

## Article

# Niche Breadth Predicts Geographical Range Size and Northern Range Shift in European Dragonfly Species (Odonata)

Kent Olsen <sup>1,\*</sup>, Jens-Christian Svenning <sup>2,3,4</sup> and Henrik Balslev <sup>2</sup>

<sup>1</sup> Research and Collections, Natural History Museum Aarhus, Wilhelm Meyers Allé 10, DK-8000 Aarhus, Denmark

<sup>2</sup> Section for Ecoinformatics and Biodiversity, Department of Biology, Aarhus University, Ny Munkegade 116, DK-8000 Aarhus, Denmark

<sup>3</sup> Center for Biodiversity Dynamics in a Changing World, Department of Biology, Aarhus University, Ny Munkegade 116, DK-8000 Aarhus, Denmark

<sup>4</sup> Center for Sustainable Landscapes under Global Change, Department of Biology, Aarhus University, Nordre Ringgade 1, DK-8000 Aarhus, Denmark

\* Correspondence: kent@nathist.dk; Tel.: +45-40272030

## Supplementary Tables

**Table S1.** List of European dragonfly (Odonata) species which (1) have been excluded from the analysis, (2) where modifications to species range have been applied, (3) which have colonized Europe after 1988, and (4) with taxonomic and nomenclatural changes between 1988 and 2010. Nomenclature and taxonomy follow IUCN [48].

### 1) SPECIES WHICH HAVE BEEN EXCLUDED IN THE ANALYSIS

#### *Anax ephippiger*

An obligate Afro-tropical migrant which expands north with the seasonal monsoon fronts [47]. It has a huge range and reproduces only temporarily in the Palearctic (northern Africa, Europe, central and southern Asia). It does not occur annually in most of the European range.

#### *Anax immaculifrons*

No distribution map included in Askew [45], only in Dijkstra & Lewington [47] and Kalkman et al. [12]. Found in south Turkey, Cyprus, and the Greek islands of Rhodes, Kápathso and Ikaria.

#### *Anax junius*

Is a trans-Atlantic vagrant with no established European populations [47].

#### *Gomphus ubadschii*

*G. ubadschii* used to be considered a subspecies of *G. flavipes* and both were included in the same distribution map in Askew [45]. Within our study area it is only found in very restricted areas in the western half of Anatolia [12,47].

#### *Libellula pontica*

Only included with distribution maps in Dijkstra & Lewington [47], but not in Askew [45] and Kalkman et al. [12]. Found only in a small area within our study area in northern Turkey.

#### *Onychogomphus assimilis*

Only included with distribution maps in Dijkstra & Lewington [47], but not in Askew [45] and Kalkman et al. [12]. Found only in a small area within our study area in southern Turkey.

#### *Onychogomphus flexuosus*

Only included with distribution maps in Dijkstra & Lewington [47], but not in Askew [45] and Kalkman et al. [12]. Found only in a small area within our study area in southern Turkey.

#### *Somatochlora borisi*

First discovered in 1999 and thus not included in Askew [45], and so far, found only in a very restricted area in the south-eastern Balkans [12,47].

## 2) SPECIES IN WHICH RANGE MAPS HAVE BEEN MODIFIED

#### *Aeshna subarctica*

A large part of Belarus was missing in the 2010 data. However, according to the map in Dijkstra & Lewington [47] this is erroneous, and that area has thus been added to the range of this species.

#### *Aeshna viridis*

A large part of Belarus and the freshwater lake, Ladoga east of Saint Petersburg was missing in the 2010 data. However, according to the map in Dijkstra & Lewington [47] this is erroneous, and that area has thus been added to the range of this species.

#### *Calopteryx xanthostoma*

Records from Sardinia included in Askew [45] are reported by Boudot et al. [72] to be erroneous and have thus been omitted from the analysis.

#### *Ceriatron tenellum*

*C. georgifreyi* used to be considered a subspecies of *C. tenellum* and both taxa were thus included in the same distribution map in Askew [45]. Both are now considered good species and their ranges are not known to overlap [47]. Consequently, the range of *C. georgifreyi* per 1988 was removed from the original *C. tenellum* map.

