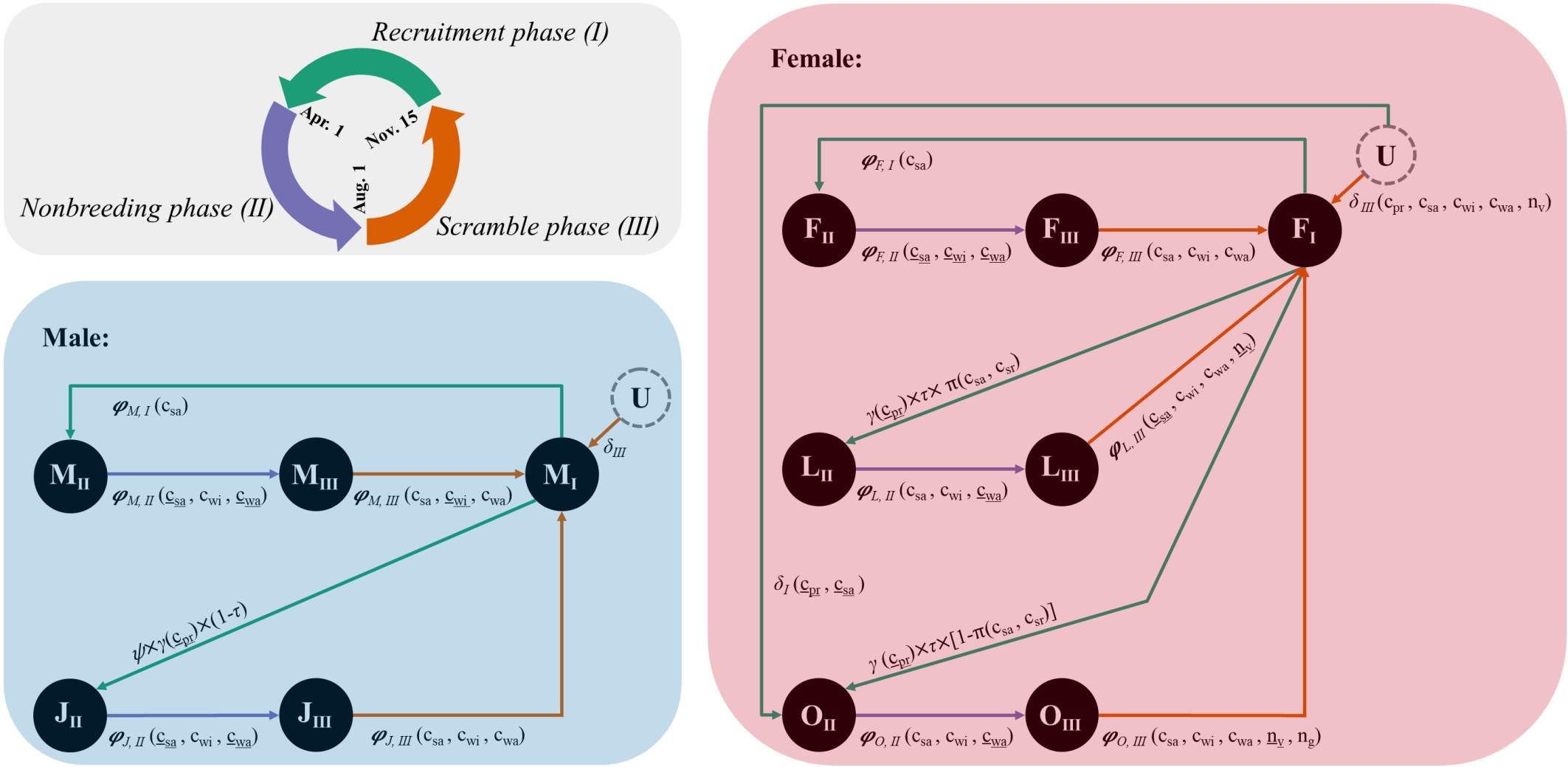
