Ecography

ECOG-02578

Pinkert, S., Brandl, R. and Zeuss, D. 2016. Colour lightness of dragonfly assemblages across North America and Europe. – Ecography doi: 10.1111/ecog.02578

Supplementary material

Appendix 1

Figures A1–A12, Table A1 and A2

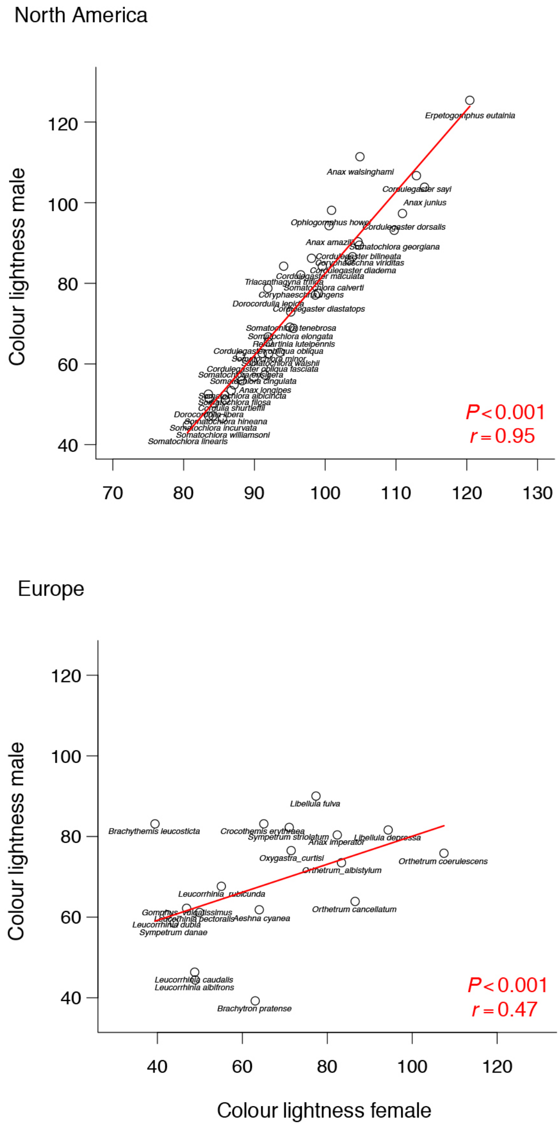


Figure A1. Scatterplots between female and male colour lightness of 44 North American (Needham et al. 2000) and 19 European (Askew 1988) dragonfly species. Note that colour lightness of females and males is highly correlated.

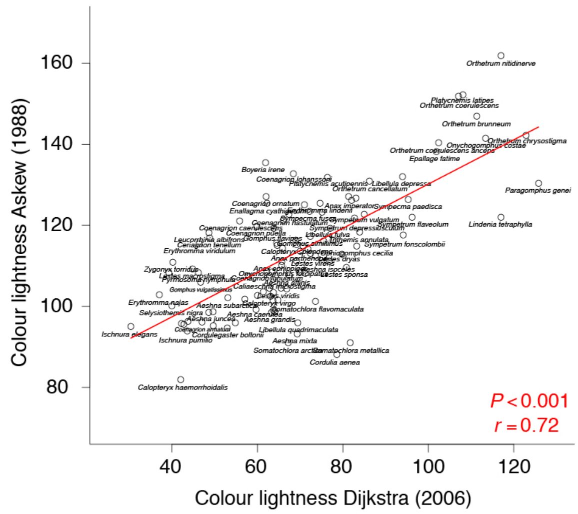


Figure A2. Correlation of the average colour lightness of European dragonfly species illustrated in both Askew (1988) and Dijkstra and Lewington (2006). Average colour lightness ranges from 0 (absolute black) to 255 (pure white). Note that the extracted colour values of dorsal dragonfly drawings from both sources are highly correlated.

