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Dragonfly assemblages in four Mediterranean wetlands of Samos Island, Greece (Odonata)

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Abstract
Dragonflies (Odonata) are considered to be valuable indicators of hydroecosystems. This study reports the composition of the dragonfly assemblages in four wetlands of Samos Island, Greece, in a geographic area especially vulnerable to climate change where a trend towards a drier climate has been observed in the last decades. Dragonfly assemblages have not yet been studied on Samos. The analysis based on the number of different species and their autochthony revealed clear differences among the wetlands. The eutrophic Glyfada Lake, despite its variable hydrology resulting from drought – the seasonal decrease in water availability – harboured the largest diversity of dragonflies, larger than the oligotrophic Mesokampos Lake. The assemblage of the spring and rivulet at Mytilini, although also influenced by drought, had its own set of species of high autochthony. The seasonal brackish lake and marsh of Psili Ammos had the lowest number of species and was dominated by one very abundant breeding species. Drought was the main factor affecting the number and composition of species. The collected data create a reference for the future monitoring of trends in the composition of odonatofauna under the changing climate of Samos Island.

Key words: Odonata, dragonfly assemblages, autochthony, Mediterranean climate, Samos Island.

Introduction

Dragonflies (Odonata) represent a relatively small taxon in terms of the number of species, with strong links with aquatic environments. It is largely recognised that dragonflies can act as indicators of aquatic ecosystem quality, functioning, structure and changes (Schmidt 1985; Castella 1987; Chovanec & Raab 1997; Corbet 1999; Simaika & Samways 2011; Kutcher & Bried 2014). The occurrence of some targeted species can characterise the condition of the ecosystems in which they live. Pressures or changes can thus be identified through the assessment of Odonata over time.

The assessment of the quality of environments and composition of animal communities or assemblages is especially important in areas of rich biodiversity and in environments especially vulnerable to human pressure and climate change. The Mediterranean region, at the junction of Europe, northern Africa and the Middle East, is among the world's diversity hotspots (Myers et al. 2000; European Environment Agency 2002). Furthermore, the Mediterranean area, including Samos Island, our study site, is considered as one the most vulnerable region to climate change and is threatened by the increase in drought, which has an impact primarily on wetlands – the typical habitat of dragonflies (Körner et al. 2005; Bangash et al. 2013).

The faunistic knowledge on the dragonflies of this geographical area, and more specifically the eastern Mediterranean Sea basin and Samos Island, is relatively advanced. Although the occurrence and distribution of the different Odonata species on Samos Island have been mapped rather precisely (Lopau 1995, 2010a, 2010b; Martens 2009; Boudot et al. 2009; Boudot & Kalkman 2015; Kalfayan & Krieg Jacquier 2018; Wildermuth & Martens 2019), neither community approaches nor population assessments have ever been applied for this island. In addition, we are aware of only two studies that have reported the diversity of dragonfly assemblages in the eastern Mediterranean region (Zaimes et al. 2017; Kisa Mencütekin & Hacet 2018). Consequently, the first aim of the present study is to characterise selected dragonfly assemblages of Samos Island.
As previously mentioned, the wetlands of Samos Islands are threatened by the climate change, and specifically by the increase in drought. A gradual reduction of rainfall has been observed on the island throughout the last four decades (Körner et al. 2005). The assessment of the present

state of dragonfly assemblages becomes an urgent need. Therefore, the second aim of our study is to provide detailed information on dragonfly assemblages which may be used as a reference for monitoring dragonflies in the future. Medium- and long-term assessments may reveal changes and trends in dragonfly assemblages that reflect changes in their environments. We report the abundance and autochthony of dragonfly species in four wetlands with different hydrological regimes, and consequently, differently threatened by drought: a permanent lake with seasonally variable water level, an artificial lake and marsh with slight hydrological variation; a spring associated with a partly temporal rivulet; and an intermittent brackish lake and marsh.

Material and Methods

Study area and habitats

Samos Island is located in the eastern part of the Aegean Sea, in Greece, close to the coast of Turkish Anatolia. The climate of Samos Island is typically Mediterranean, formed by the wet season in winter, when most of the annual precipitation falls, and the dry season in summer, when temperatures may reach 40 °C, resulting in drought for several consecutive months (Körner et al. 2005). Despite the arid climate, streams, water reservoirs and marshes hold an important part of biodiversity of Samos Island. From among these, four different wetlands were selected in the south-eastern part of the island (Fig. 1).