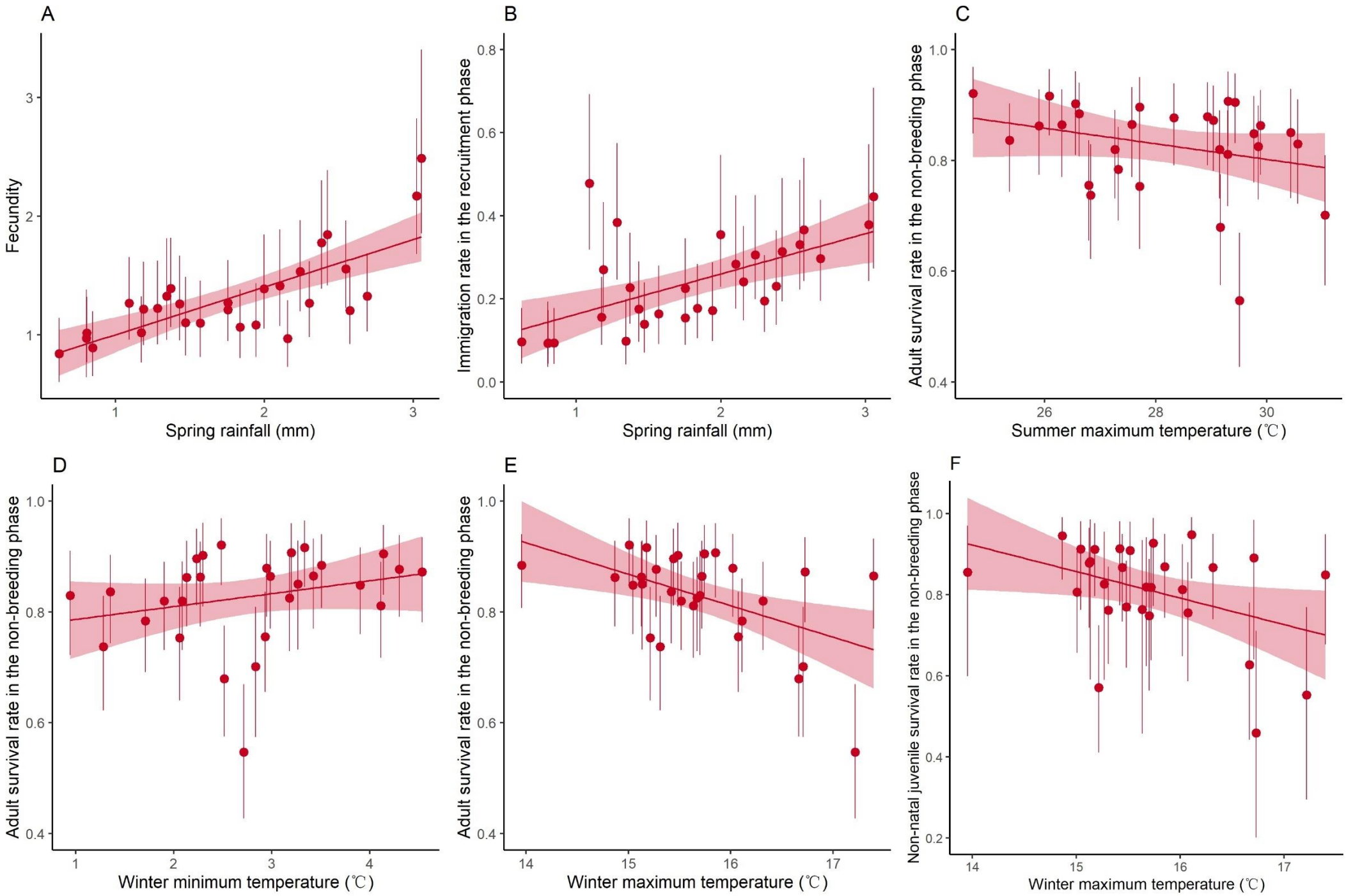
Supplementary Information

