4). Numerous anthropogenic pressures were documented both in lotic and lentic habitats (Figs 5 and 6, Tabs 1 and 2**).**

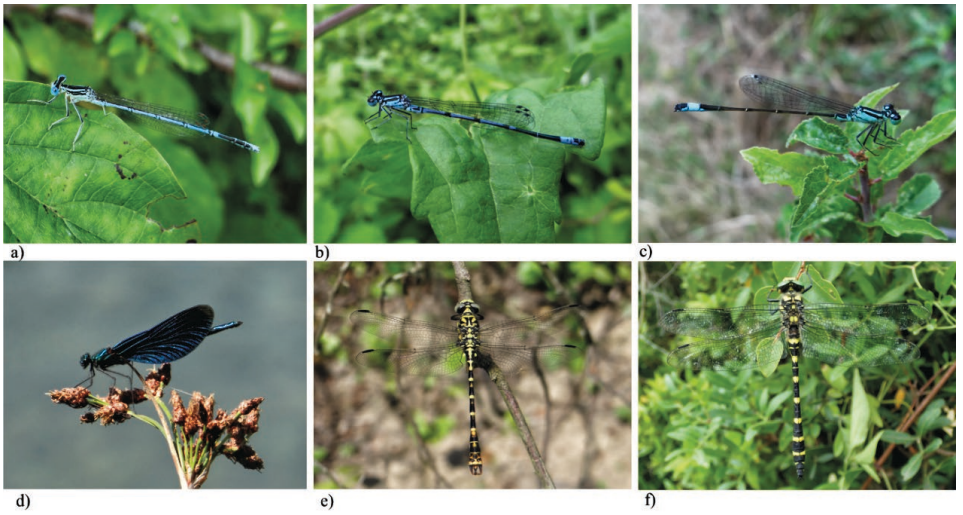

Fig. 3. The most frequently recorded species at lentic sites: a) *Platycnemis pennipes*, b) *Coenagrion puella*, c) *Ischnura elegans*, and at lotic sites: d) *Calopteryx virgo*, e) *Onychogomphus forcipatus*, f) *Cordulegaster bidentata*.

Fig. 4. Examples of species of national conservation concern, vulnerable a) *Epitheca bimaculata* and *Hemianax ephipiger*, and species of international conservation concern, near threatened c) *Coenagrion ornatum* and d) *Cordulegaster heros*.

Fig. 5. Examples of anthropogenic pressures recorded in lotic habitats in Papuk Nature Park, Croatia: a) the Marin stream: hydromorphological alteration of riverbed (covered in concrete), b) and c) the Vetovka stream: construction and domestic waste disposal, shore banks erosion, small dams' construction.

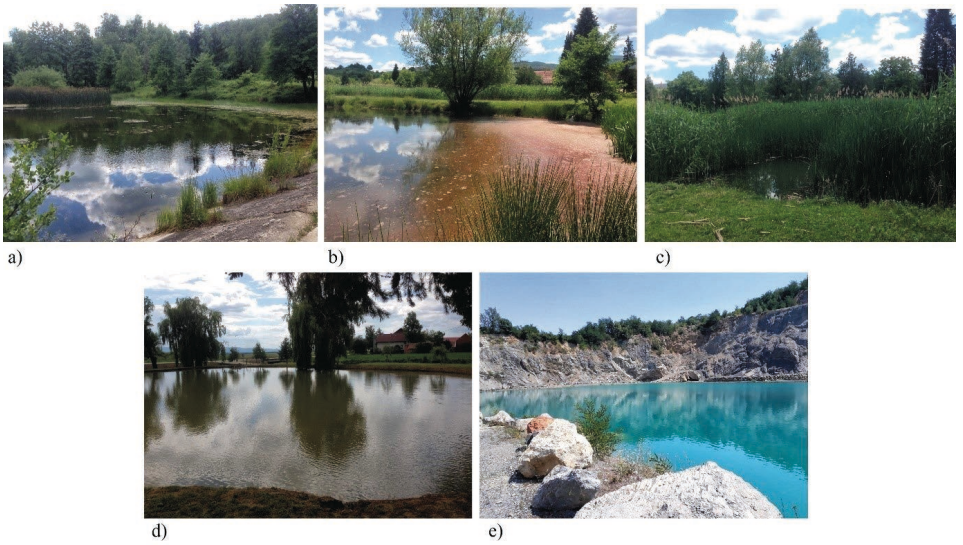

Fig. 6. Examples of anthropogenic pressures recorded in lentic habitats in Papuk Nature Park, Croatia: a), b), c) the Voćinska lakes: shoreline covered with concrete, eutrophication, succession, d) fishpond in Vetovo: riparian and aquatic vegetation absence, e) gravel pit in Orahovica: very low density of riparian and aquatic vegetation, excavation of gravel.