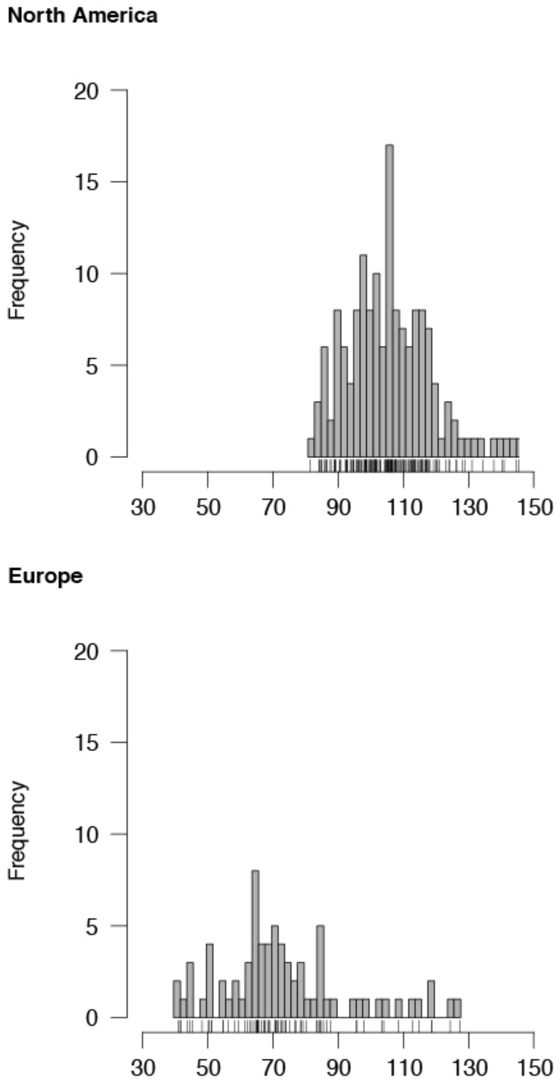


Figure A3. Frequency distribution of the average colour lightness of 152 North American and 74 European dragonfly species. Average colour lightness ranges from 0 (absolute black) to 255 (pure white). Rugs at the abscissa indicate the value of each species. Note that colour values are from different sources (North America: Needham et al. 2000, Europe: Askew 1988), and hence absolute values are not directly comparable.

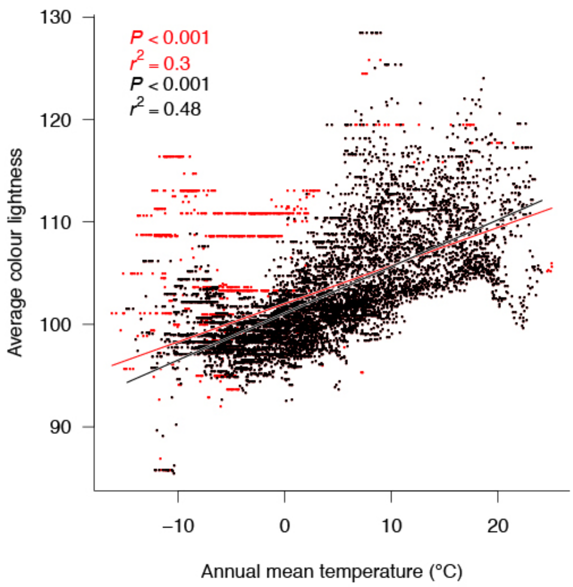


Figure A4. Scatterplots of single ordinary least-squares regressions between average colour lightness of 8,127 North American dragonfly assemblages and mean temperature of the warmest quarter. Red dots represent assemblages that were excluded from the analysis because they contained less than five species. Note that those assemblages that were excluded scatter more than those with more than five species (c.f. the coefficients of determination) due to the inherent effect of very low sampling sizes.

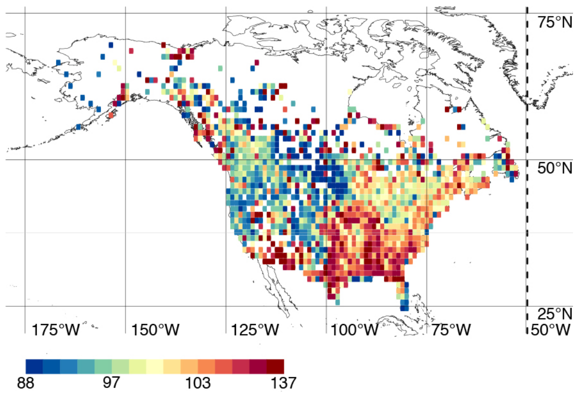


Figure A5. Map of the spatial variation in average colour lightness of North American dragonfly assemblages. Colour lightness ranges from 0 (absolute black) to 255 (pure white). Colour scale intervals follow an equal-frequency classification, ranging from blue (darkest) to red (lightest). The dataset represents occurrence records provided by OdonataCentral.org (Abbott 2006), which were resampled to 1,373 one-degree grid cells (EPSG: 4326).