Contents

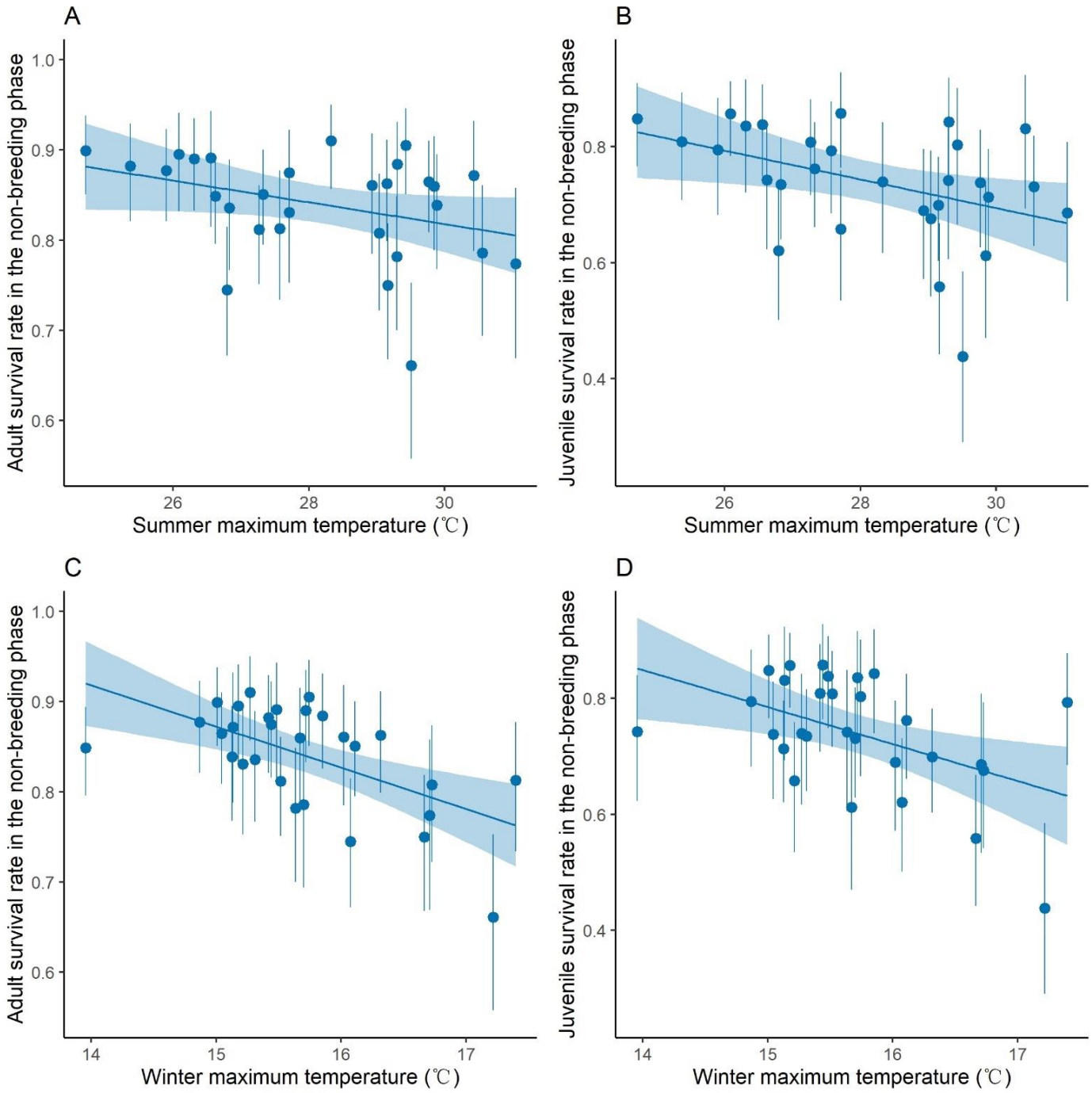


Extended Data Fig. 1 | Detailed life-cycle diagram of superb fairy-wrens with climate/density variables. The top panel shows three phases throughout the annual cycle with three dates to distinguish five stage classes of individuals in the population: F: adult females; L: natal juvenile