#### *Ceriatron georgifreyi*

*C. georgifreyi* used to be considered a subspecies of *C. tenellum* and both taxa were thus included in the same distribution map in Askew [45]. Both are now considered good species and their ranges are not known to overlap [47]. Consequently, the range of *C. georgifreyi* per 1988 was drawn based on the original *C. tenellum* map.

#### *Chalcolestes viridis* / *Chalcolestes parvidens*

*C. parvidens* used to be considered a subspecies of *C. viridis* and both were included in the same distribution map in Askew [45]. Both are now considered good species and as their ranges are known to overlap substantially, the maps of both taxa per 2010 were combined in order to compare it with the 1988 maps which include both species in one map.

#### *Coenagrion hylas*

The population in Germany went extinct in the mid-1960s whereas the population in western Austria remains [45,47]. The map from 1988 have been updated to include the Austrian range as it is mentioned within the text, but not specified in the map whereas the extinct population has been omitted.

#### *Coenagrion intermedium*

Included in the same distribution map as *C. puella* in Askew [45], but as *C. intermedium* according to Dijkstra & Lewington [47] replaces *C. puella* in Crete and their distributions are not known to overlap, the range of *C. intermedium* per 1988 was drawn based on the original *C. puella* map.

#### *Cordulegaster boltonii*

*C. trinacriae* used to be considered a subspecies of *C. boltonii* and was thus included in the same distribution map in 1988 [45]. Both are now considered good species and as their ranges are not known to overlap as *C. trinacriae* replaces *C. boltonii* in Italy south of Rome [47], the range of *C. trinacriae* was removed from the original *C. boltonii* map in 1988.

#### *Cordulegaster helladica*

Three weakly differentiated subspecies have been described, namely *C. helladica helladica*, *C. h. buccholzi*, and *C. h. kastalia*. The ranges of all three subspecies are combined within one map in 2010 as *C. helladica*. Askew [45] presented *C. helladica* in the same distribution map as *C. picta*, but as their distributions are not known to overlap according to Dijkstra & Lewington [47], the range of *C. helladica* per 1988 was drawn based on the original *C. picta* map.

#### ***Cordulegaster picta***

Askew [45] presented *C. helladica* in the same distribution map as *C. picta*, but as their distributions are not known to overlap according to Dijkstra & Lewington [47], the range of *C. helladica* was removed from the original *C. picta* map in 1988.

#### ***Cordulegaster trinacriae***

Included in the same distribution map as *C. boltonii* in Askew [45], but as *C. trinacriae* replaces *C. boltonii* in Italy south of Rome [47], the range of *C. trinacriae* per 1988 was drawn from the original *C. boltonii* map.

#### ***Lestes sponsa***

Records from Crete, Andalusia and Maghreb included in Askew [45] are considered erroneous [72] and thus omitted from the map in 1988.

#### ***Libellula fulva***

A large part of Czech Republic and all of Belarus was missing in the 2010 data. However, according to Dijkstra & Lewington [47] this is erroneous and both areas have thus been added to the range of this species.

#### ***Onychogomphus forcipatus***

Three weakly differentiated subspecies have been described, namely *O. f. forcipatus*, *O. f. albotibialis*, and *O. f. unguiculatus* [47]. The ranges of all three subspecies have been combined in the 2010 map of *O. forcipatus*.

#### ***Orthetrum cancellatum***

A large part of Belarus was missing in the 2010 data. However, according to maps in Dijkstra & Lewington [47] this is erroneous, and that area has thus been added to the range of this species.

#### ***Orthetrum coerulescens* / *Orthetrum ramburii***

The southern ssp. *anceps* was once considered a good species, formerly called *O. ramburii* [45], but as intermediate individuals occur in large areas this seems unjustified, and they are thus considered to be two subspecies [47]. For the analysis, the two maps from 1988 where they were treated as separate species have been combined in order to allow a direct comparison to the distribution per 2010, which include both subspecies in one map.

