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Supplementary information

Latitudinal gradients in avian colourfulness

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Supplementary Information:

Latitudinal gradients in avian colourfulness

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Study	Taxa	Geographic extent	Colour data	Conclusions	Notes
Adams et al. (2014) [6]	Butterflies (*n* = 247)	New World (Ecuador, Florida, Maine)	Digital photographs of museum specimens (VIS only)	Gradient present – Ecuadorian species more variable in colour intensity, saturation, and hue than species of other regions	Incomplete colour measurements (no UV), limited geographical extent.
Bailey (1978) [7]	Passerine birds (*n* = 784)	North and Central America (Alaska/Canada to Panama)	Human scores of field guide illustrations	No gradient present – Some significant differences between regions but overall weak support for enhanced tropical colorfulness	Qualitative, subjective scores of colourfulness, limited geographic extent
Dale *et al.* (2015) [11]	Passerine birds (*n* = 2,471)	Global	'Maleness' scores based on RGB data for front-facing body regions measured from handbook illustrations	Gradient present – Species with tropical life histories have more elaborate plumages (higher 'maleness' scores)	Incomplete colour measurements (no UV), colour elaboration rather than colourfulness *per se*, composite predictor variable (latitude + clutch size + environmental stability)
Dalrymple *et al.* (2015, 2018) [9, 5]	Birds (*n* = 570), butterflies (*n* = 424), flowers (*n* = 339)	Eastern Australia	Reflectance spectrometry (300-700 nm; birds, flowers) and UV/VIS digital photography (butterflies)	No gradient present – High rather than low latitude regions tend to contain the most colourful species	Limited geographical extent
Dunn et al. (2015) [12]	Birds (*n* = 977)	Global	Reflectance spectrometry (320-700 nm)	Equivocal – In monomorphic species (*n* = 489), subtropical taxa were brighter but tropical taxa were duller than non-tropical taxa	Colour quantified in terms of brightness and hue; colourfulness *per se* not measured
Friedman & Remeš (2017) [10]	Australian passerines (Meliphagidae, *n* = 97; Acanthizidae, *n* = 40)	Australia, New Guinea	Reflectance spectrometry (300-700 nm)	No gradient present – birds living close to the equator were not more colourful	Limited taxonomic and geographic extent
Wilson & Von Neaumann (1972) [8]	Birds (*n* = 1,678)	N and S America, Europe	Binary categorisation of species as 'colourful' or 'not so' based on pictures and written descriptions	Gradient present – Birds of the South American lowland tropics were more frequently colourful than those of South American extra-tropics, North America and Europe	Qualitative, subjective classification of colourfulness based on photos and/or written descriptions, somewhat geographically limited

Supplementary Table 1. Summaries of studies addressing latitudinal gradients in organismal colourfulness. Numbers in square brackets in the 'Study' column indicate the corresponding reference number in the main text.

		Mean colourfulness				SES colourfulness			
Variable	**Sex**	**Slope**	***P***	***I***	***P***	**Slope**	***P***	***I***	***P***
Volume (UVS)	M	-0.462	0	0.047	0.029	-0.231	3.18×10^{-14}	0.032	0.100
	F	-0.472	0	0.061	0.008	-0.226	6.51×10^{-14}	0.050	0.025
Loci (UVS)	M	-0.461	0	0.059	0.010	-0.220	7.51×10^{-14}	0.046	0.035
	F	-0.490	0	0.063	0.007	-0.211	4.02×10^{-14}	0.058	0.012
Volume (VS)	M	-0.438	0	0.043	0.041	-0.217	1.07×10^{-12}	0.030	0.119
	F	-0.517	0	0.054	0.016	-0.237	2.44×10^{-15}	0.048	0.031
Loci (VS)	M	-0.486	0	0.054	0.017	-0.233	3.77×10^{-15}	0.045	0.040
	F	-0.509	0	0.051	0.021	-0.211	5.11×10^{-14}	0.052	0.022
Volume (UVS, RW)	M	-0.383	2.73×10^{-12}	0.042	0.048	-0.260	1.99×10^{-07}	0.026	0.148
	F	-0.437	0	0.061	0.009	-0.319	9.56×10^{-12}	0.048	0.031
Loci (UVS, RW)	M	-0.353	1.52×10^{-11}	0.036	0.077	-0.228	9.82×10^{-07}	0.021	0.200
	F	-0.400	0	0.048	0.031	-0.247	1.70×10^{-09}	0.031	0.109
Volume (VS, RW)	M	-0.410	3.95×10^{-14}	0.041	0.051	-0.275	1.58×10^{-08}	0.026	0.147
	F	-0.464	0	0.056	0.015	-0.333	7.72×10^{-13}	0.047	0.034
Loci (VS, RW)	M	-0.380	2.16×10^{-13}	0.034	0.092	-0.244	1.42×10^{-07}	0.023	0.178
	F	-0.429	0	0.037	0.073	-0.258	2.42×10^{-10}	0.025	0.161
Volume (UVS, PTQ)	M	-0.551	0	0.054	0.017	-0.267	0	0.031	0.108
	F	-0.570	0	0.053	0.015	-0.266	0	0.041	0.054
Loci (UVS, PTQ)	M	-0.647	0	0.066	0.004	-0.275	0	0.036	0.081
	F	-0.662	0	0.055	0.014	-0.267	0	0.058	0.013
Volume (VS, PTQ)	M	-0.650	0	0.062	0.007	-0.314	0	0.030	0.117
	F	-0.582	0	0.068	0.003	-0.290	0	0.056	0.014
Loci (VS, PTQ)	M	-0.666	0	0.054	0.015	-0.292	0	0.033	0.094
	F	-0.711	0	0.061	0.008	-0.298	0	0.065	0.006