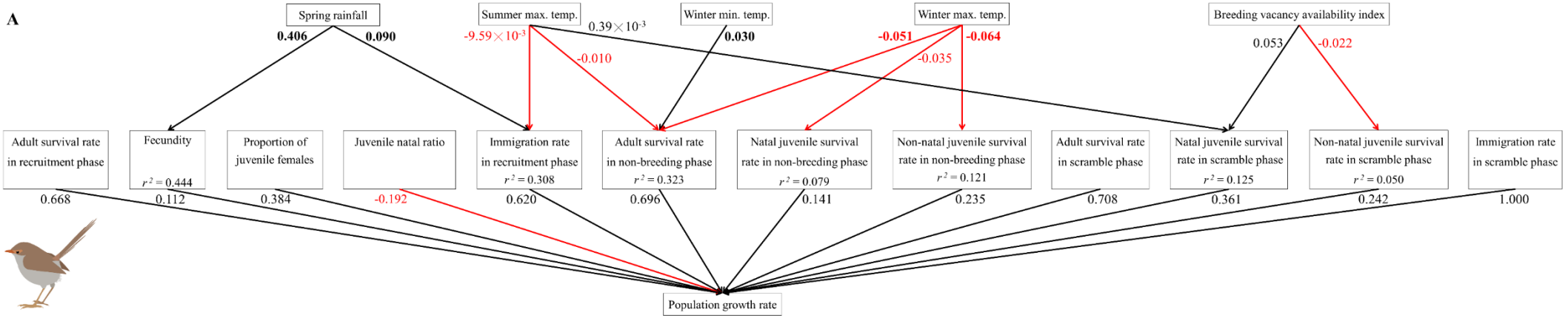
females; O: non-natal juvenile females; M: adult males; J: juvenile males (which are virtually all natal). ‘U’ denotes unobservable individuals outside of the study area which are the source of immigrants. Arrows indicated the transition probabilities among state classes (i.e., vital rates; see details in the main text). Letters in parentheses indicate each variable that may influence a given vital rate. Climate variables: ‘c_{pr}’: spring rainfall; ‘c_{sa}’: summer maximum temperature; ‘c_{sr}’: summer rainfall; ‘c_{wi}’: winter minimum temperature; ‘c_{wa}’: winter maximum temperature. Density variables: ‘n_v’: the breeding vacancy availability index (see materials and methods); ‘n_g’: male group size, calculated as average number of males per female on 1 August. Climate/density variables which were retained after the variable selection procedure (see materials and methods) and therefore included in the path analysis were shown with underlines.

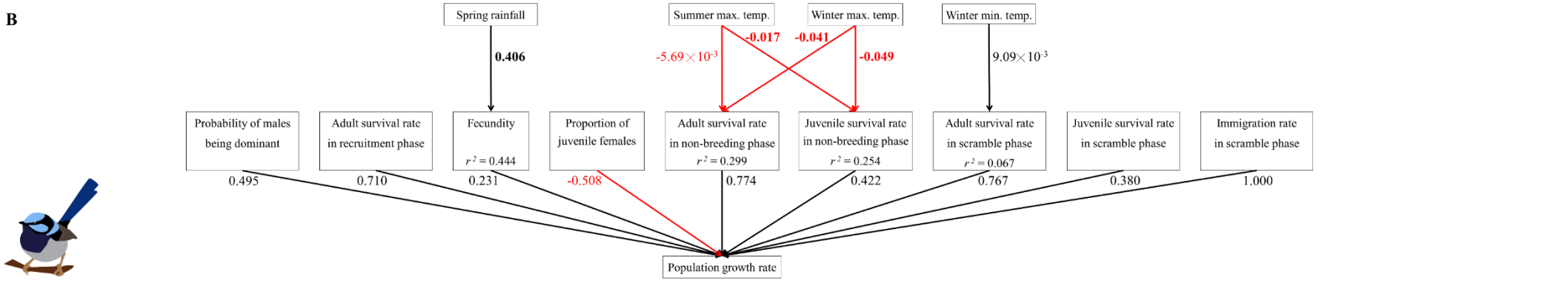

A
Fecundity
Spring rainfall (mm)
B
Immigration rate in the recruitment phase
Spring rainfall (mm)
C
Adult survival rate in the non-breeding phase
Summer maximum temperature (℃)
D
Adult survival rate in the non-breeding phase
Winter minimum temperature (℃)
E
Adult survival rate in the non-breeding phase
Winter maximum temperature (℃)
F
Non-natal juvenile survival rate in the non-breeding phase
Winter maximum temperature (℃)

Extended Data Fig. 2 | The significant effects of climate variables on vital rates in *female* superb fairy-wrens. The lines are simple linear regressions through the 29 data points (mean±95% credible intervals; dots and error bars), and the shaded areas represent 95% confidence intervals of the lines.