#### ***Pantala flavescens***

Single records from Spain and France which were originally included in Askew [45] have been omitted as they are now believed to have been based on a misinterpretation of French literature by Aguesse [73]. The species is considered to be at least partly ship assisted in the west Mediterranean area [47].

#### ***Pyrrhosoma nymphula* / *Pyrrhosoma elisabethae***

*P. elisabethae* used to be considered a subspecies of *P. nymphula* [45]. For the analysis, in 2010 the ranges of the two taxa were combined in order to compare with the 1988 maps which include both species in one map. However, it makes very little difference, as compared to the large distribution of *P. nymphula*, *P. elisabethae* is currently known from only a small number of localities on the Peloponnese, Kérkira (Corfu) and southern Albania [47].

#### ***Sympetrum pedemontanum***

The distribution in 2010 included parts of the Baltic Sea and the Black Sea. These erroneous parts of the range were removed in the analysis by using the European coastline.

#### ***Sympetrum striolatum* / *Sympetrum nigrescens***

*S. nigrescens* from the Atlantic coast of Ireland, Scotland and Norway has been considered a good species [45], but molecular work has showed that the genetic distance between *S. striolatum* and *S. nigrescens* is small and fall in the range of within-species variation

[74]. The two maps from 1988 where they were treated as separate species have been combined in order to allow a direct comparison with the distribution per 2010, which included both taxa as subspecies. Additionally, all of Belarus was missing in the 2010 data. However, according to Dijkstra & Lewington [47] this is erroneous, and that area has thus been added to the range of the species in 2010.

#### *Trithemis festiva*

No distribution map for this species was included in Askew [45] but in the text it was noted as occurring on Rhodes and Cyprus and we have added this area to the range per 1988. In 2010 it also occurs in a small area within our study area in southern Turkey.

### 3) SPECIES WHICH IN 2010 HAVE BEEN INCLUDED AS NEW IN EUROPE

#### *Ischnura fountaineae*

No distribution map for this species was included in Askew [45], and within Europe it currently occurs only on the Italian island Pantelleria southwest of Sicily [12,47].

#### *Orthetrum Sabina*

No distribution map for this species was included in Askew [45] and the text states that it does not penetrate into Europe west of the Caucasus. However, it is included both in Dijkstra & Lewington [47] and Kalkman et al. [12] with a range along the Turkish Mediterranean coast and some Greek islands.

#### *Orthetrum taeniolatum*

No distribution map for this species was included in Askew [45] and the text states that its distribution only very nearly extends into Europe. However, it is included both in Dijkstra & Lewington [47] and Kalkman et al. [12] with a range along the Turkish Mediterranean coast and some Greek islands.

#### *Trithemis kirbyi*

No distribution map for this species was included in Askew [45] and it does not seem to occur within our study area per 2006 [47]. However, by 2010 it has jumped from North Africa to Sardinia [12].

### 4) SPECIES WITH CHANGES IN TAXONOMY AND SCIENTIFIC NAME

#### *Brachythemis impartita*

The taxon *B. leucosticta* included in Askew [45] was believed to feature two morphotypes, which are now considered to represent separate species where *B. impartita* is the one found in Europe [47] and thus the one included in this work.

#### *Chalcolestes viridis* / *Chalcolestes parvidens*

*C. parvidens* used to be considered a subspecies of *C. viridis* and both were thus included in the same distribution map in 1988 [45]. They were both formerly in the genus *Lestes*.

#### *Ceriatron tenellum* / *Ceriatron georgifreyi*

*C. georgifreyi* used to be considered a subspecies of *C. tenellum* and both were thus included in the same distribution map in 1988 [45].

#### *Sympetrum sinaiticum*

Previously incorrectly called *S. decoloratum* and the individuals in Europe treated as the subspecies *S. d. sinaiticum* [45], but according to Dijkstra & Lewington [47] *S. sinaiticum* is now considered a good species on its own.