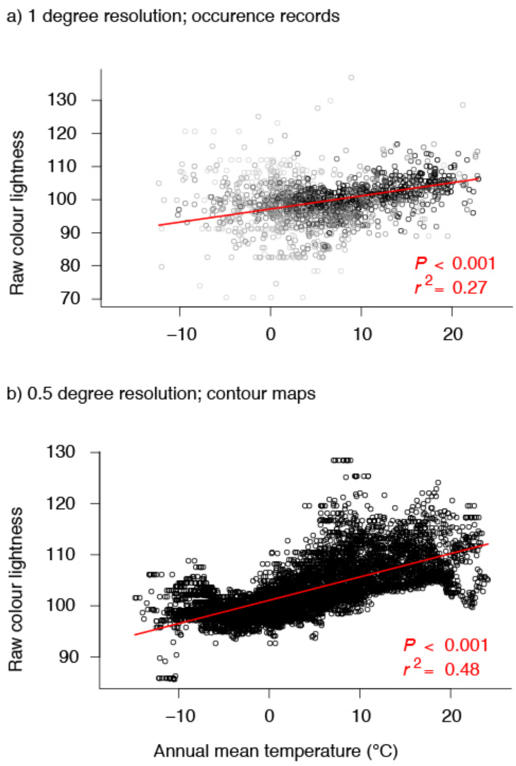
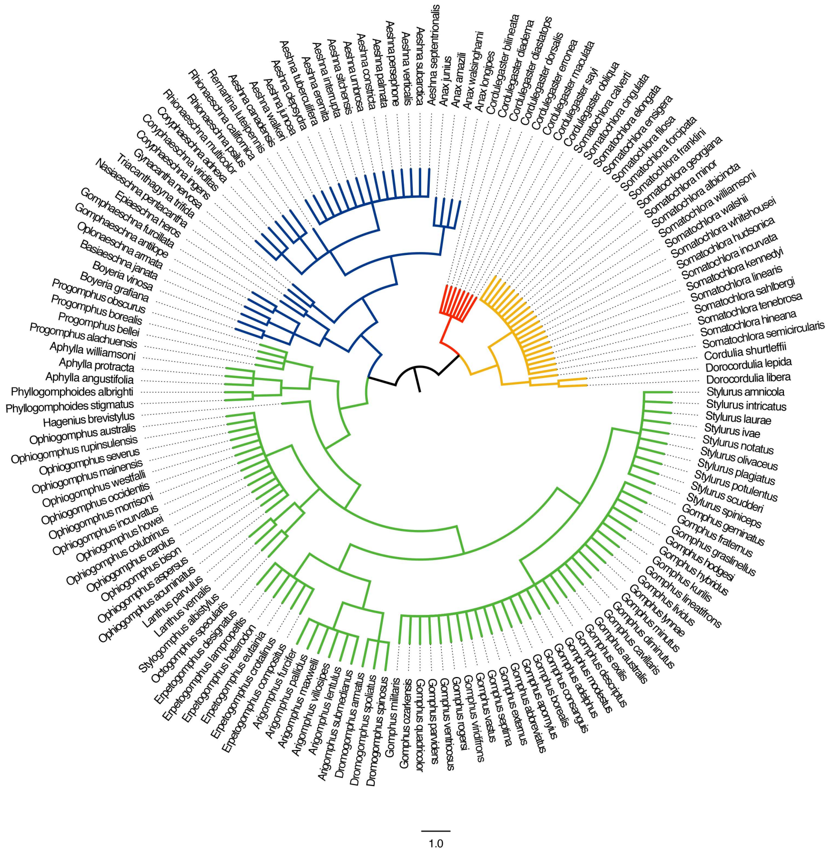
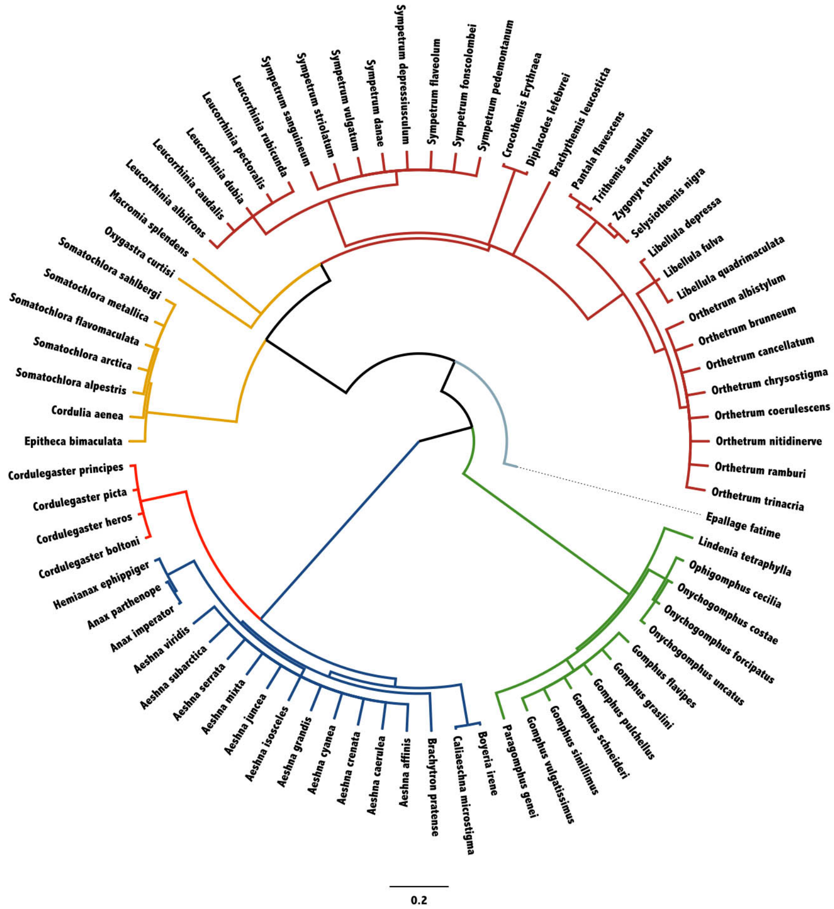


Figure A6. Scatterplots showing the correlation of the spatial variation in average colour lightness. **a)** Average colour lightness was based on occurrence records that were resampled to one-degree resolution (weighted by sampling density, i.e. the number of records). **b)** Average colour lightness was based on contour maps of distribution ranges that were resampled to half-degree grid cells against the main predictor annual mean temperature (see main text). Colour lightness ranges from 0 (absolute black) to 255 (pure white). Dot colours follow an equal-frequency classification, ranging from light grey (low sampling density) to black (high sampling density). Note that data from both occurrence records and contour maps basically support the thermal melanism hypothesis, but they also indicate that the correlation between average colour lightness and temperature is less strong and the slope is less steep for dragonflies in North American than for dragonflies in Europe.