Supplementary Table 2. Spatial simultaneous autoregressive (SAR) models for the effect of absolute latitude on male and female colourfulness across terrestrial ecoregions (*n* = 800) using different datasets. Slope refers to the estimated slope of the relationship between colourfulness score (loci or volume) and absolute latitude in each model, with asterisks indicating significant effects (two-sided test, no adjustments for multiple tests). Moran's *I* refers to the global Moran's *I* estimate for each model assessing the presence of residual spatial autocorrelation in the model residuals, with asterisks indicating associated significance level. All variables were standardised (mean = 0, sd = 1) prior to model fitting. SES, standardised effect size; UVS, ultraviolet sensitive; VS, violet sensitive; RW, range weighted; PTQ, proportion of species in the top (25%) colour diversity quartile.

Variable	Sex	Estimate (95% CI)	P_{MCMC}
Volume (UVS)	M	-0.034 (-0.059, -0.008)	0.010
	F	-0.107 (-0.136, -0.078)	3.00×10^{-06}
Loci (UVS)	M	-0.043 (-0.068, -0.017)	9.15×10^{-04}
	F	-0.118 (-0.144, -0.090)	3.00×10^{-06}
Volume (VS)	M	-0.038 (-0.064, -0.012)	0.004
	F	-0.121 (-0.151, -0.092)	3.00×10^{-06}
Loci (VS)	M	-0.049 (-0.075, -0.024)	1.10×10^{-04}
	F	-0.140 (-0.167, -0.113)	3.00×10^{-06}

Supplementary Table 3. Bayesian phylogenetic mixed model results for the effect of absolute latitude on male and female colourfulness across passerine species (*n* = 4,527). All variables were standardised (mean = 0, sd = 1) prior to model fitting. Tests were two-sided and no adjustments for multiple tests were made. UVS, ultraviolet sensitive; VS, violet sensitive. All models were run over 100 posterior phylogenetic trees.