#### *Sympetrum vulgatum decoloratum*

*S. decoloratum* used to be considered a good species which included *sinaiticum* as a subspecies [45], but according to Dijkstra & Lewington [47] *decoloratum* is now considered to be a subspecies of *S. vulgatum* and *sinaiticum* a good species on its own. *S. v. decoloratum* occurs in Turkey where nominate form *S. vulgatum* on the other hand does not occur and *decoloratum* is thus included

within the distribution maps of *Sympetrum vulgatum* from both 1988 and 2010. The distribution map *decolora* only includes the North African range which was believed to be the subspecies *Sympetrum decoloratum sinaiticum*, whereas *Sympetrum vulgatum* was considered to be the one occurring in Turkey. There is no specific distribution map available for *decoloratum* in 2010 where its Turkish range is included within the *Sympetrum vulgatum* range.

**Table S2** Table showing the taxonomic suborder and scientific names of all European dragonfly (Odonata) species included in the analysis ( $n = 123$ ) of how species groups with different habitat adaptations react to climatic change. Also presented are overall range size expressed as number of occupied  $100 \times 100$  km grid cells and latitudinal range expressed as the latitudinal extent of distributional range between northern and southern range borders in 1988 and 2010, respectively; range shift between 1988 and 2010 expressed as change in latitudinal range and shift in northern range margin; and ecological habitat category for each species classified according to references as permanent running (perennial lotic) water (LOT), permanent standing (perennial lentic) water (PER), and temporary (running or standing) water (TEM). See methods for detailed descriptions of the entries on species range in this table. Nomenclature and taxonomy follow IUCN [48].

SUBORDER	SPECIES	OVERALL RANGE 1988 (Number of grid cells)	OVERALL RANGE 2010 (Number of grid cells)	LATITUDINAL RANGE 1988 (km)	LATITUDINAL RANGE 2010 (km)	RANGE SHIFT Latitudinal (km)	RANGE SHIFT North border (km)	HABITAT CATEGORY (Type)	HABITAT UTILIZA- TION (Reference)
Zygoptera	<i>Calopteryx haemorrhoidalis</i>	158	172	1034	1165	130	130	LOT	[27,47,50]
Zygoptera	<i>Calopteryx splendens</i>	596	644	3255	3259	4	4	LOT	[27,47,50]
Zygoptera	<i>Calopteryx virgo</i>	748	803	3836	3796	-40	-62	LOT	[27,47,50]
Zygoptera	<i>Calopteryx xanthostoma</i>	127	121	1274	1229	-46	-45	LOT	[27,47,50]
Zygoptera	<i>Ceriagrion georgifreyi</i>	6	7	106	408	302	299	LOT	[27,47,50]
Zygoptera	<i>Ceriagrion tenellum</i>	283	318	2041	2267	226	226	PER	[27,47,50]
Zygoptera	<i>Chalcolestes viridis</i>	507	547	2041	2331	290	290	TEM	[27,52]
Zygoptera	<i>Coenagrion armatum</i>	292	321	2369	2493	124	236	PER	[27,47,50]
Zygoptera	<i>Coenagrion caeruleum</i>	125	140	912	933	21	21	LOT	[27,47,50]
Zygoptera	<i>Coenagrion hastulatum</i>	480	482	3186	3189	3	-9	PER	[27,47,50]
Zygoptera	<i>Coenagrion hylas</i>	2	2	75	75	0	0	PER	[47,50]
Zygoptera	<i>Coenagrion intermedium</i>	6	6	64	63	-1	-1	LOT	[47,50]
Zygoptera	<i>Coenagrion johanssoni</i>	157	197	1445	1676	232	0	PER	[45,47,50]
Zygoptera	<i>Coenagrion lunulatum</i>	403	393	2890	3012	122	37	PER	[45,47,50]
Zygoptera	<i>Coenagrion mercuriale</i>	229	243	1968	1909	-59	-46	LOT	[27,47,50]
Zygoptera	<i>Coenagrion ornatulum</i>	147	280	1480	2214	734	520	LOT	[45,47,50]
Zygoptera	<i>Coenagrion puella</i>	646	703	2884	3004	120	97	PER	[27,47,50]
Zygoptera	<i>Coenagrion pulchellum</i>	589	631	3172	3409	237	122	PER	[27,47,50]
Zygoptera	<i>Coenagrion scitulum</i>	155	345	1924	1926	2	2	PER	[47,50]
Zygoptera	<i>Enallagma cyathigerum</i>	761	833	3802	3858	56	-97	PER	[27,47,50]