Glyfada: an open, permanent eutrophic lake near Pythagoreio town. The lake is eutrophic, inferred from the dense aquatic vegetation of hydrophytes and algae dominated by *Zannichellia* (Langangen 2014). The coastal vegetation consists of a helophyte belt dominated by *Juncus* species. Sunlight exposure is high during the whole day and causes an increase in water temperature in the entire water body. The hydrological variations are quite important during drought periods, reducing the depth and the surface area of the lake but keeping it mostly wet even in summer.

Mesokampos: a marsh and an artificial oligotrophic lake. The site includes an old man-made reservoir (approximately 15×25 m) in the upper part and a marsh in the lower part, close to the sea shoreline. Half of the edge of the reservoir is formed by an old stone wall, and the other half is formed by a dense reed bed. Its character is oligotrophic, inferred from the lack of macrophytes and the presence of scattered stands of charophytes, e.g., *Chara corfuensis* (Groves, 1937) (Langangen 2014). It is likely fed by either a spring or underground circulation considering the low water temperature even in summer and slight hydrological variation. A small channel discharges the water from the reservoir and a dense reed vegetation has developed around. The rest of the marsh is characterised by a low proportion of standing water during the dry season and shorter vegetation of helophytes.

Mytilini: a spring with a reservoir and a rivulet near Mytilini town. The wetland called the Mytilini spring is principally defined by a soft- and cold-water spring that flows all year round, with a small reservoir in front of it maintaining few cubic meter of water. Additionally, a small rivulet flows from the hilly area above the spring during the wet season. Only one section of about 30 m of the rivulet bed remains wet in summer because some water is supplied from the spring, forming a tiny flow and several pools.

Psili Ammos: a coastal intermittent brackish lake and marsh. This seasonal coastal lake is supplied with rain and sea water and presents high salinity. The lake is shallow, surrounded by reeds and other salt-tolerant plants, e.g., *Juncus subulatus* (Forssk, 1775) and *Lamprothamnium papulosum* (Groves, 1916) (Langangen 2014), and becomes dry in early summer. This part of Samos Island experiences intense sun exposure; the vegetation surrounding the lake is short and xerophilic.

Data collection

Five to seven Odonata sampling points were established in each of the four wetlands (see Appendix 1 for coordinates). A sampling point was defined as an area of 15 m in diameter with homogenous habitat. In the case of rel-

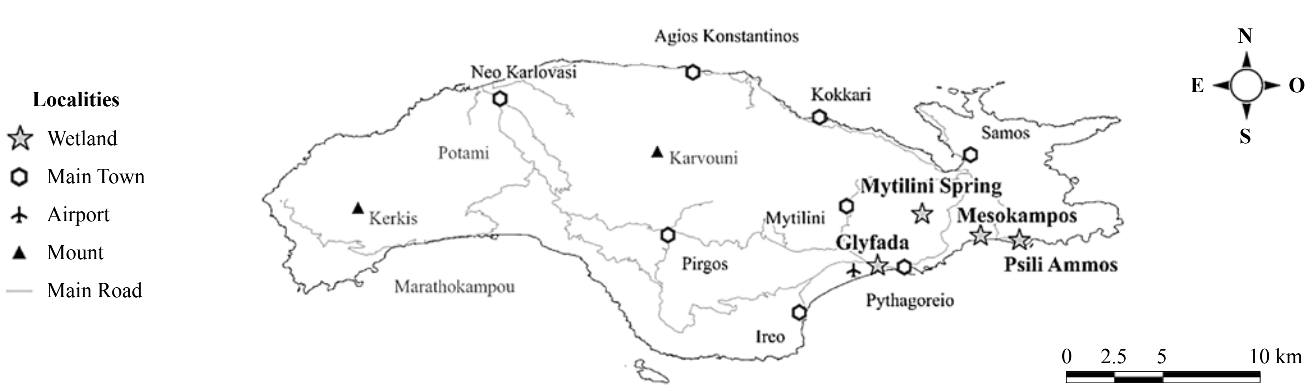

Fig. 1 – Samos Island; stars indicate the locations of the study sites.

atively small areas, the point covered the whole surface area of a given habitat type. At each point of a wetland, two operators were searching for dragonflies with binoculars and capturing imagoes during 15 minutes. For every new species seen or caught during each sampling session at each sampling point, 2 minutes were added to the sampling time. The handling time necessary for species determination was not included in the sampling time. The behaviour of individuals (in tandem, mating, egg deposition, territorial defence) was observed and recorded. Exuviae were also collected at the same points during 15 additional minutes. They were identified afterward in the laboratory according to Doucet (2010) and Brochard et al. (2013).