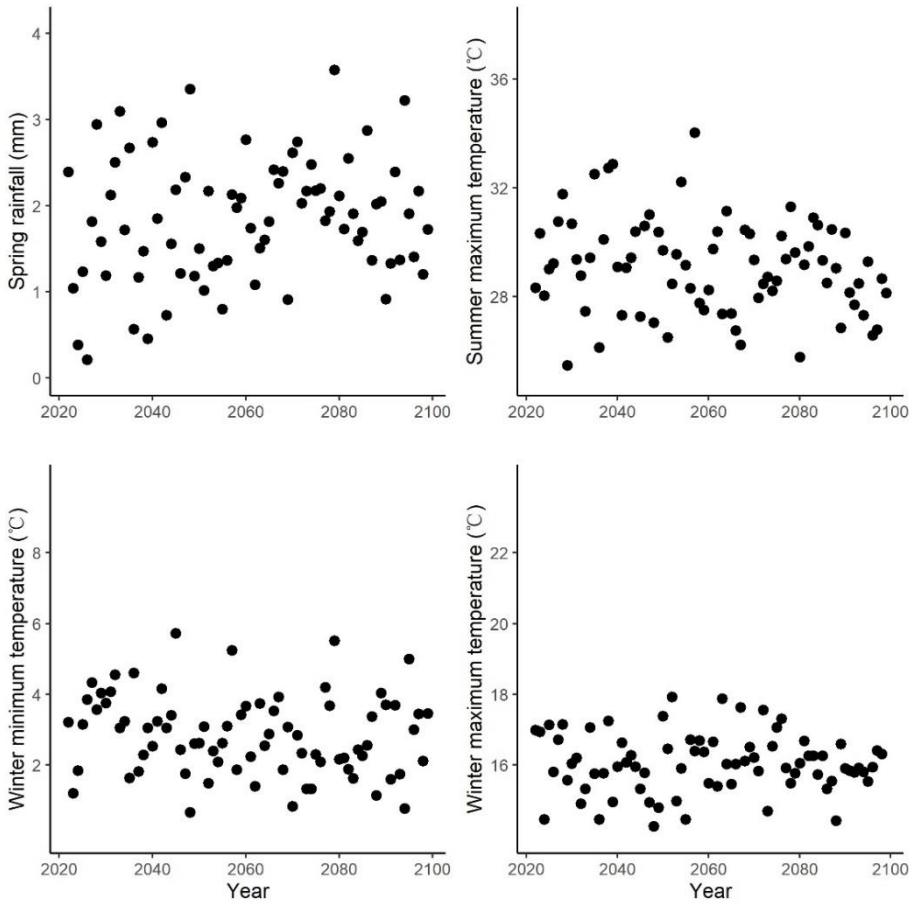


13 **Extended Data Fig. 3 | The significant effects of climate variables on vital rates in *male***
14 **superb fairy-wrens.** The lines are simple linear regressions through the 29 data points
15 (mean±95% credible intervals; dots and error bars), and the shaded areas represent 95%
16 confidence intervals of the lines.