Zygoptera	<i>Epallage fatime</i>	55	61	1249	802	-448	-526	LOT	[27,47,50]
Zygoptera	<i>Erythromma lindenii</i>	316	404	1908	2066	158	158	PER	[27,47,50]
Zygoptera	<i>Erythromma najas</i>	506	587	3102	3341	239	2	PER	[27,47,50]
Zygoptera	<i>Erythromma viridulum</i>	369	552	1879	2302	423	350	PER	[47,50]
Zygoptera	<i>Ischnura elegans</i>	666	734	3386	3516	129	129	TEM	[27]
Zygoptera	<i>Ischnura fountaineae</i>	0	1	0	12	12	NA	TEM	[48,54]
Zygoptera	<i>Ischnura genei</i>	23	23	783	783	0	0	PER	[47,50]
Zygoptera	<i>Ischnura graellsii</i>	74	77	885	885	0	0	TEM	[27]
Zygoptera	<i>Ischnura pumilio</i>	461	612	2803	2854	51	51	TEM	[27,47,50]
Zygoptera	<i>Lestes barbarus</i>	542	579	2241	2465	224	224	TEM	[27,47,50]
Zygoptera	<i>Lestes dryas</i>	604	658	3302	3488	186	129	TEM	[27,47,50]
Zygoptera	<i>Lestes macrostigma</i>	221	185	1405	1599	194	172	TEM	[51,55]
Zygoptera	<i>Lestes sponsa</i>	596	673	3027	3218	191	118	TEM	[27]
Zygoptera	<i>Lestes virens</i>	450	590	2106	2628	521	503	TEM	[27,48,52]
Zygoptera	<i>Nehalennia speciosa</i>	229	224	1884	1804	-79	13	PER	[27,47,50]
Zygoptera	<i>Platycnemis acutipennis</i>	127	134	1445	1445	0	0	LOT	[27,47,50]
Zygoptera	<i>Platycnemis latipes</i>	115	102	1259	1007	-252	-252	LOT	[47,50]
Zygoptera	<i>Platycnemis pennipes</i>	628	624	3384	3371	-13	81	LOT	[27,47,50]
Zygoptera	<i>Pyrrhosoma nymphula</i>	717	757	3391	3403	12	12	PER	[27,47,50]
Zygoptera	<i>Sympecma fusca</i>	576	562	2477	2743	267	267	PER	[27,47,50]
Zygoptera	<i>Sympecma paedisca</i>	178	216	1476	1896	419	474	PER	[27,47,50]
Anisoptera	<i>Aeshna affinis</i>	349	575	1759	2394	636	562	TEM	[27,47,49,52]
Anisoptera	<i>Aeshna caerulea</i>	263	283	2941	2913	-28	0	PER	[27,47,49]
Anisoptera	<i>Aeshna crenata</i>	23	50	372	1118	745	229	PER	[47,49]
Anisoptera	<i>Aeshna cyanea</i>	616	611	3009	3024	15	15	PER	[27,47,49]
Anisoptera	<i>Aeshna grandis</i>	498	556	3107	3070	-37	-63	PER	[27,47,49]
Anisoptera	<i>Aeshna isoceles</i>	436	578	2386	3176	790	777	PER	[27,47,49]
Anisoptera	<i>Aeshna juncea</i>	553	593	3426	3321	-106	-37	PER	[27,47,49]
Anisoptera	<i>Aeshna mixta</i>	542	657	2152	2918	765	670	PER	[27,47,49]
Anisoptera	<i>Aeshna serrata</i>	58	70	836	987	151	119	PER	[47,49]
Anisoptera	<i>Aeshna subarctica</i>	291	358	2945	2986	42	-72	PER	[27,47,49]
Anisoptera	<i>Aeshna viridis</i>	235	257	1785	1988	203	42	PER	[27,47,49]
Anisoptera	<i>Anax imperator</i>	555	645	2200	2655	455	477	TEM	[27,54]
Anisoptera	<i>Anax parthenope</i>	379	524	1850	2657	806	806	TEM	[27,54]
Anisoptera	<i>Boyeria cretensis</i>	3	6	46	63	18	3	LOT	[47,49]
Anisoptera	<i>Boyeria irene</i>	136	189	1294	1445	151	151	LOT	[27,47,49]
Anisoptera	<i>Brachythemis impartita</i>	25	43	779	833	54	-4	PER	[27,47,49]
Anisoptera	<i>Brachytron pratense</i>	524	586	2864	2997	133	32	PER	[27,47,49]
Anisoptera	<i>Caliaeschna microstigma</i>	74	89	988	906	-82	-62	LOT	[47,49]
Anisoptera	<i>Cordulegaster bidentata</i>	135	253	1598	1699	101	149	LOT	[27,47,49]
Anisoptera	<i>Cordulegaster boltonii</i>	527	483	3165	3281	116	116	LOT	[27,47,49]
Anisoptera	<i>Cordulegaster helladica</i>	5	12	107	301	194	32	LOT	[47,49]