Odonata sampling was conducted in 2017 during three periods. The first sampling was conducted in spring, from 2-16 May 2017, to include the flight period of spring species such as *Brachytron pratense* (Müller, 1764) and *Gomphus schneiderii* (Selys, 1850). The second one was conducted between 19-29 June 2017. The last one was performed in late summer, between 14-20 August 2017, to include the flight period of late-season species such as some Lestidae and various species of Aeshnidae. To study each area thoroughly and to enhance the detection of relatively inconspicuous species, each sampling point was visited and sampled twice during each of the three periods. The time between the two visits was 6.2 days on average, with a range of between 3 and 12. Data collection only occurred when the weather was suitable for dragonfly activity: under the conditions of temperatures not lower than 16-17 °C, wind speeds less than 15-20 km/h, a maximum cloud cover of 75%, and absolutely no rainfall. Field work was conducted between 10 a.m. and 4 or 5 p.m., when the imago activity was at its peak.

In general, data collection followed the Rhoméo methodology (Pont & Mathieu 2011; Collectif Rhoméo 2014), although that method advises only one visit to a site per sampling period, and we visited each site two times. From two visits to a site during the same period, a larger number of individuals of each species is reported. The numbers of individuals from two visits were not summed to avoid counting the same individuals twice, especially because the males of most species of Anisoptera and calopterygid Zygoptera are territorial (Corbet & Brooks 2008; Suhonen et al. 2010), and the life expectancy of many mature dragonflies is longer than the time period between two visits to a site (Corbet 1999; Cordero-Rivera & Stoks 2010).

Determination of the autochthony degree of species

Autochthony may be defined for a given species by its capability to form a self-sustaining population. Four autochthony classes may be established (Pont & Mathieu 2011):

1. Sure: presence of exuviae, emergence or teneral individuals;
2. Probable: presence of larvae, females showing oviposition behaviour, or individuals of the two sexes in several sampling points;
3. Potential: presence of individuals exhibiting territorial behaviour in one location in the wetland;
4. Doubtful: single individuals showing no reproductive behaviour.

The highest class of autochthony detected for a species in a given wetland throughout the whole survey was used to determine its autochthony.

Results

A total of 23 dragonfly species were recorded in the 4 wetlands under study (Table 1; the detailed number of individuals per species recorded during the 3 sampling periods over the season is given in Appendix 2). This number presents 68% of all species recorded on Samos (Martens 2009; Lopau 2010b; Kalfayan & Krieg-Jacquier 2018). The highest number (14 species) was found in both the Glyfada lake and Mesokampos (7 in the lake and 7 in the marsh in the latter wetland). Glyfada and Mesokampos were also characterised by high proportions of species which were classed with a high level of autochthony, 71% and 57%, respectively (Table 2). High occurrence of *Enallagma cyathigerum* (Charpentier, 1840) and *Ischnura elegans* (Vander Linden, 1820) compared to the abundances of other species was found in Glyfada.

The intermittent brackish lake and marsh in Psili Ammos harboured 7 species, the lowest number among the four wetlands. *Lestes macrostigma* (Eversmann, 1836) was very abundant there and strongly outnumbered all other species. Furthermore, *L. macrostigma* bred in Psili Ammos, as evidenced by exuviae and teneral individuals during the first sampling period. In addition to *L. macrostigma*, only *Sympetrum fonscolombii* (Selys, 1840) was probably autochthonous, and other species were identified as visitors because of observations of only single individuals. The Mytilini spring and rivulet harboured 8 species. Five of these 8 species (62%) were surely or probably autochthonous.

Discussion

Dragonflies from the assemblage and Mediterranean habitat perspective

Our description of dragonfly assemblages represents a further step towards greater knowledge of dragonflies on Samos and their environmental determinants compared with previous faunistic studies on the island. Out of our study, faunistic observations were conducted only in Psili Ammos (Lopau 1995). We revealed substantial differences between the richness and composition of the assemblages in the four wetlands under study.

The Glyfada and Mesokampos wetlands presented the highest and the same richness of observed species. How-

Table 1 – Dragonfly species and the total numbers of individuals recorded; the indices of the diversity and evenness of the four dragonfly assemblages are also shown; E = presence of exuviae; (T) = presence of teneral individuals; * = species observed on the Mesokampos lake.