		Males		Females	
Variable	**Term**	**Estimate (95% CI)**	**P_{MCMC}**	**Estimate (95% CI)**	**P_{MCMC}**
Loci (UVS)	(Intercept)	0.140 (-0.691, 0.971)	0.739	0.228 (-0.643, 1.115)	0.609
	Temperature	0.019 (-0.024, 0.061)	0.379	0.046 (-0.001, 0.092)	0.055
	Precipitation	**0.040 (0.005, 0.074)**	**0.022**	**0.065 (0.027, 0.102)**	**0.001**
	Net primary productivity	**0.052 (0.019, 0.085)**	**0.002**	**0.086 (0.049, 0.123)**	**5.00×10^{-06}**
	Solar radiation	0.013 (-0.021, 0.046)	0.445	-0.021 (-0.059, 0.016)	0.257
	UV-B radiation	-0.024 (-0.059, 0.011)	0.175	-0.024 (-0.062, 0.015)	0.227
	Body mass	**-0.143 (-0.188, -0.098)**	**2.50×10^{-06}**	**-0.123 (-0.172, -0.073)**	**2.50×10^{-06}**
	Sexual dichromatism	**0.250 (0.221, 0.279)**	**2.50×10^{-06}**	0.005 (-0.027, 0.036)	0.753
	Forest dependency	**0.045 (0.021, 0.070)**	**3.25×10^{-04}**	**0.073 (0.046, 0.101)**	**2.50×10^{-06}**
	Frugivore-nectarivore	**0.036 (0.006, 0.068)**	**0.021**	**0.041 (0.006, 0.074)**	**0.019**
	Migratory	-0.015 (-0.041, 0.011)	0.272	**-0.040 (-0.069, -0.012)**	**0.006**
	Ground nesting	-0.007 (-0.033, 0.019)	0.592	-0.007 (-0.035, 0.021)	0.642
	Territoriality	0.002 (-0.035, 0.039)	0.932	-0.012 (-0.052, 0.028)	0.572
	Community diversity	**0.087 (0.055, 0.118)**	**2.50×10^{-06}**	**0.086 (0.051, 0.121)**	**5.00×10^{-06}**
Loci (VS)	(Intercept)	0.159 (-0.666, 0.982)	0.703	0.279 (-0.599, 1.150)	0.527
	Temperature	0.010 (-0.031, 0.053)	0.628	0.045 (-0.004, 0.091)	0.064
	Precipitation	**0.056 (0.021, 0.090)**	**0.001**	**0.089 (0.051, 0.127)**	**5.00×10^{-06}**
	Net primary productivity	**0.051 (0.018, 0.085)**	**0.002**	**0.084 (0.047, 0.122)**	**2.50×10^{-06}**
	Solar radiation	0.022 (-0.011, 0.056)	0.194	-0.019 (-0.056, 0.019)	0.330
	UV-B radiation	-0.019 (-0.054, 0.015)	0.285	-0.017 (-0.056, 0.022)	0.405
	Body mass	**-0.141 (-0.185, -0.096)**	**2.50×10^{-06}**	**-0.123 (-0.171, -0.074)**	**2.50×10^{-06}**
	Sexual dichromatism	**0.258 (0.229, 0.287)**	**2.50×10^{-06}**	-0.006 (-0.038, 0.026)	0.713
	Forest dependency	**0.040 (0.016, 0.065)**	**0.002**	**0.060 (0.032, 0.087)**	**5.00×10^{-06}**
	Frugivore-nectarivore	0.026 (-0.004, 0.057)	0.093	**0.037 (0.003, 0.072)**	**0.032**
	Migratory	-0.009 (-0.035, 0.017)	0.486	**-0.039 (-0.068, -0.010)**	**0.008**
	Ground nesting	-0.006 (-0.032, 0.020)	0.638	-0.004 (-0.033, 0.024)	0.788
	Territoriality	0.003 (-0.034, 0.039)	0.872	0.006 (-0.034, 0.046)	0.756
	Community diversity	**0.086 (0.055, 0.118)**	**2.50×10^{-06}**	**0.090 (0.054, 0.125)**	**2.50×10^{-06}**

Supplementary Table 4. Bayesian phylogenetic mixed model results for the effect of predictor variables on male and female colour loci scores across passerine species (*n* = 4,415). All variables were standardised (mean = 0, sd = 1) prior to model fitting. Tests were two-sided and no adjustments for multiple tests were made. UVS, ultraviolet sensitive; VS, violet sensitive. All models were run over 100 posterior phylogenetic trees.