((((((((Stylurus amnicola,Stylurus intricatus,Stylurus laurae,Stylurus ivae,Stylurus notatus,Stylurus olivaceus,Stylurus plagiatus,Stylurus potulentus,Stylurus scudderi,Stylurus spiniceps),(Gomphus geminatus,Gomphus fraternus,Gomphus graslinellus,Gomphus hodgesi,Gomphus hybridus,Gomphus kurilis,Gomphus lineatifrons,Gomphus lividus,Gomphus lynnae,Gomphus minutus,Gomphus diminutus, Gomphus cavillaris,Gomphus australis,Gomphus exilis,Gomphus descriptus,Gomphus modestus,Gomphus adelphus,Gomphus consanguis,Gomphus borealis,Gomphus apomyius,Gomphus abbreviatus,Gomphus externus,Gomphus septima,Gomphus vastus,Gomphus viridifrons,Gomphus rogersi,Gomphus ventricosus,Gomphus parvidens,Gomphus quadricolor,Gomphus ozarkensis,Gomphus militaris)),(((Dromogomphus spinosus,Dromogomphus spoliatus,Dromogomphus armatus),(Arigomphus submedianus,Arigomphus lentulus,Arigomphus villosipes,Arigomphus maxwelli,Arigomphus pallidus,Arigomphus furcifer)),(Erpetogomphus compositus,Erpetogomphus crotalinus,Erpetogomphus eutainia,Erpetogomphus heterodon,Erpetogomphus lampropeltis,Erpetogomphus designatus))),((Octogomphus specularis,Stylogomphus albistylus),(Lanthus vernalis,Lanthus parvulus)),(Ophiogomphus acuminatus,Ophiogomphus aspersus,Ophiogomphus bison,Ophiogomphus carolus,Ophiogomphus colubrinus,Ophiogomphus howei,Ophiogomphus incurvatus,Ophiogomphus morrisoni,Ophiogomphus occidentis,Ophiogomphus westfalli,Ophiogomphus mainensis,Ophiogomphus severus,Ophiogomphus rupinsulensis,Ophiogomphus australis)),Hagenius brevistylus),(((Phyllogomphoides

stigmatus,Phyllogomphoides albrighti),(Aphylla angustifolia,Aphylla protracta,Aphylla williamsoni)),(Progomphus alachuensis,Progomphus bellei,Progomphus borealis,Progomphus obscurus))),((((Boyeria grafiana,Boyeria vinosa),(Basiaeschna janata,Oplonaeschna armata),(Gomphaeschna antilope,Gomphaeschna furcillata)),(Epiaeschna heros,Nasiaeschna pentacantha)),((Triacanthagyna trifida,Gynacantha nervosa),(((Coryphaeschna ingens,Coryphaeschna viriditas,Coryphaeschna adnexa),(Rhionaeschna multicolor,Rhionaeschna psilus,Rhionaeschna californica),Remartinia luteipennis,(Aeshna canadensis,Aeshna walkeri,Aeshna juncea,Aeshna clepsydra,Aeshna tuberculifera,Aeshna eremita,Aeshna interrupta,Aeshna sitchensis,Aeshna umbrosa,Aeshna constricta,Aeshna palmata,Aeshna persephone,Aeshna verticalis,Aeshna subarctica,Aeshna septentrionalis)),(Anax junius,Anax amazili,Anax walsinghami,Anax longipes))))),((Cordulegaster bilineata,Cordulegaster diadema,Cordulegaster diastatops,Cordulegaster dorsalis,Cordulegaster erronea,Cordulegaster maculata,Cordulegaster sayi,Cordulegaster obliqua),((Somatochlora calverti,Somatochlora cingulata,Somatochlora elongata,Somatochlora ensigera,Somatochlora filosa,Somatochlora forcipata,Somatochlora franklini,Somatochlora georgiana,Somatochlora minor,Somatochlora albicincta,Somatochlora williamsoni,Somatochlora walshii,Somatochlora whitehousei,Somatochlora hudsonica,Somatochlora incurvata,Somatochlora kennedyi,Somatochlora linearis,Somatochlora sahlbergi,Somatochlora tenebrosa,Somatochlora hineana,Somatochlora semicircularis),(Cordulia shurtleffii,(Dorocordulia lepida,Dorocordulia libera)))));