Anisoptera	<i>Cordulegaster heros</i>	15	83	941	1173	232	82	LOT	[47,49]
Anisoptera	<i>Cordulegaster insignis</i>	57	47	1275	815	-459	-459	LOT	[47,49]
Anisoptera	<i>Cordulegaster picta</i>	38	45	905	729	-176	-294	LOT	[47,49]
Anisoptera	<i>Cordulegaster trinacriae</i>	20	21	627	572	-55	-8	LOT	[47,49]
Anisoptera	<i>Cordulia aenea</i>	492	629	3110	3433	324	219	PER	[27,47,49]
Anisoptera	<i>Crocothemis erythraea</i>	372	537	1849	2152	304	326	TEM	[27,47,49,54]
Anisoptera	<i>Diplacodes lefebvrii</i>	22	32	523	533	10	11	TEM	[48,53,54]
Anisoptera	<i>Epithea bimaculata</i>	263	330	2208	2242	35	-45	PER	[27,47,49]
Anisoptera	<i>Gomphus flavipes</i>	280	344	2006	2461	456	651	LOT	[27,47,49]
Anisoptera	<i>Gomphus graslinii</i>	22	62	1118	1297	179	106	LOT	[47,49]
Anisoptera	<i>Gomphus pulchellus</i>	153	184	1784	1840	55	55	PER	[47,49]
Anisoptera	<i>Gomphus schneiderii</i>	46	63	797	816	19	0	LOT	[47,49]
Anisoptera	<i>Gomphus simillimus</i>	128	142	1651	1457	-194	-194	LOT	[47,49]
Anisoptera	<i>Gomphus vulgatissimus</i>	446	562	2718	2992	274	105	LOT	[27,47,49]
Anisoptera	<i>Leucorrhinia albifrons</i>	242	220	2104	2429	325	61	PER	[47,49]
Anisoptera	<i>Leucorrhinia caudalis</i>	255	309	2112	2367	255	-72	PER	[27,47,49]
Anisoptera	<i>Leucorrhinia dubia</i>	463	488	3271	3166	-105	-73	PER	[27,47,49]
Anisoptera	<i>Leucorrhinia pectoralis</i>	232	382	2439	2724	285	61	PER	[27,47,49]
Anisoptera	<i>Leucorrhinia rubicunda</i>	353	378	2773	2744	-29	15	PER	[47,49]
Anisoptera	<i>Libellula depressa</i>	680	706	3048	3102	54	-3	TEM	[27]
Anisoptera	<i>Libellula fulva</i>	483	573	2878	3100	222	153	PER	[27,47,49]
Anisoptera	<i>Libellula quadrimaculata</i>	675	738	3685	3411	-274	-283	PER	[27,47,49]
Anisoptera	<i>Lindenia tetraphylla</i>	75	59	954	886	-68	30	PER	[47,49]
Anisoptera	<i>Macromia splendens</i>	23	50	910	1030	120	64	PER	[47,49]
Anisoptera	<i>Onychogomphus costae</i>	16	32	338	695	357	192	TEM	[47]
Anisoptera	<i>Onychogomphus forcipatus</i>	504	608	3290	3462	172	172	LOT	[27,47,49]
Anisoptera	<i>Onychogomphus uncatus</i>	135	157	1481	1435	-46	-104	LOT	[27,47,49]
Anisoptera	<i>Ophiogomphus cecilia</i>	331	342	2686	2854	168	-62	LOT	[27,47,49]
Anisoptera	<i>Orthetrum albistylum</i>	220	302	1678	2082	404	404	TEM	[27]
Anisoptera	<i>Orthetrum brunneum</i>	431	515	1955	2304	349	349	LOT	[27,47,49]
Anisoptera	<i>Orthetrum cancellatum</i>	666	731	3159	3128	-31	-31	TEM	[27]
Anisoptera	<i>Orthetrum chrysostigma</i>	26	60	356	707	351	351	TEM	[27,54]
Anisoptera	<i>Orthetrum coerulescens</i>	552	604	2947	3086	139	139	LOT	[27,47,49]
Anisoptera	<i>Orthetrum nitidinerve</i>	33	79	609	811	202	202	PER	[47,49]
Anisoptera	<i>Orthetrum sabina</i>	0	16	0	347	347	NA	TEM	[27,53]
Anisoptera	<i>Orthetrum taeniolatum</i>	0	18	0	436	436	NA	PER	[47,49]
Anisoptera	<i>Orthetrum trinacria</i>	14	50	437	715	278	127	TEM	[48]
Anisoptera	<i>Oxygastra curtisii</i>	154	148	1842	1509	-333	-372	LOT	[47,49]
Anisoptera	<i>Pantala flavescens</i>	2	14	48	752	704	498	TEM	[27,45,49,54]
Anisoptera	<i>Paragomphus genei</i>	27	36	591	617	27	27	TEM	[27,47,49,54]
Anisoptera	<i>Selysiothemis nigra</i>	38	120	815	1464	648	626	TEM	[48,54]
Anisoptera	<i>Somatochlora alpestris</i>	179	211	3085	3070	-15	-9	PER	[27,47,49]

