

Climate change is driving shifts in dragonfly species richness across Europe via differential dynamics of taxonomic and biogeographic groups

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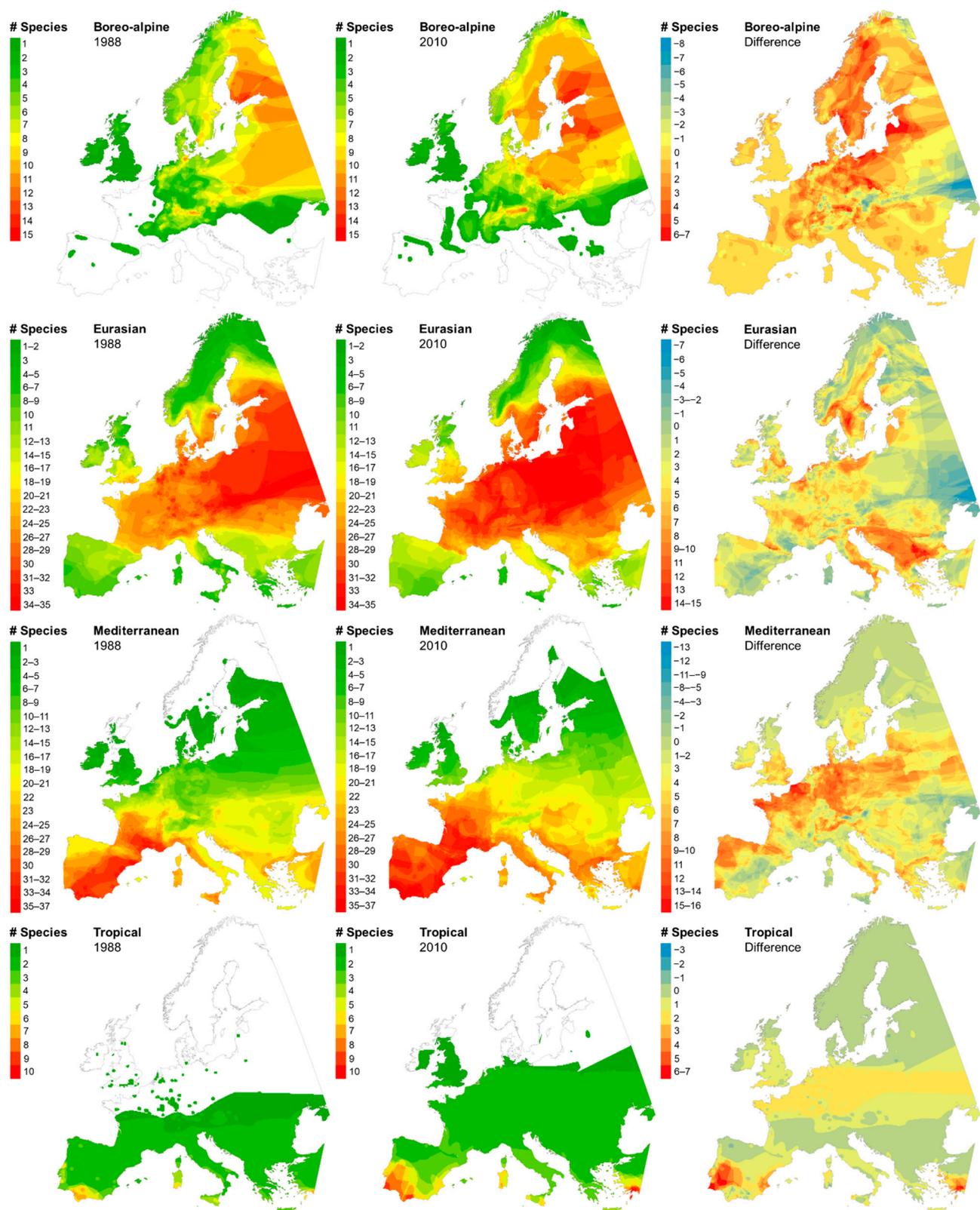


Figure S1. Geographical patterns of European dragonfly (Odonata) species richness and changes by biogeographical groups. Observed species richness in 1988 according to Askew [49] (left column), observed species richness in 2010 according to Kalkman et al. [34] (middle column), difference in observed species richness between 1988 and 2010 (negative value: decrease and positive value: increase in species richness, respectively) (right column). European data presented by biogeographical groups (Tropical, Mediterranean, Eurasian, and Boreo-alpine) at 10 km × 10km grid resolution.