		Males		Females	
Variable	**Term**	**Estimate (95% CI)**	P_{MCMC}	**Estimate (95% CI)**	P_{MCMC}
Volume (UVS)	(Intercept)	0.181 (-0.576, 0.931)	0.635	0.221 (-0.569, 1.012)	0.581
	Temperature	-0.001 (-0.045, 0.042)	0.951	-0.002 (-0.053, 0.049)	0.948
	Precipitation	**0.054 (0.019, 0.090)**	**0.003**	**0.086 (0.044, 0.127)**	**4.50×10^{-06}**
	Net primary productivity	**0.035 (0.000, 0.069)**	**0.048**	**0.068 (0.027, 0.108)**	**0.001**
	Solar radiation	**0.040 (0.005, 0.075)**	**0.023**	0.031 (-0.009, 0.071)	0.139
	UV-B radiation	-0.031 (-0.068, 0.005)	0.092	**-0.045 (-0.087, -0.004)**	**0.035**
	Body mass	**-0.171 (-0.215, -0.127)**	**2.50×10^{-06}**	**-0.163 (-0.212, -0.112)**	**2.50×10^{-06}**
	Sexual dichromatism	**0.235 (0.206, 0.264)**	**2.50×10^{-06}**	**-0.044 (-0.078, -0.011)**	**0.009**
	Forest dependency	**0.034 (0.008, 0.059)**	**0.010**	**0.079 (0.049, 0.108)**	**2.50×10^{-06}**
	Frugivore-nectarivore	**0.032 (0.000, 0.063)**	**0.048**	**0.037 (0.000, 0.073)**	**0.045**
	Migratory	-0.010 (-0.037, 0.017)	0.477	**-0.046 (-0.077, -0.014)**	**0.004**
	Ground nesting	-0.002 (-0.028, 0.025)	0.901	0.016 (-0.015, 0.046)	0.318
	Territoriality	0.000 (-0.036, 0.037)	0.985	0.015 (-0.025, 0.056)	0.459
	Community diversity	**0.089 (0.057, 0.122)**	**2.50×10^{-06}**	**0.106 (0.069, 0.144)**	**2.50×10^{-06}**
Volume (VS)	(Intercept)	0.236 (-0.514, 0.979)	0.531	0.316 (-0.434, 1.059)	0.406
	Temperature	-0.005 (-0.050, 0.039)	0.818	-0.011 (-0.063, 0.041)	0.684
	Precipitation	**0.062 (0.027, 0.099)**	**0.001**	**0.109 (0.067, 0.151)**	**2.50×10^{-06}**
	Net primary productivity	**0.035 (0.001, 0.071)**	**0.047**	**0.067 (0.026, 0.108)**	**0.001**
	Solar radiation	**0.042 (0.006, 0.077)**	**0.021**	0.035 (-0.005, 0.078)	0.097
	UV-B radiation	-0.026 (-0.063, 0.011)	0.167	-0.038 (-0.081, 0.005)	0.085
	Body mass	**-0.175 (-0.219, -0.130)**	**2.50×10^{-06}**	**-0.170 (-0.219, -0.120)**	**2.50×10^{-06}**
	Sexual dichromatism	**0.233 (0.203, 0.262)**	**2.50×10^{-06}**	**-0.050 (-0.084, -0.017)**	**0.003**
	Forest dependency	**0.030 (0.004, 0.056)**	**0.021**	**0.066 (0.035, 0.096)**	**1.50×10^{-06}**
	Frugivore-nectarivore	0.017 (-0.015, 0.049)	0.310	0.031 (-0.005, 0.069)	0.094
	Migratory	-0.003 (-0.030, 0.024)	0.826	**-0.043 (-0.075, -0.012)**	**0.008**
	Ground nesting	0.003 (-0.025, 0.029)	0.848	0.019 (-0.013, 0.050)	0.240
	Territoriality	-0.001 (-0.037, 0.035)	0.949	0.021 (-0.019, 0.062)	0.303
	Community diversity	**0.090 (0.057, 0.123)**	**2.50×10^{-06}**	**0.110 (0.072, 0.148)**	**2.50×10^{-06}**

Supplementary Table 5. Bayesian phylogenetic mixed model results for the effect of predictor variables on male and female colour volume scores across passerine species (*n* = 4,415). All variables were standardised (mean = 0, sd = 1) prior to model fitting. Tests were two-sided and no adjustments for multiple tests were made. UVS, ultraviolet sensitive; VS, violet sensitive. All models were run over 100 posterior phylogenetic trees.

Variable	Term[a]	Estimate (95% CI)	P_{MCMC}
Volume (UVS)	Absolute latitude	-0.059 (-0.082, -0.036)	3.00×10^{-06}
	Sex	-0.111 (-0.123, -0.100)	3.00×10^{-06}
	Absolute latitude x Sex	-0.003 (-0.015, 0.009)	0.606
Loci (UVS)	Absolute latitude	-0.066 (-0.090, -0.042)	3.00×10^{-06}
	Sex	-0.094 (-0.103, -0.084)	3.00×10^{-06}
	Absolute latitude x Sex	-0.018 (-0.027, -0.008)	3.25×10^{-04}
Volume (VS)	Absolute latitude	-0.069 (-0.092, -0.045)	3.00×10^{-06}
	Sex	-0.112 (-0.124, -0.099)	3.00×10^{-06}
	Absolute latitude x Sex	-0.004 (-0.017, 0.008)	0.488
Loci (VS)	Absolute latitude	-0.081 (-0.104, -0.058)	3.00×10^{-06}
	Sex	-0.099 (-0.110, -0.089)	3.00×10^{-06}
	Absolute latitude x Sex	-0.081 (-0.028, -0.008)	4.30×10^{-04}

Supplementary Table 6. Bayesian phylogenetic mixed model results for the effects of absolute latitude and sex on male and female colourfulness across passerine species (*n* = 4,527). All variables were standardised (mean = 0, sd = 1) prior to model fitting. Tests were two-sided and no adjustments for multiple tests were made. UVS, ultraviolet sensitive; VS, violet sensitive. All models were run over 100 posterior phylogenetic trees. [a], For Sex, 'Male' is the reference category.