DISCUSSION

With more than half of the Croatian Odonata fauna recorded (Belančić *et al*., 2008; excluding regionally extinct and doubtful taxa), our study revealed high Odonata species richness in freshwater habitats in the area of Papuk Nature Park in Croatia. Those results are not surprising since the area is rich in lotic and lentic habitats. The most widespread species were lotic *Calopteryx virgo* and eurytopic *Platycnemis pennipes* (Dijkstra & Lewington, 2006). Nymphs and adults of *Calopteryx virgo* were recorded at most of the investigated streams, while adults were also in some cases recorded at lentic habitats located in the vicinity of streams, most probably in their search for food. *Platycnemis pennipes* was recorded at most of the lentic sites but also by some sunny streams. The dominance of

this species is not unusual considering that it is a species that has a wide ecological tolerance for habitat conditions (Dijkstra & Lewington, 2006).

Most of the streams located on the slopes of the Papuk Mountains were pristine, in a good and natural state, and no major causes of potential endangerment have been recorded. However, at several sites, mostly in populated or near populated areas, anthropogenic pressures were numerous and significant, and the Odonata fauna could have already changed in some of them. For instance, a lower number of species was recorded, or the recorded species were eurytopic generalists, similar to the results of previous studies (e.g. Vilenica *et al*., 2020). There are no natural standing water habitats in the study area, hence, for a high number of lentic species, the existence of man-made lentic habitats, such as fishponds, gravel pits, and reservoirs represent an important resource for life cycle completion. Old man-made lakes in the area are particularly important habitats for Odonata because, over the years, the environmental conditions in these habitats have become much closer to natural lake habitats or even swamps. However, potential factors that could negatively affect the composition of the lentic Odonata assemblages were observed at many lentic sites, which should be monitored and managed to preserve the existing Odonata fauna of the Park.

As shown by some previous studies (e.g. Vilenica *et al*., 2020), Odonata fauna of lentic man-made water bodies in the area studied largely consisted of widespread, generalist species, such as *Ischnura elegans, Coenagrion puella, Libellula depressa, Orthetrum albistylum*. However, almost a quarter of species recorded are of conservation concern, such as *Hemianax epphipiger* and *Epitheca bimaculata*, which indicates the importance of such habitats for distribution and protection of rare species (Dolný & Harabiš, 2012; Holtmann *et al*., 2018; Vilenica *et al*., 2016), especially in areas where natural lentic habitats are scarce or absent. To be adequate for a high number of Odonata species, man-made habitats need to meet the species' ecological requirements, i.e. should be characterized by well-developed aquatic and riparian vegetation (Vilenica *et al*., 2016, 2022a, b). Therefore, it is not surprising that lentic habitats with such characteristics, such as the Jankovac Lake, and some of the Voćinska lakes (i.e. lakes 1 and 2), had high Odonata species richness, including those of national conservation concern (Belančić *et al*., 2008). On the other hand, sites without any aquatic and riparian vegetation, such as the fishpond in Vetovo, proved to be highly unfavourable for any Odonata species.

Lotic habitats were characterized by lower Odonata species richness, as expected (Askew, 2004; Vilenica *et al*., 2022b). Nevertheless, the stream assemblages are unique and interesting consisting of species preferring shaded streams with higher water velocity, such as *Cordulegaster* spp., *Onychogomphus forcipatus*, and *Somatochlora meridionalis* (Dijkstra & Lewington, 2006). Moreover, their conservation value is reflected in the presence of species with restricted distribution in Europe, such as *Cordulegaster heros* and *Somatochlora meridionalis* (Dijkstra & Lewington, 2006; Kalkman *et al*., 2010).

Cordulegaster heros, together with *Coenagrion ornatum*, is among the EU Habitats Directive species. They are both enlisted as near threatened at the European Red list of Odonata (Kalkman et al., 2010). The international conservation concern of those species is due to the anthropogenic pressures to their habitats. *Cordulegaster heros* is a typical inhabitant of shaded forest streams, which are negatively influenced by various anthropogenic pressures such as deforestation, hydro-morphological alterations and climate change (Boudot, 2020). *Coenagrion ornatum* inhabits sunny streams but also channels with well-developed aquatic and riparian vegetation. Such habitats are often

surrounded by agricultural fields and are therefore negatively influenced by the inflow of pesticides, herbicides, as well as by the removal of both aquatic and riparian vegetation (Boudot, 2010).

CONCLUSIONS

The results of this study represent the first Odonata checklist of Papuk Nature Park. The collected data indicate the importance of pristine stream habitats but also man-made lentic habitats for maintaining local Odonata species richness. Such habitats were even shown to have high conservation potential with 11 species of national or international concern recorded. Moreover, the presented results could contribute to filling the gaps in our knowledge of the distribution of rare Croatian Odonata, and their habitat preferences, which could help in future assessments of the species' conservation status, both in Croatia and in their whole distribution area.

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