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) that colonized Europe after 1988, and (4) with taxonomic and nomenclatural changes between 1988 and 2010. Nomenclature and taxonomy follow IUCN [80].

1) Species that have been excluded in the analysis

Anax ephippiger

An obligate Afro-tropical migrant which expands north with the seasonal monsoon fronts [50]. 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 [49], only in Dijkstra and Lewington [50] and Kalkman et al. [34]. Found in south Turkey, Cyprus, and the Greek islands of Rhodes, Kárpáthos and Ikaria.

Anax junius

Is a trans-Atlantic vagrant with no established European populations [50].

Gomphus ubadschii

G. ubadschii used to be considered a subspecies of *G. flavipes* and both were included in the same distribution map in Askew [49]. Within our study area it is only found in very restricted areas in the western half of Anatolia [34,50].

Libellula pontica

Only included with distribution maps in Dijkstra and Lewington [50], but not in Askew [49] and Kalkman et al. [34]. Found only in a small area within our study area in northern Turkey.

Onychogomphus assimilis

Only included with distribution maps in Dijkstra and Lewington [50], but not in Askew [49] and Kalkman et al. [34]. Found only in a small area within our study area in southern Turkey.

Onychogomphus flexuosus

Only included with distribution maps in Dijkstra and Lewington [50], but not in Askew [49] and Kalkman et al. [34]. 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 [49], and so far, found only in a very restricted area in the south-eastern Balkans [34,50].

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 and Lewington [50] 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 and Lewington [50] this is erroneous, and that area has thus been added to the range of this species.

Calopteryx xanthostoma

Records from Sardinia included in Askew [49] are reported by Boudot et al. [71] 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 [49]. Both are now considered good species and their ranges are not known to overlap [50]. Consequently, the range of *C. georgifreyi* per 1988 was removed from the original *C. tenellum* map.

Ceriagrion 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 [49]. Both are now considered good species and their ranges are not known to overlap [50]. 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 [49]. 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 [49,50]. 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 [49], but as *C. intermedium* according to Dijkstra and Lewington [50] 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 [49]. 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 [50], 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 [49] presented *C. helladica* in the same distribution map as *C. picta*, but as their distributions are not known to overlap according to Dijkstra and Lewington [50], the range of *C. helladica* per 1988 was drawn based on the original *C. picta* map.

Cordulegaster picta

Askew [49] presented *C. helladica* in the same distribution map as *C. picta*, but as their distributions are not known to overlap according to Dijkstra and Lewington [50], 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 [49], but as *C. trinacriae* replaces *C. boltonii* in Italy south of Rome [50], 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 [49] are considered erroneous [71] 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 and Lewington [50] 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* [50]. 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 and Lewington [50] 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* [49], but as intermediate individuals occur in large areas this seems unjustified, and they are thus considered to be two subspecies [50]. 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 [49] have been omitted as they are now believed to have been based on a misinterpretation of French literature by Aguesse [78]. The species is considered to be at least partly ship assisted in the west Mediterranean area [50].

Pyrrhosoma nymphula / *Pyrrhosoma elisabethae*

P. elisabethae used to be considered a subspecies of *P. nymphula* [49]. 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 with 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 [50].

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 [49], 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 [79]. 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 and Lewington [50] 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 [49] 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 [49], and within Europe it currently occurs only on the Italian island Pantelleria southwest of Sicily [34,50].

Orthetrum sabina

No distribution map for this species was included in Askew [49] and the text states that it does not penetrate into Europe west of the Caucasus. However, it is included both in Dijkstra and Lewington [50] and Kalkman et al. [34] with a range along the Turkish Mediterranean coast and some Greek islands.

Orthetrum taeniolatum

No distribution map for this species was included in Askew [49] and the text states that its distribution only very nearly extends into Europe. However, it is included both in Dijkstra and Lewington [50] and Kalkman et al. [34] with a range along the Turkish Mediterranean coast and some Greek islands.

Trithemis kirbyi

No distribution map for this species was included in Askew [49] and it does not seem to occur within our study area per 2006 [50]. However, by 2010 it has jumped from North Africa to Sardinia [34].