(((((Epitheca bimaculata, (Cordulia aenea, (Somatochlora alpestris, Somatochlora arctica, Somatochlora flavomaculata, Somatochlora metallica, Somatochlora sahlbergi))), (Oxygastra curtisi, Macromia splendens, (((Leucorrhinia albifrons, Leucorrhinia caudalis, Leucorrhinia dubia, Leucorrhinia pectoralis, Leucorrhinia rubicunda), (Sympetrum sanguineum, Sympetrum striolatum, Sympetrum vulgatum, Sympetrum danae, Sympetrum depressiusculum, Sympetrum flaveolum, Sympetrum fonscolombei, Sympetrum pedemontanum)), (Crocothemis erythraea, Diplacodes lefebvrei), Brachythemis leucosticta, (((Pantala flavescens, Trithemis annulata), (Zygonyx torridus, Selysiothemis nigra)), ((Libellula depressa, Libellula fulva, Libellula quadrimaculata), (Orthetrum albistylum, Orthetrum brunneum, Orthetrum cancellatum, Orthetrum chrysostigma, Orthetrum coerulescens, Orthetrum nitidinerve, Orthetrum ramburi, Orthetrum trinacria)))))), Epallage fatime), (Lindenia tetraphylla, ((Ophigomphus cecilia, (Onychogomphus costae, Onychogomphus forcipatus, Onychogomphus uncatus)), (Gomphus flavipes, Gomphus graslini, Gomphus pulchellus, Gomphus schneideri, Gomphus simillimus, Gomphus vulgatissimus), Paragomphus genei))), (((Boyeria irene, Caliaeschna microstigma), (Brachytron pratense, ((Aeshna affinis, Aeshna caerulea, Aeshna crenata, Aeshna cyanea, Aeshna grandis, Aeshna isosceles, Aeshna juncea, Aeshna mixta, Aeshna serrata, Aeshna subarctica, Aeshna viridis), ((Anax imperator, Anax parthenope), Hemianax ephippiger)))), (Cordulegaster boltoni, Cordulegaster heros, Cordulegaster picta, Cordulegaster principes)));

Figure A7. Phylogenetic hypotheses for the 152 North American and 74 European dragonfly species, compiled from different sources (see Methods). Branch colours on the tree represent the families: Aeshnidae (dark blue), Cordulegastridae (bright red), Corduliidae (ochre), Gomphidae (green), Libellulidae (dark red) and Euphaeidae (bright blue). Note that both continents share six families, but colour data for North American dragonflies was only available for four of them (Aeshnidae, Cordulegastridae, Corduliidae, Gomphidae).

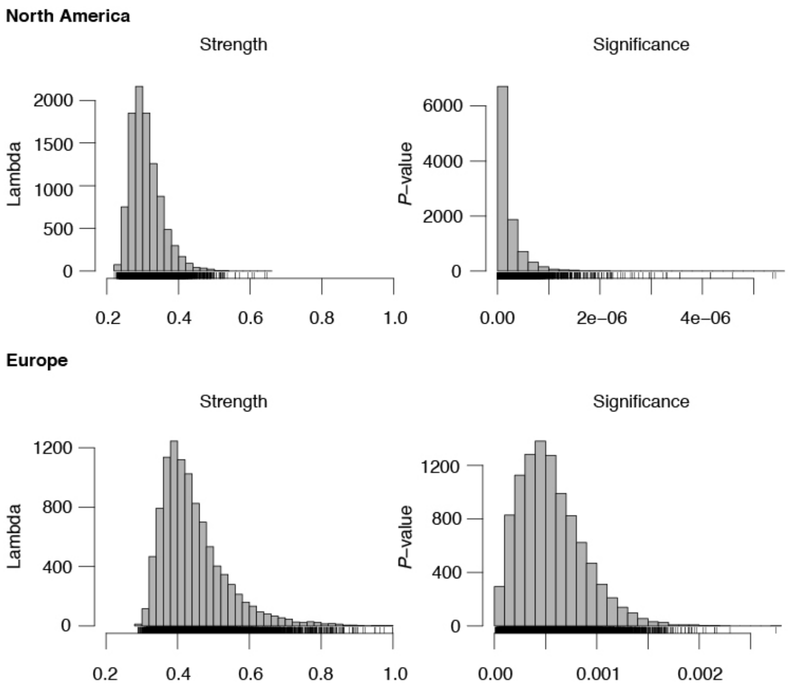


Figure A8. Frequency plots of strength and significance of the phylogenetic signal in colour lightness of 152 North American and 74 European dragonfly species. Pagel's lambda was repeatedly calculated for 10,000 randomly resolved phylogenetic trees (see Methods). Note that all of the alternative trees had a significant phylogenetic signal (*P* < 0.05).