Anisoptera	<i>Somatochlora arctica</i>	283	399	3162	3186	24	31	PER	[27,47,49]
Anisoptera	<i>Somatochlora flavomaculata</i>	358	524	2664	3258	594	432	PER	[27,47,49]
Anisoptera	<i>Somatochlora meridionalis</i>	72	138	972	1486	514	393	LOT	[47,49]
Anisoptera	<i>Somatochlora metallica</i>	584	588	3232	3282	50	-84	PER	[27,47,49]
Anisoptera	<i>Somatochlora sahlbergi</i>	9	11	202	284	82	12	PER	[27,47,49]
Anisoptera	<i>Sympetrum danae</i>	529	554	2840	2895	55	53	TEM	[47]
Anisoptera	<i>Sympetrum depressiusculum</i>	143	314	1531	2500	969	782	TEM	[27,47,49]
Anisoptera	<i>Sympetrum flaveolum</i>	632	669	3154	3291	137	129	TEM	[27,47,49]
Anisoptera	<i>Sympetrum fonscolombii</i>	443	588	2397	2441	44	46	TEM	[27,49,54]
Anisoptera	<i>Sympetrum meridionale</i>	373	543	1895	2106	211	211	TEM	[52,53]
Anisoptera	<i>Sympetrum pedemontanum</i>	168	310	1726	2107	381	533	TEM	[48,51]
Anisoptera	<i>Sympetrum sanguineum</i>	631	693	2887	2902	15	44	TEM	[27,47,49]
Anisoptera	<i>Sympetrum sinaiticum</i>	4	23	55	571	516	70	TEM	[54]
Anisoptera	<i>Sympetrum striolatum</i>	718	740	3313	3330	17	39	TEM	[27,49]
Anisoptera	<i>Sympetrum vulgatum</i>	475	545	3187	3343	156	95	TEM	[27,49]
Anisoptera	<i>Trithemis annulata</i>	69	169	691	1164	473	378	TEM	[54]
Anisoptera	<i>Trithemis festiva</i>	3	7	70	262	192	192	LOT	[47]
Anisoptera	<i>Trithemis kirbyi</i>	0	5	0	216	216	NA	TEM	[27,54]
Anisoptera	<i>Zygonyx torridus</i>	6	19	261	363	102	64	LOT	[45,47]