4) Species with changes in taxonomy og scientific name

Brachythemis impartita

The taxon *B. leucosticta* included in Askew [49] was believed to feature two morphotypes, that are now considered to represent separate species where *B. impartita* is the one found in Europe [50] 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 [49]. They were both formerly in the genus *Lestes*.

Ceriagrion tenellum* / *Ceriagrion georgifreyi

C. georgifreyi used to be considered a subspecies of *C. tenellum* and both were thus included in the same distribution map in 1988 [49].

Sympetrum sinaiticum

Previously incorrectly called *S. decoloratum* and the individuals in Europe treated as the subspecies *S. d. sinaiticum* [49], but according to Dijkstra and Lewington [50] *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 [49], but according to Dijkstra and Lewington [50] *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. Data for the analysis of range shift in European dragonfly (Odonata) species included in analysis ($n = 123$). The list includes taxonomic suborder and scientific names of all species included in the analysis of range shift and changes in species richness 1988–2010. Also presented are the per species biogeographic group, range shift trend, relative change in range (percent change in number of occupied 100×100 km grid cells), distance of shift in northern, southern, eastern, and western range margins, and direction of shift in range centroid and distance of shift in range centroid. See methods for detailed descriptions of the entries on this table. * Indicate the four species that in 2010 were included as new in Europe. Nomenclature and taxonomy follow IUCN [80].

Suborder	Species	Biogeographical group	Range shift trend	Range shift (%)	Range shift north border (km)	Range shift south border (km)	Range shift east border (km)	Range shift west border (km)	Range shift Compass direction (°)	Range shift Compass distance (km)
Zygoptera	<i>Calopteryx haemorrhoidalis</i> Vander Linden, 1825	Mediterranean	Expansion	9	130	0	0	0	69	106
Zygoptera	<i>Calopteryx splendens</i> Harris, 1780	Eurasian	Expansion	8	4	0	0	77	292	14
Zygoptera	<i>Calopteryx virgo</i> Linnaeus, 1758	Eurasian	Expansion	7	-62	23	0	45	270	99
Zygoptera	<i>Calopteryx xanthostoma</i> Charpentier, 1825	Mediterranean	Contraction	-5	-45	-1	50	0	239	41
Zygoptera	<i>Ceriagrion georgifreyi</i> Schmidt, 1953	Mediterranean	Expansion	17	299	3	-4	739	281	152
Zygoptera	<i>Ceriagrion tenellum</i> De Villers, 1789	Mediterranean	Expansion	12	226	0	0	0	10	125
Zygoptera	<i>Chalcolestes viridis</i> Vander Linden, 1825	Mediterranean	Expansion	8	290	0	0	0	31	60
Zygoptera	<i>Coenagrion armatum</i> Charpentier, 1840	Boreo-alpine	Expansion	10	236	-112	-82	-238	326	248
Zygoptera	<i>Coenagrion caerulescens</i> Fonscolombe, 1838	Mediterranean	Expansion	12	21	0	0	0	293	90
Zygoptera	<i>Coenagrion hastulatum</i> Charpentier, 1825	Boreo-alpine	Expansion	0	-9	12	-159	-61	254	73
Zygoptera	<i>Coenagrion hylas</i> Trybom, 1889	Boreo-alpine	Stable	0	0	0	0	0	NA	0
Zygoptera	<i>Coenagrion intermedium</i> Lohmann, 1990	Mediterranean	Stable	0	-1	0	0	0	NA	0
Zygoptera	<i>Coenagrion johanssoni</i> Wallengren, 1894	Boreo-alpine	Expansion	25	0	232	144	-119	133	175
Zygoptera	<i>Coenagrion lunulatum</i> Charpentier, 1840	Boreo-alpine	Contraction	-2	37	85	-140	81	322	258
Zygoptera	<i>Coenagrion mercuriale</i> Charpentier, 1840	Mediterranean	Expansion	6	-46	-14	-414	0	30	167
Zygoptera	<i>Coenagrion ornatum</i> Selys, 1850	Mediterranean	Expansion	90	520	214	0	292	359	156
Zygoptera	<i>Coenagrion puella</i> Linnaeus, 1758	Mediterranean	Expansion	9	97	23	0	0	51	46