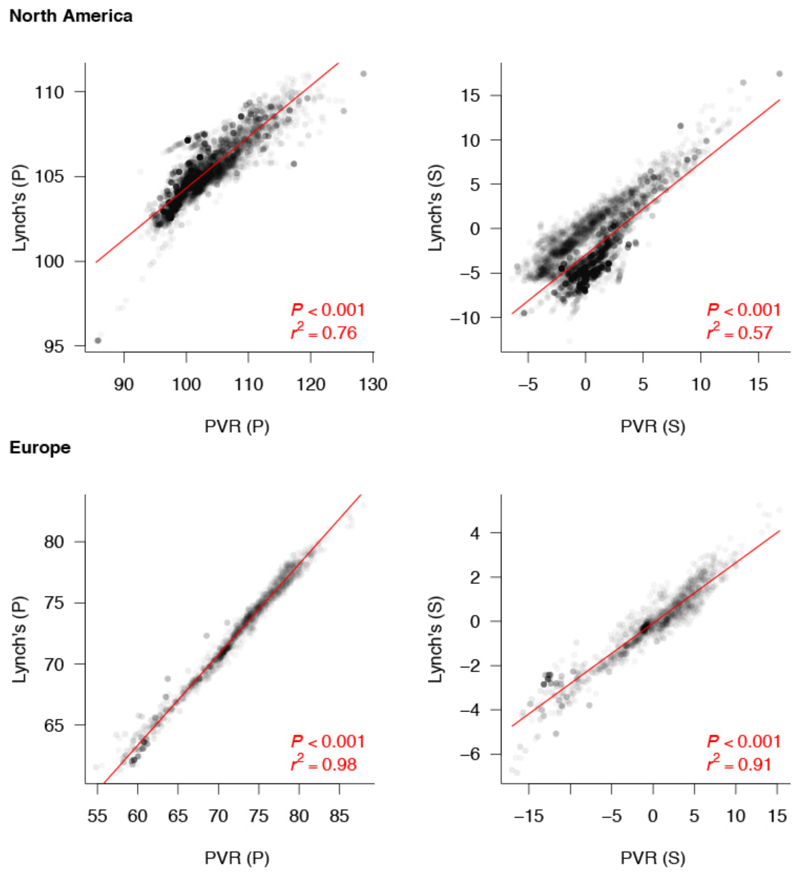


Figure A9. Correlations between phylogenetic components (P) and between specific components (S) of the colour lightness of 8,127 North American and 1,839 European dragonfly assemblages obtained from Lynch's comparative method (Lynch's) and phylogenetic eigenvector regression (PVR). Partly transparent dots indicate data density. Both methods were used to partition the phylogenetically predicted part of colour lightness (P) of dragonfly species based on 10,000 randomly resolved phylogenetic trees (see Methods) and the species-specific deviation from this prediction (S). However, because the results of the two approaches were highly similar only the spatial variation of the P and S components obtained from Lynch's comparative method was discussed in the main text.

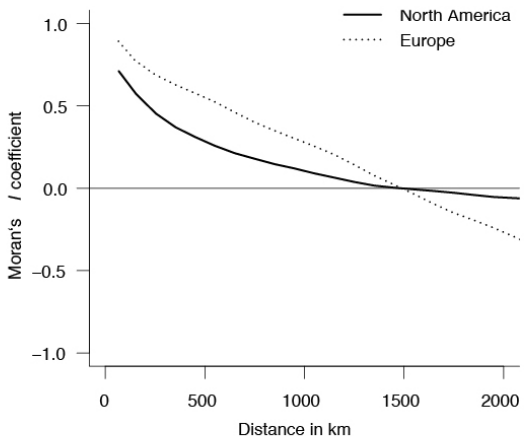


Figure A10. Spatial autocorrelation (Moran's *I* correlation coefficient) of the residuals from the model of average colour lightness of 8,127 North American and 1,839 European dragonfly assemblages and six environmental variables (mean annual temperature, temperature seasonality, mean temperature of the warmest quarter, mean altitude, mean annual precipitation and mean precipitation of the warmest quarter). Note the spatial autocorrelation up to about a distance of 1,400 km in North America and 1,500 km in Europe.