**Table S3** Measures of range size in European dragonfly (Odonata) species in 1988 and 2010, respectively. Overall range size is expressed as number of occupied 100 × 100 km grid cells whereas latitudinal range is expressed as the latitudinal extent of distributional range between northern and southern range borders. Ecological habitat category: Permanent running (perennial lotic) water, permanent standing (perennial lentic) water, and temporary (running or standing) water used in two-way combinations as three unmatched test groups in Mann-Whitney-Wilcoxon tests. Bold font indicates significant variables at  $\alpha = 0.05$

	Data set	Perm. Running		Perm. Standing		Temporary		Perm. Running–Perm. Standing				Perm. Running–Temporary				Perm. Standing–Temporary			
		n	Mean ± 1 SD	n	Mean ± 1 SD	n	Mean ± 1 SD	n	df	W	<i>p</i> -value	n	df	W	<i>p</i> -value	n	df	W	<i>p</i> -value
Overall range (number of cells)	1988	37	194 ± 211	48	325 ± 216	34	315 ± 257	85	1	566	<b>0.0030</b>	71	1	533	0.1025	82	1	938	0.7902
	2010	37	224 ± 225	49	375 ± 233	37	383 ± 278	86	1	572	<b>0.0035</b>	74	1	488	<b>0.0341</b>	86	1	887	0.8649
Latitudinal range (km)	1988	37	1514 ± 1040	48	2214 ± 1026	34	1717 ± 1154	85	1	580	<b>0.0044</b>	71	1	613	0.4427	82	1	1141	<b>0.0412</b>
	2010	37	1578 ± 1071	49	2373 ± 991	37	1996 ± 1096	86	1	545	<b>0.0016</b>	74	1	552	0.1520	86	1	1093	0.1047

**Table S4** Measures of range shift in European dragonfly (Odonata) species between 1988 and 2010. Shift in latitudinal range is expressed as the change in latitudinal extent of distributional range, and shift in northern range border is expressed as the change in maximum latitude of distributional range for all species, whereas the subset of species experiencing range contraction used to express contraction in latitudinal range and north border, respectively. Ecological habitat category: Permanent running (perennial lotic) water, permanent standing (perennial lentic) water, and temporary (running or standing) water used in two-way combinations as three unmatched test groups in Mann-Whitney-Wilcoxon tests. Bold font indicates significant variables at  $\alpha = 0.05$

	Perm. Running		Perm. Standing		Temporary		Perm. Running–Perm. Standing				Perm. Running–Temporary				Perm. Standing–Temporary			
	n	Mean ± 1 SD	n	Mean ± 1 SD	n	Mean ± 1 SD	n	df	W	<i>p</i> -value	n	df	W	<i>p</i> -value	n	df	W	<i>p</i> -value
Shift in latitudinal range (km)	37	64 ± 243	49	159 ± 226	37	279 ± 250	86	1	711	0.0890	74	1	349	<b>0.0003</b>	86	1	632	<b>0.0169</b>
Shift in north border (km)	37	34 ± 239	48	91 ± 192	34	246 ± 234	85	1	805	0.4618	71	1	326	<b>0.0005</b>	82	1	439	<b>0.0004</b>
Contraction in latitudinal range (km)	14	-157 ± 158	9	-82 ± 79	1	-31	23	1	49	0.3950	15	1	2	0.2972	10	1	3	0.8000
Contraction in north border (km)	14	-178 ± 175	12	-71 ± 74	2	-17 ± 20	26	1	62	0.2573	16	1	3	0.0945	14	1	3	0.1199