Zygoptera	<i>Coenagrion pulchellum</i> Vander Linden, 1825	Eurasian	Expansion	7	122	115	-47	230	198	24
Zygoptera	<i>Coenagrion scitulum</i> Rambur, 1842	Mediterranean	Expansion	123	2	0	0	122	310	203
Zygoptera	<i>Enallagma cyathigerum</i> Charpentier, 1840	Eurasian	Expansion	9	-97	153	0	0	202	128
Zygoptera	<i>Epallage fatime</i> Charpentier, 1840	Mediterranean	Expansion	11	-526	78	0	-152	254	125
Zygoptera	<i>Erythromma lindenii</i> Selys, 1840	Mediterranean	Expansion	28	158	0	70	0	43	218
Zygoptera	<i>Erythromma najas</i> Hansemann, 1823	Eurasian	Expansion	16	2	237	0	31	203	15
Zygoptera	<i>Erythromma viridulum</i> Charpentier, 1840	Mediterranean	Expansion	50	350	73	0	0	78	184
Zygoptera	<i>Ischnura elegans</i> Vander Linden, 1820	Eurasian	Expansion	10	129	0	0	133	253	133
Zygoptera	<i>Ischnura fontaineae</i> * Morton, 1905	Mediterranean	Expansion	100	NA	NA	NA	NA	NA	NA
Zygoptera	<i>Ischnura genei</i> Rambur, 1842	Mediterranean	Stable	0	0	0	0	0	NA	0
Zygoptera	<i>Ischnura graellsii</i> Rambur, 1842	Mediterranean	Expansion	4	0	0	67	0	72	16
Zygoptera	<i>Ischnura pumilio</i> Charpentier, 1825	Mediterranean	Expansion	33	51	0	0	167	318	176
Zygoptera	<i>Lestes barbarus</i> Fabricius, 1798	Mediterranean	Expansion	7	224	0	0	0	349	49
Zygoptera	<i>Lestes dryas</i> Kirby, 1890	Eurasian	Expansion	9	129	57	0	-1	113	95
Zygoptera	<i>Lestes macrostigma</i> Eversmann, 1836	Mediterranean	Contraction	-16	172	22	0	184	36	238
Zygoptera	<i>Lestes sponsa</i> Hansemann, 1823	Eurasian	Expansion	13	118	73	0	32	184	131
Zygoptera	<i>Lestes virens</i> Charpentier, 1825	Eurasian	Expansion	31	503	18	0	0	74	208
Zygoptera	<i>Nehalennia speciosa</i> Charpentier, 1840	Boreo-alpine	Contraction	-2	13	-92	-57	27	329	55
Zygoptera	<i>Platycnemis acutipennis</i> Selys, 1841	Mediterranean	Expansion	6	0	0	94	0	32	28
Zygoptera	<i>Platycnemis latipes</i> Rambur, 1842	Mediterranean	Contraction	-11	-252	0	-14	0	216	67
Zygoptera	<i>Platycnemis pennipes</i> Pallas, 1771	Eurasian	Contraction	-1	81	-94	0	0	341	49
Zygoptera	<i>Pyrrhosoma nymphula</i> Sulzer, 1776	Eurasian	Expansion	6	12	0	0	0	13	43
Zygoptera	<i>Sympecma fusca</i> Vander Linden, 1820	Mediterranean	Contraction	-2	267	0	0	1	224	111
Zygoptera	<i>Sympecma paedisca</i> Brauer, 1877	Boreo-alpine	Expansion	21	474	-55	-136	-48	298	284
Anisoptera	<i>Aeshna affinis</i> Vander Linden, 1820	Mediterranean	Expansion	65	562	73	0	0	23	284
Anisoptera	<i>Aeshna caerulea</i> Ström, 1783	Boreo-alpine	Expansion	8	0	-28	-8	39	172	61
Anisoptera	<i>Aeshna crenata</i> Hagen, 1856	Boreo-alpine	Expansion	117	229	517	7	46	313	54