		Males		Females	
Variable	**Term**	**Estimate (95% CI)**	**P_{MCMC}**	**Estimate (95% CI)**	**P_{MCMC}**
Loci (UVS)	(Intercept)	-0.119 (-0.765, 0.556)	0.715	-0.201 (-0.890, 0.488)	0.554
	Temperature	0.036 (-0.204, 0.279)	0.769	0.141 (-0.126, 0.407)	0.302
	Precipitation	-0.090 (-0.237, 0.056)	0.228	-0.024 (-0.186, 0.139)	0.770
	Net primary productivity	0.133 (-0.009, 0.275)	0.066	0.118 (-0.041, 0.277)	0.146
	Solar radiation	-0.003 (-0.194, 0.186)	0.971	-0.140 (-0.352, 0.069)	0.191
	UV-B radiation	0.088 (-0.145, 0.316)	0.455	0.055 (-0.203, 0.310)	0.671
	Body mass	**-0.226 (-0.329, -0.124)**	**1.00×10^{-05}**	**-0.203 (-0.314, -0.092)**	**4.65×10^{-04}**
	Sexual dichromatism	**0.327 (0.248, 0.405)**	**2.50×10^{-06}**	0.006 (-0.079, 0.091)	0.891
	Social mating system	-0.028 (-0.111, 0.055)	0.504	-0.022 (-0.112, 0.070)	0.640
	Forest dependency	**0.083 (0.012, 0.155)**	**0.023**	**0.121 (0.042, 0.200)**	**0.003**
	Frugivore-nectarivore	0.053 (-0.027, 0.132)	0.193	0.061 (-0.026, 0.148)	0.165
	Migratory	0.021 (-0.067, 0.110)	0.644	-0.055 (-0.153, 0.042)	0.268
	Ground nesting	-0.004 (-0.071, 0.065)	0.920	0.003 (-0.071, 0.078)	0.946
	Territoriality	**-0.096 (-0.177, -0.013)**	**0.022**	-0.036 (-0.125, 0.055)	0.437
	Community diversity	0.080 (-0.022, 0.185)	0.126	**0.116 (0.000, 0.230)**	**0.048**
Volume (UVS)	(Intercept)	-0.164 (-0.787, 0.473)	0.603	-0.303 (-0.951, 0.345)	0.347
	Temperature	0.082 (-0.152, 0.315)	0.492	0.141 (-0.129, 0.418)	0.312
	Precipitation	-0.092 (-0.232, 0.049)	0.201	-0.096 (-0.261, 0.071)	0.254
	Net primary productivity	**0.146 (0.010, 0.283)**	**0.035**	**0.171 (0.009, 0.332)**	**0.039**
	Solar radiation	0.059 (-0.125, 0.242)	0.529	-0.062 (-0.277, 0.155)	0.578
	UV-B radiation	-0.026 (-0.249, 0.196)	0.819	-0.035 (-0.302, 0.226)	0.796
	Body mass	**-0.247 (-0.345, -0.148)**	**2.50×10^{-06}**	-0.220 (-0.331, -0.110)	**1.45×10^{-04}**
	Sexual dichromatism	**0.288 (0.211, 0.363)**	**2.50×10^{-06}**	-0.057 (-0.144, 0.030)	0.194
	Social mating system	0.041 (-0.039, 0.120)	0.316	-0.022 (-0.113, 0.071)	0.644
	Forest dependency	0.053 (-0.017, 0.121)	0.134	**0.091 (0.009, 0.170)**	**0.027**
	Frugivore-nectarivore	0.059 (-0.018, 0.136)	0.132	0.082 (-0.007, 0.168)	0.068
	Migratory	0.004 (-0.081, 0.090)	0.933	-0.072 (-0.172, 0.028)	0.157
	Ground nesting	0.005 (-0.060, 0.071)	0.875	0.007 (-0.069, 0.084)	0.868
	Territoriality	**-0.116 (-0.195, -0.037)**	**0.004**	-0.038 (-0.130, 0.053)	0.415
	Community diversity	0.096 (-0.002, 0.196)	0.057	**0.145 (0.027, 0.262)**	**0.016**

Supplementary Table 7. Bayesian phylogenetic mixed model results for the effect of predictor variables on male and female colour loci scores across passerine species (*n* = 608), including the effect of social mating system. All variables were standardised (mean = 0, sd = 1) prior to model fitting. Tests were two-sided and no adjustments for multiple tests were made. UVS, ultraviolet sensitive; VS, violet sensitive. All models were run over 100 posterior phylogenetic trees.