Species	Glyfada	Mesokampos	Mytilini	Psili Ammos
Calopteryx virgo (Linnaeus, 1758)			15 +E	
Lestes macrostigma (Eversmann, 1836)	7 +E			167(T) +E
Chalcolestes parvidens (Artobolevskij, 1929)			7	
Enallagma cyathigerum (Charpentier, 1840)	114 +E			
Erythromma lindenii (Selys, 1840)	7			
Ischnura elegans (Vander Linden, 1820)	114(T)	5		1
Platycnemis pennipes (Pallas, 1771)			59 +E	
Aeshna isosceles (Müller, 1767)	2	10		
Anax imperator (Leach, 1815)	17	13*		
Anax parthenope (Selys, 1839)	1	2*		
Brachytron pratense (Müller, 1764)		5		3
Caliaeschna microstigma (Schneider, 1845)			2	
Crocothemis erythraea (Brullé, 1832)	7	16*	1	2
Libellula fulva (Müller, 1764)		20*	1	
Orthetrum brunneum (Fonscolombe, 1837)			3	1
Orthetrum cancellatum (Linnaeus, 1758)	37	1		
Orthetrum coerulescens (Fabricius, 1798)	3	11*	12	
Orthetrum sabina (Drury, 1770)	3			
Selysiothemis nigra (Vander Linden, 1825)	1	3*		
Sympetrum fonscolombii (Selys, 1840)	4	14		16
Sympetrum meridionale (Selys, 1841)		2		
Sympetrum striolatum (Charpentier, 1840)	5	1		2
Trithemis arteriosa (Burmeister, 1839)		7*		
Number of species	**14**	**14**	**8**	**7**

ever, the species assemblages were substantially different. First, the Mesokampos wetland is formed by two distinct habitats, the lake and the adjacent marsh, whereas the Glyfada wetland presents only one main habitat for dragonflies, the lake. Two species, *B. pratense* and *Sympetrum meridionale* (Selys, 1841), were found only in the Mesokampos marsh. Furthermore, when the Mesokampos lake excluding the marsh is considered, its number of species is reduced to half of that in the Glyfada lake. This could result from the different characteristics of the two lakes because the lake in Glyfada is eutrophic and warm, while the lake in Mesokampos is oligotrophic and colder. The species *Orthetrum sabina* (Drury, 1770) and *I. elegans*, reported in Glyfada, were not seen on the Mesokampos lake (the latter was only observed in one point of the Mesokampos marsh); *O. sabina* is generally associated with warmer water due to its larval requirements (Mathavan 1990), and *I. elegans* is much more abundant in eutrophic and mesotrophic water (Piersanti et al. 2015). The dragonfly assemblage observed at the eutrophic Glyfada lake was characterized by many species that were surely or probably autochthonous when compared to the Mesokampos wetland. Wet areas close of the lake shores, including small waterbodies connected with a lake when water level is high, can represent attractive habitats to euryecious species (species with wide range of tolerance to environmental parameters). As a consequence of the Mediterranean climate, many waterbodies or shore zones dry out and can be considered as temporal habitat, as occurred in the Glyfada lake, the water level of which decreased in the dry season. The display of reproductive behaviour by *Orthetrum cancellatum* (Linnaeus, 1758) was observed many times in such habitats. Small pools in the marsh at the Mesokampos site, where the lake presents more stable hydrology, were attractive to *Libellula fulva* (Müller, 1764), which was probably autochthonous there.

The seasonal character of the brackish lake and marsh of Psili Ammos, reflected in their complete dryness in summer, was probably a major factor shaping the species assemblage at this site. In the year of the study, the lake

Table 2 – Autochthony classes of the dragonfly species recorded in four localities. 1: Sure; 2: Probable; 3: Potential; 4: Doubtful (for further details see main text).

Species	Glyfada	Mesokampos	Mytilini	Psili Ammos
Calopteryx virgo			**1**	
Lestes macrostigma	**1**			**1**
Chalcolestes parvidens			**2**	
Enallagma cyathigerum	**1**			
Erythromma lindenii	**4**			
Ischnura elegans	**1**	**3**		**3**
Platycnemis pennipes			**1**	
Aeshna isosceles	**3**	**2**		
Anax imperator	**2**	**2**		
Anax parthenope	**4**	**4**		
Brachytron pratense		**3**		**4**
Caliaeschna microstigma			**3**	
Crocothemis erythraea	**2**	**2**	**4**	**3**
Libellula fulva		**2**	**4**	
Orthetrum brunneum			**2**	**4**
Orthetrum cancellatum	**2**	**4**		
Orthetrum coerulescens	**2**	**2**	**2**	
Orthetrum sabina	**2**			
Selysiothemis nigra	**4**	**2**		
Sympetrum fonscolombii	**2**	**2**		**2**
Sympetrum meridionale		**3**		
Sympetrum striolatum	**2**	**3**		**3**
Trithemis arteriosa		**2**		
Number of species with autochthony classes 1 and 2 and the % of the total number	**10 (71%)**	**8 (57%)**	**5 (62%)**	**2 (29%)**