Anisoptera	<i>Aeshna cyanea</i> Müller, 1764	Eurasian	Contraction	-1	15	0	-70	0	269	76
Anisoptera	<i>Aeshna grandis</i> Linnaeus, 1758	Eurasian	Expansion	12	-63	25	6	60	180	115
Anisoptera	<i>Aeshna isocoetes</i> (Müller, 1767)	Mediterranean	Expansion	33	777	13	0	0	32	329
Anisoptera	<i>Aeshna juncea</i> Linnaeus, 1758	Boreo-alpine	Expansion	7	-37	-68	-226	-59	202	78
Anisoptera	<i>Aeshna mixta</i> Latreille, 1805	Mediterranean	Expansion	21	670	96	0	0	17	118
Anisoptera	<i>Aeshna serrata</i> Hagen, 1856	Eurasian	Expansion	21	119	32	-78	104	307	160
Anisoptera	<i>Aeshna subarctica</i> Walker, 1908	Boreo-alpine	Expansion	23	-72	114	-126	12	280	235
Anisoptera	<i>Aeshna viridis</i> Eversmann, 1836	Eurasian	Expansion	9	42	161	11	75	289	93
Anisoptera	<i>Anax imperator</i> Leach, 1815	Mediterranean	Expansion	16	477	-23	0	0	5	116
Anisoptera	<i>Anax parthenope</i> Selys, 1839	Mediterranean	Expansion	38	806	0	0	170	295	321
Anisoptera	<i>Boyeria cretensis</i> Peters, 1991	Mediterranean	Expansion	100	3	15	176	24	90	72
Anisoptera	<i>Boyeria irene</i> Fonscolombe, 1838	Mediterranean	Expansion	39	151	0	113	0	303	36
Anisoptera	<i>Brachythemis impartita</i> Karsch, 1890	Tropical	Expansion	72	-4	57	-18	54	41	130
Anisoptera	<i>Brachytron pratense</i> Müller, 1764	Eurasian	Expansion	12	32	101	0	129	266	68
Anisoptera	<i>Caliaeschna microstigma</i> Schneider, 1845	Mediterranean	Expansion	20	-62	-19	0	170	326	57
Anisoptera	<i>Cordulegaster bidentata</i> Selys, 1843	Mediterranean	Expansion	87	149	-48	186	57	94	196
Anisoptera	<i>Cordulegaster boltonii</i> Donovan, 1807	Eurasian	Contraction	-8	116	0	-317	0	253	296
Anisoptera	<i>Cordulegaster helladica</i> Lohmann, 1993	Mediterranean	Expansion	140	32	162	145	110	218	72
Anisoptera	<i>Cordulegaster heros</i> Theischinger, 1979	Mediterranean	Expansion	453	82	150	247	104	124	280
Anisoptera	<i>Cordulegaster insignis</i> Schneider, 1845	Mediterranean	Contraction	-18	-459	0	-70	71	201	203
Anisoptera	<i>Cordulegaster picta</i> Selys, 1854	Mediterranean	Expansion	18	-294	119	0	-788	113	223
Anisoptera	<i>Cordulegaster trinacriae</i> Waterston, 1976	Mediterranean	Expansion	5	-8	-47	53	0	105	59
Anisoptera	<i>Cordulia aenea</i> Linnaeus, 1758	Eurasian	Expansion	28	219	105	0	22	185	31
Anisoptera	<i>Crocothemis erythraea</i> Brullé, 1832	Tropical	Expansion	44	326	-23	70	0	31	408
Anisoptera	<i>Diplacodes lefebvrii</i> Rambur, 1842	Tropical	Expansion	45	11	-1	14	37	350	53
Anisoptera	<i>Epitheca bimaculata</i> Charpentier, 1825	Eurasian	Expansion	25	-45	79	-107	196	252	401
Anisoptera	<i>Gomphus flavipes</i> Selys, 1837	Eurasian	Expansion	23	651	-196	0	112	317	248