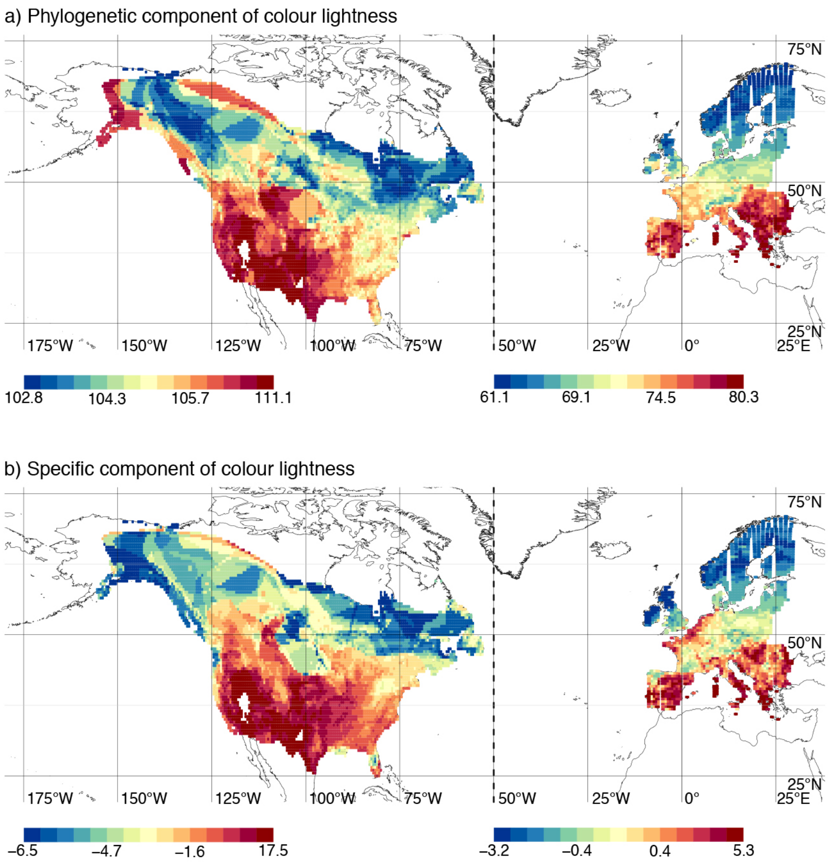


Figure A11. Maps of the spatial variation of the average phylogenetic (P) and specific (S) components of the colour lightness of North American and European dragonfly assemblages. Raw colour lightness, ranges from 0 (absolute black) to 255 (pure white), and was divided into two components with Lynch's comparative method to differentiate the influence of phylogenetic autocorrelation in the data (see Methods). We randomly resolved multifurcations of the original tree 10,000 times, calculated P and S components for each alternative phylogenetic tree and averaged these values for each species. **a)** P component, i.e. the proportion of colour lightness explained by the species' ancestral relations. **b)** S component, i.e. the deviation from the ancestral predicted colour lightness. Colour scale intervals follow an equal-frequency classification, ranging from blue (darkest) to red (lightest). Because of different data sources for North America and Europe, only the classes but not the values can be directly compared. Note that the colour lightness decreases in both continents towards northern and increases towards warmer regions. The datasets comprise 8,127 half-degree grid cells in North America and 1,839 approximately half-degree grid cells in Europe (EPSG: 4326 and EPSG: 3537; rectangular latitude and longitude grid).