was dry in early June, before the second sampling period. The lowest number of species was observed in Psili Ammos, and the assemblage was dominated by *L. macrostigma*, a species typical of brackish temporary water bodies. Such a site has low attractiveness even for many euryecious dragonfly species. For example, *Crocothemis erythraea* (Brullé, 1832), which is thermophilic and relatively tolerant to drought (Johansson & Suhling 2004), was seen only twice in Psili Ammos, whereas it was often present on the Glyfada and Mesokampos lakes. The very low autochthony or absence of various species of *Sympetrum* in Psili Ammos might be explained by the strong degree of aridity of the lake that lasts too long to complete the larval stage, even with adaptations to temporal waterbodies. It should be mentioned that *L. macrostigma*, abundant in Psili Ammos, which breeds there and also in Glyfada as proved by the presence of exuviae, has been classed as NT (Near Threatened) species in the Red List of Mediterranean Odonata (Riservato et al. 2009).

The dragonfly assemblage of the spring and rivulet of Mytilini was composed of a few species, but the majority of them were surely or probably autochthonous, which highlights their strong affinity with this specific habitat. The rivulet presented a slow flow in early spring and was defined as partly temporary. Because of the presence of stagnant pools and tiny water flow in the lower part of the rivulet bed in summer, due to the water supply from the nearby spring, five dragonfly species were recorded there in August. In its upper part, the rivulet became completely dry in summer. Several species were observed there in May, but after becoming dry in early June, no more individuals were observed in the rivulet's upper portion.

A common trait of all the studied wetlands is the climatic pressure of the Mediterranean habitat, which seasonally decreases water availability and creates temporary habitats during the warm season. Drought, by affecting hydrology, determines the presence of some species according to their preferences or phenology. This point is particularly important because it facilitates the understanding of the composition of dragonfly assemblages and dragonfly adaptations.

Dragonfly assemblages in the changing climate of the Mediterranean area

The Mediterranean-climate region, including Samos Island, is regularly under the pressure of seasonal drought (Gasith & Resh 1999), and a clear trend towards a drier climate has been observed in recent decades (Diffenbaugh et al. 2007). On Samos Island, a gradual reduction of rainfall and the loss of rural springs have been documented since approximately the 1970s (Körner et al. 2005). The observed trend of extended droughts is predicted to continue into the future. Furthermore, the Mediterranean basin is considered to be highly vulnerable to climate change, which strongly affects the local hydrology and consequently biocenoses (Bangash et al. 2013). Accelerating drought in sensitive regions may result in future declines in odonatofauna, especially in vulnerable species that require perennial water (Korkeamaki & Suhonen 2002; Boulton 2003). Interestingly, Lopau (1995) observed several dragonfly species on Psili Ammos lake in June 1993, including *Anax imperator* (Leach, 1815), *Libellula fulva*, and *Orthetrum coerulescens* (Fabricius, 1798) which we did not observe at this site. However, in 2017, the year of our study, the lake was dry at that time, that might result from the increasing dryness of the area.

Future assemblages in some Mediterranean areas may shift to drought-tolerant specialists adapted to ephemeral habitats (Boulton 2003; Bêche et al. 2006, 2009; Hassall & Thompson 2008). Mobile species with desiccation-resistant stages or short lifecycles may replace other species (Gasith & Resh 1999). For example, *O. brunneum* (Fonscolombe, 1837) and *Trithemis arteriosa* (Burmeister, 1839), which are already present in the Mytilini dragonfly assemblage, as well as *O. sabina*, *Selysiothemis nigra* (Vander Linden, 1825) and two species of *Sympetrum* on Glyfada Lake, are species adapted to temporal water bodies and have a wide range of ecological tolerances (Carchini et al. 2003; Suhling et al. 2003; Johansson & Suhling 2004; Beschovski & Marinov 2007).