Anisoptera	<i>Gomphus graslinii</i> Rambur, 1842	Mediterranean	Expansion	182	106	72	11	249	247	452
Anisoptera	<i>Gomphus pulchellus</i> Selys, 1840	Mediterranean	Expansion	20	55	0	-226	0	45	194
Anisoptera	<i>Gomphus schneiderii</i> Selys, 1850	Mediterranean	Expansion	37	0	19	0	-9	283	114
Anisoptera	<i>Gomphus simillimus</i> Selys, 1840	Mediterranean	Expansion	11	-194	0	-74	0	45	99
Anisoptera	<i>Gomphus vulgatissimus</i> Linnaeus, 1758	Eurasian	Expansion	26	105	168	0	20	203	186
Anisoptera	<i>Leucorrhinia albifrons</i> Burmeister, 1839	Boreo-alpine	Contraction	-9	61	264	-310	183	271	497
Anisoptera	<i>Leucorrhinia caudalis</i> Charpentier, 1840	Boreo-alpine	Expansion	21	-72	327	-104	431	293	219
Anisoptera	<i>Leucorrhinia dubia</i> Vander Linden, 1825	Eurasian	Expansion	5	-73	-31	-175	43	243	150
Anisoptera	<i>Leucorrhinia pectoralis</i> Charpentier, 1825	Eurasian	Expansion	65	61	225	-52	263	267	342
Anisoptera	<i>Leucorrhinia rubicunda</i> Linnaeus, 1758	Boreo-alpine	Expansion	7	15	-44	-119	199	259	143
Anisoptera	<i>Libellula depressa</i> Linnaeus, 1758	Eurasian	Expansion	4	-3	57	0	0	351	15
Anisoptera	<i>Libellula fulva</i> Müller, 1764	Eurasian	Expansion	19	153	68	0	178	160	10
Anisoptera	<i>Libellula quadrimaculata</i> Linnaeus, 1758	Eurasian	Expansion	9	-283	9	0	65	63	60
Anisoptera	<i>Lindenia tetraphylla</i> Vander Linden, 1825	Mediterranean	Contraction	-21	30	-98	241	-784	260	223
Anisoptera	<i>Macromia splendens</i> Pictet, 1843	Mediterranean	Expansion	117	64	56	-27	70	252	424
Anisoptera	<i>Onychogomphus costae</i> Selys, 1885	Mediterranean	Expansion	100	192	164	26	-37	228	125
Anisoptera	<i>Onychogomphus forcipatus</i> Linnaeus, 1758	Mediterranean	Expansion	21	172	0	-70	0	289	151
Anisoptera	<i>Onychogomphus uncatatus</i> Charpentier, 1840	Mediterranean	Expansion	16	-104	57	163	0	8	11
Anisoptera	<i>Ophiogomphus cecilia</i> Fourcroy, 1785	Eurasian	Expansion	3	-62	230	-227	125	261	181
Anisoptera	<i>Orthetrum albistylum</i> Selys, 1848	Mediterranean	Expansion	37	404	0	0	77	317	147
Anisoptera	<i>Orthetrum brunneum</i> Fonscolombe, 1837	Mediterranean	Expansion	19	349	0	0	0	19	172
Anisoptera	<i>Orthetrum cancellatum</i> Linnaeus, 1758	Mediterranean	Expansion	10	-31	0	0	190	277	128
Anisoptera	<i>Orthetrum chrysostigma</i> Burmeister, 1839	Tropical	Expansion	131	351	0	-3	198	289	459
Anisoptera	<i>Orthetrum coerulescens</i> Fabricius, 1798	Mediterranean	Expansion	9	139	0	-70	0	329	212
Anisoptera	<i>Orthetrum nitidinerve</i> Selys, 1841	Mediterranean	Expansion	139	202	0	4	147	278	931
Anisoptera	<i>Orthetrum sabina</i> * Drury, 1773	Tropical	Expansion	100	NA	NA	NA	NA	NA	NA
Anisoptera	<i>Orthetrum taeniolatum</i> * Schneider, 1845	Tropical	Expansion	100	NA	NA	NA	NA	NA	NA