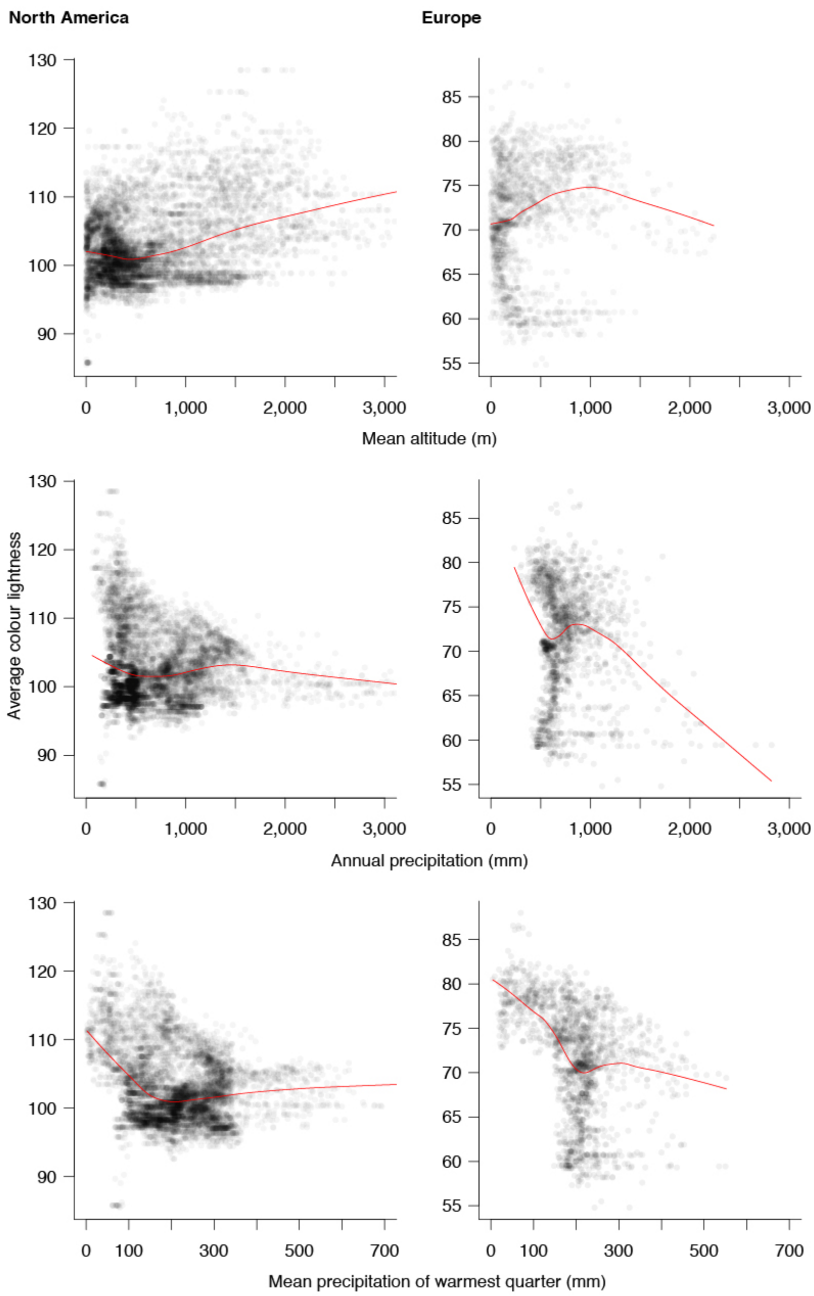


Figure A12. Scatterplots of single ordinary least-squares regressions between average colour lightness of 8,127 North American and 1,839 European dragonfly assemblages and three environmental variables (mean altitude, annual precipitation, mean precipitation of warmest quarter). Partly transparent dots indicate data density. Red lines were fitted with spline-based smoothed regressions. Note that correlation trends between average colour lightness and the environmental variables in the two continents are similar.

Table A1. Total sums of squares loadings, proportion of explained variance and cumulative explained variance of three principal components that characterise major trends of a set of six biologically relevant environmental variables for each continent based on a correlation matrix (highest contributions are in bold).

	Continent					
	Europe			North America		
Variable	PC 1	PC 2	PC 3	PC 1	PC 2	PC 3
Annual mean temperature	0.90	0.36	–0.10	0.96	0.24	–0.09
Temperature seasonality	–0.31	–0.82	–0.04	–0.62	–0.51	0.53
Mean temperature of warmest quarter	**0.92**	0.01	–0.13	**0.97**	0.00	0.19
Mean altitude	–0.14	0.12	**0.98**	–0.08	–0.30	**–0.89**
Annual mean precipitation	–0.42	**0.85**	0.19	0.17	**0.95**	0.04
Precipitation of warmest quarter	–0.83	0.29	0.09	0.08	0.83	0.35
SS loadings	2.65	1.63	1.04	2.30	2.01	1.26
Proportion of variance	0.44	0.27	0.17	0.38	0.33	0.21
Cumulative variance	0.44	0.71	0.89	0.38	0.72	0.93

Table A2. Individual slopes from a multiple regression model between colour lightness of 8,127 North American and 1,839 European dragonfly assemblages and three environmental variables. Models were controlled for spatial autocorrelation using trend surface generalized additive models, i.e. a smoothing term for longitude and latitudes (effective degrees of freedom = 29). Differences in slopes between the two continents that were significant at $P < 0.001$ are shaded grey. Variables: TWaQ, mean temperature of the warmest quarter; A, mean altitude; and AP, mean annual precipitation. Note that the individual slopes of the correlations between colour lightness and environmental variables are significantly steeper in Europe than in North America, with mean temperature of the warmest quarter having the steepest slopes in each continent. All results, except for the relationship of colour lightness of North American dragonflies and AP that was corrected for spatial autocorrelation, were significant at $P < 0.001$.

Model	Variable	Individual slopes ± SE		Intercept ± SE
		North America	Europe	
None	TWaQ	$7.3 \times 10^{-1} \pm 6.0 \times 10^{-3}$	$1.5 \times 10^{0} \pm 1.9 \times 10^{-2}$	$8.8 \times 10^{1} \pm 1.3 \times 10^{-1}$
	A	$4.4 \times 10^{-3} \pm 6.1 \times 10^{-5}$	$5.2 \times 10^{-3} \pm 2.0 \times 10^{-4}$	
	AP	$-6.1 \times 10^{-4} \pm 7.8 \times 10^{-5}$	$-1.9 \times 10^{-3} \pm 2.8 \times 10^{-4}$	
Corrected	TWaQ	$5.6 \times 10^{-1} \pm 2.3 \times 10^{-2}$	$-1.7 \times 10^{-1} \pm 4.2 \times 10^{-2}$	$8.9 \times 10^{1} \pm 4.3 \times 10^{-1}$
	A	$2.1 \times 10^{-3} \pm 1.4 \times 10^{-4}$	$-2.7 \times 10^{-3} \pm 2.8 \times 10^{-4}$	
	AP	$-3.4 \times 10^{-5} \pm 1.1 \times 10^{-4}$	$-2.0 \times 10^{-3} \pm 2.5 \times 10^{-4}$	

Supplementary references

Abbott, J. C. 2006. OdonataCentral: An online resource for the distribution and identification of Odonata. - Digital resource at <http://www.odonatacentral.org>, accessed 28 Nov 2012.

Askew, R. R. 1988. The Dragonflies of Europe. - 2nd ed., Harley Books, Colchester, UK.

Dijkstra, K.-D. B. and Lewington, R. 2006. Field Guide to the Dragonflies of Britain and Europe. British Wildlife Publishing, Gillingham, UK.

Needham, J. G. et al. 2000. Dragonflies of North America. - 2nd ed., Scientific Publishers, Gainesville, Florida, USA.