Monitoring abundant resident species in the studied wetlands, e.g., *L. macrostigma* in Psili Ammos, may be important for detecting the early decline of a habitat (Hawking & New 2002). Additionally, resident stenoecious species, e.g., *E. fatime*, *Chalcolestes parvidens* (Artobolevskij, 1929), and *Cordulegaster* sp. (Lopau 1999; Beschovski & Marinov 2007; Marinov et al. 2007), can act as valuable indicators because of their narrow habitat requirements (Smith et al. 2007). On the other hand, colonisation of the island by dragonfly species can also provide information on general environmental change. Several European studies have reported the northward expansion of Mediterranean species and their acclimation to new environments (Ott 2001, 2010; De Knijf & Anselin 2010). Similarly, the thermophilic species *T. arteriosa* has shown recent northward range expansion in Anatolia and Greece (Hupało & Tończyk 2014; Kalfayan & Krieg-Jacquier 2018). The possible establishment of a stable population of *T. arteriosa* on Samos Island may reveal local environmental change associated with climate change.

To summarise, drought – the seasonal decrease in water availability – was a main factor affecting the number, composition and abundance of species. Monitoring and assessing dragonfly assemblages in the studied area is of great importance considering the clear trend towards a drier climate observed in the Mediterranean area and the vulnerability of the regional ecosystems. Our study is one of the first descriptions of dragonfly assemblages in the eastern Mediterranean region, includes their environmental background, and creates a reference for further studies on dragonfly assemblages on Samos Island in the context of changing Mediterranean climate.

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Appendix 1 – Coordinates of sampling points in four study sites.

Point No.	**Glyfada** coordinates	**Mesokampos** coordinates	**Mytilini** coordinates	**Psili Ammos** coordinates
1	N 37.69128° E 26.92894°	N 37.70838° E 26.98413°	N 37.72223° E 26.95265°	N 37.70905° E 27.01395°
2	N 37.69162° E 26.92896°	N 37.70782° E 26.98420°	N 37.72293° E 26.95278°	N 37.70903° E 27.01234°
3	N 37.69189° E 26.92854°	N 37.70787° E 26.98834°	N 37.72381° E 26.95299°	N 37.70835° E 27.00751°
4	N 37.69157° E 26.92826°	N 37.70863° E 26.98856°	N 37.72239° E 26.95248°	N 37.70725° E 27.00748°
5	N 37.69168° E 26.92797°	N 37.70932° E 26.98842°	N 37.72239° E 26.95252°	N 37.70638° E 27.00896°
6		N 37.71007° E 26.98850°	N 37.72233° E 26.95250°	
7		N 37.71049° E 26.98859°		

Appendix 2 – Number of individuals recorded during three sampling periods over the year (each period included two sampling visits to the site, denoted with "a" and "b"; each site included 5 to 7 sampling points); E = presence of exuviae; (T) = presence of teneral individuals among the recorded dragonflies.

Species	Glyfada						Mesokampos						Mytilini						Psili Ammos					
	1a	1b	2a	2b	3a	3b	1a	1b	2a	2b	3a	3b	1a	1b	2a	2b	3a	3b	1a	1b	2a	2b	3a	3b
Calopteryx virgo													1	7+E	8	8								
Lestes macrostigma		2+E	5	2															167 (T) +E	161 (T) +E				
Chalcolestes parvidens															4	1	3	2						
Enallagma cyathigerum	62 +E	110			2	4																		
Erythromma lindenii			2	1		5																		
Ischnura elegans	37 (T)	64 (T)	42	19	8	1		1	2		2								1					
Platycnemis pennipes													18	20 +E	31	13	8	5						
Aeshna isoceles		2						3	7	5														
Anax imperator	2	7	6	4	4	2	4	5	6	3		2		2	1+E									
Anax parthenope			1									2												
Brachytron pratense							5	4												3				
Caliaeschna microstigma																2								
Crocothemis erythraea	2	2	1		1	4		3	3	4	9	6		1					1		1			
Libellula depressa													3	4	1(T)	1								
Libellula fulva							8	10	3	10					1									
Orthetrum brunneum															1		2	2					1	
Orthetrum cancellatum	6	8	11	6	11	18			1															
Orthetrum coerulescens			1		2				6	7	4	2		5	2	4	2	3						
Orthetrum sabina			1	3																				
Selysiothemis nigra					1						3	3												
Sympetrum fonscolombii	1	1			2	3					14	8											12	16
Sympetrum meridionale									2															
Sympetrum striolatum		3	1	2					1	1											2			
Trithemis arteriosa										3	4	4			3	2+E	2	3						
Number of species	6	9	10	7	8	7	3	6	9	7	6	7	3	6	9	7	5	5	3	2	2	0	2	1