Anisoptera	<i>Orthetrum trinacria</i> Selys, 1841	Tropical	Expansion	257	127	151	11	160	270	839
Anisoptera	<i>Oxygastra curtisii</i> Dale, 1834	Mediterranean	Contraction	-4	-372	40	138	57	68	130
Anisoptera	<i>Pantala flavescens</i> Fabricius, 1798	Tropical	Expansion	600	498	206	-43	995	297	370
Anisoptera	<i>Paragomphus genei</i> Selys, 1841	Tropical	Expansion	33	27	0	43	37	276	1081
Anisoptera	<i>Selysiotthemis nigra</i> Vander Linden, 1825	Mediterranean	Expansion	216	626	23	267	314	295	327
Anisoptera	<i>Somatochlora alpestris</i> Selys, 1840	Boreo-alpine	Expansion	18	-9	-7	66	-20	356	105
Anisoptera	<i>Somatochlora arctica</i> Zetterstedt, 1840	Boreo-alpine	Expansion	41	31	-8	29	60	195	213
Anisoptera	<i>Somatochlora flavomaculata</i> Vander Linden, 1825	Eurasian	Expansion	46	432	162	0	127	225	190
Anisoptera	<i>Somatochlora meridionalis</i> Nielsen, 1935	Mediterranean	Expansion	92	393	121	80	156	330	184
Anisoptera	<i>Somatochlora metallica</i> Vander Linden, 1825	Eurasian	Contraction	1	-84	133	0	0	183	14
Anisoptera	<i>Somatochlora sahlbergi</i> Trybom, 1889	Boreo-alpine	Expansion	22	12	70	44	177	295	89
Anisoptera	<i>Sympetrum danae</i> Sulzer, 1776	Eurasian	Expansion	5	53	2	26	0	233	145
Anisoptera	<i>Sympetrum depressiusculum</i> Selys, 1841	Eurasian	Expansion	120	782	187	0	551	285	269
Anisoptera	<i>Sympetrum flaveolum</i> Linnaeus, 1758	Eurasian	Expansion	6	129	8	0	11	332	138
Anisoptera	<i>Sympetrum fonscolombii</i> Selys, 1840	Tropical	Expansion	33	46	-1	0	0	0	278
Anisoptera	<i>Sympetrum meridionale</i> Selys, 1841	Mediterranean	Expansion	46	211	0	0	0	338	315
Anisoptera	<i>Sympetrum pedemontanum</i> O.F.Müller, 1766	Eurasian	Expansion	85	533	-152	-112	-435	312	267
Anisoptera	<i>Sympetrum sanguineum</i> Müller, 1764	Eurasian	Expansion	10	44	-29	0	102	261	107
Anisoptera	<i>Sympetrum sinaiticum</i> Dumont, 1977	Mediterranean	Expansion	475	70	446	92	670	239	344
Anisoptera	<i>Sympetrum striolatum</i> Charpentier, 1840	Eurasian	Expansion	3	39	-23	0	0	8	32
Anisoptera	<i>Sympetrum vulgatum</i> Linnaeus, 1758	Eurasian	Expansion	15	95	60	0	475	271	174
Anisoptera	<i>Trithemis annulate</i> Palisot de Beauvois, 1807	Tropical	Expansion	145	378	96	42	0	7	179
Anisoptera	<i>Trithemis festiva</i> Rambur, 1842	Tropical	Expansion	133	192	0	101	0	22	121
Anisoptera	<i>Trithemis kirbyi</i> * Selys, 1891	Tropical	Expansion	100	NA	NA	NA	NA	NA	NA
Anisoptera	<i>Zygonyx torridus</i> Kirby, 1889	Tropical	Expansion	217	64	38	2551	262	72	178

Table S3. Summary statistics of range shifts in taxonomic suborders for European dragonfly (Odonata) species. Measures of range shift for species from 1988 to 2010. Damselflies (Zygoptera) and true dragonflies (Anisoptera) used as unmatched groups in a Mann–Whitney–Wilcoxon test. SD = standard deviation, n = sample size, df = degrees of freedom, W = Wilcoxon test statistic, and p -value = statistical test score. Bold font indicates significant variables at $\alpha = 0.05$.

	Zygoptera	Anisoptera	n	df	W	p -value
	Mean \pm 1 SD	Mean \pm 1 SD				
Shift in range (%)	16 \pm 28	65 \pm 105	123	1	2453	< 0.0000
Shift in range: margin north (km)	91 \pm 193	131 \pm 252	119	1	1666	0.6305
Shift in range: margin south (km)	26 \pm 76	56 \pm 113	119	1	1784	0.2473
Shift in range: margin east (km)	-16 \pm 85	30 \pm 306	119	1	1772	0.2604
Shift in range: margin west (km)	38 \pm 146	77 \pm 225	119	1	2033	0.0092
Shift in range centroid: distance (km)	110 \pm 80	210 \pm 189	116	1	2179	0.0008
Shift in range centroid: direction (°)	192 \pm 117	207 \pm 110	116	1	1530	0.6871

Table S4. Summary statistics of range shifts in biogeographical groups for European dragonfly (Odonata) species. Measures of range shift in species from 1988 to 2010 for all species (All), damselfly (Zygoptera) species and true dragonfly (Anisoptera) species, respectively. Biogeographic groups: Tropical, Mediterranean, Eurasian, and Boreo-alpine used as unmatched groups in a Kruskal–Wallis test. SD = standard deviation, n = sample size, df = degrees of freedom, H = Kruskal–Wallis test statistic, and p -value = statistical test score Bold font indicates significant variables at $\alpha = 0.05$.

	Species	Tropical	Mediterranean	Eurasian	Boreo-alpine	n	df	H	p -value
		Mean \pm 1 SD							
Shift in range (%)	All	144 \pm 147	54 \pm 95	18 \pm 25	18 \pm 29	123	3	27.34	< 0.0000
	Zygoptera	NA	21 \pm 36	11 \pm 8	8 \pm 12	41	2	0.79	0.6736
	Anisoptera	144 \pm 147	77 \pm 115	22 \pm 29	26 \pm 35	82	3	24.16	< 0.0000
Shift in range: margin north (km)	All	183 \pm 176	130 \pm 274	110 \pm 218	53 \pm 138	119	3	5.27	0.1533
	Zygoptera	NA	88 \pm 218	86 \pm 160	107 \pm 183	40	2	0.14	0.9347
	Anisoptera	183 \pm 176	158 \pm 306	120 \pm 241	16 \pm 86	79	3	5.80	0.1218
Shift in range: margin south (km)	All	48 \pm 74	33 \pm 80	55 \pm 99	71 \pm 171	119	3	3.73	0.2918
	Zygoptera	NA	18 \pm 49	53 \pm 90	10 \pm 119	40	2	3.23	0.199
	Anisoptera	48 \pm 74	42 \pm 95	55 \pm 105	114 \pm 194	79	3	1.25	0.741
Shift in range: margin east (km)	All	252 \pm 764	23 \pm 105	-32 \pm 73	-69 \pm 114	119	3	15.76	0.0013
	Zygoptera	NA	-7 \pm 95	-4 \pm 14	-62 \pm 106	40	2	6.76	0.0340
	Anisoptera	252 \pm 764	43 \pm 107	-44 \pm 85	-75 \pm 124	79	3	12.31	0.0064
Shift in range: margin west (km)	All	158 \pm 292	43 \pm 222	77 \pm 153	42 \pm 149	119	3	4.19	0.242
	Zygoptera	NA	61 \pm 176	50 \pm 73	-51 \pm 105	40	2	4.71	0.0947
	Anisoptera	158 \pm 292	31 \pm 250	89 \pm 178	107 \pm 144	79	3	2.37	0.4994
Shift in range centroid: distance (km)	All	373 \pm 322	171 \pm 148	131 \pm 99	164 \pm 122	119	3	8.83	0.0316
	Zygoptera	NA	107 \pm 73	85 \pm 62	156 \pm 113	40	2	2.29	0.3185
	Anisoptera	373 \pm 322	214 \pm 170	151 \pm 107	169 \pm 134	79	3	6.66	0.0836
Shift in range centroid: direction (°)	All	150 \pm 142	177 \pm 122	226 \pm 86	269 \pm 63	116	3	8.60	0.0351
	Zygoptera	NA	165 \pm 128	195 \pm 97	277 \pm 76	37	2	4.63	0.0987
	Anisoptera	150 \pm 142	185 \pm 119	239 \pm 79	264 \pm 58	79	3	4.56	0.2071

Table S5. Summary statistics of range margin shifts for European dragonfly (Odonata) species. Measures of range shift at the range margins in species from 1988 to 2010. Northern margin and the southern, eastern, and western margins combined (=other margins) used as unmatched groups in a Mann–Whitney–Wilcoxon test of all species (All), damselfly (Zygoptera) species and true dragonfly (Anisoptera) species, respectively, and for species in the biogeographical groups: Tropical, Mediterranean, Eurasian, and Boreo-alpine, respectively. SD = standard deviation, *n* = sample size, df = degrees of freedom, *W* = Wilcoxon test statistic, and *p*-value = statistical test score. Bold font indicates significant variables at $\alpha = 0.05$.

	North margin	Other margins	<i>n</i>	df	<i>W</i>	<i>p</i> -value
	Mean ± 1 SD (km)	Mean ± 1 SD (km)				
All	118 ± 234	41 ± 197	119	1	26533	< 0.0000
Zygoptera	91 ± 193	16 ± 109	40	1	3229	0.0007
Anisoptera	131 ± 252	54 ± 229	79	1	11306	0.0055
Tropical	183 ± 176	153 ± 467	11	1	256	0.0457
Mediterranean	130 ± 274	33 ± 148	55	1	5841	0.0010
Eurasian	110 ± 218	33 ± 122	36	1	2377	0.0438
Boreo-alpine	53 ± 138	14 ± 156	17	1	508	0.2977