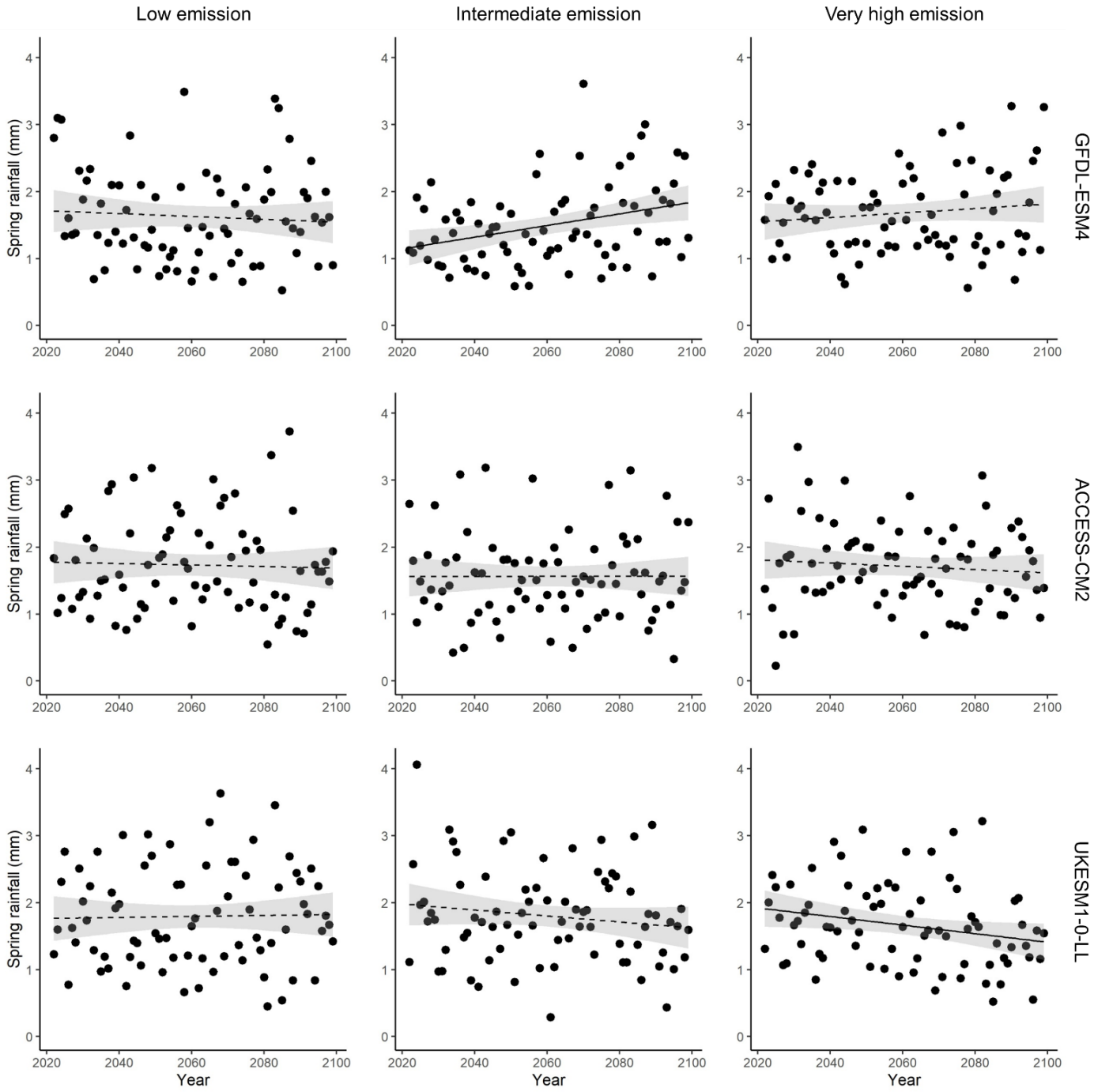

A
Spring rainfall
Summer max. temp.
Winter min. temp.
Winter max. temp.
Breeding vacancy availability index
0.406
0.090
-9.59×10-3
0.39×10-3
0.030
-0.051
-0.064
0.053
-0.022
-0.010
-0.035
Adult survival rate in recruitment phase
Fecundity
r2 = 0.444
Proportion of juvenile females
Juvenile natal ratio
Immigration rate in recruitment phase
r2 = 0.308
Adult survival rate in non-breeding phase
r2 = 0.323
Natal juvenile survival rate in non-breeding phase
r2 = 0.079
Non-natal juvenile survival rate in non-breeding phase
r2 = 0.121
Adult survival rate in scramble phase
Natal juvenile survival rate in scramble phase
r2 = 0.125
Non-natal juvenile survival rate in scramble phase
r2 = 0.050
Immigration rate in scramble phase
0.668
0.112
0.384
-0.192
0.620
0.696
0.141
0.235
0.708
0.361
0.242
1.000
Population growth rate

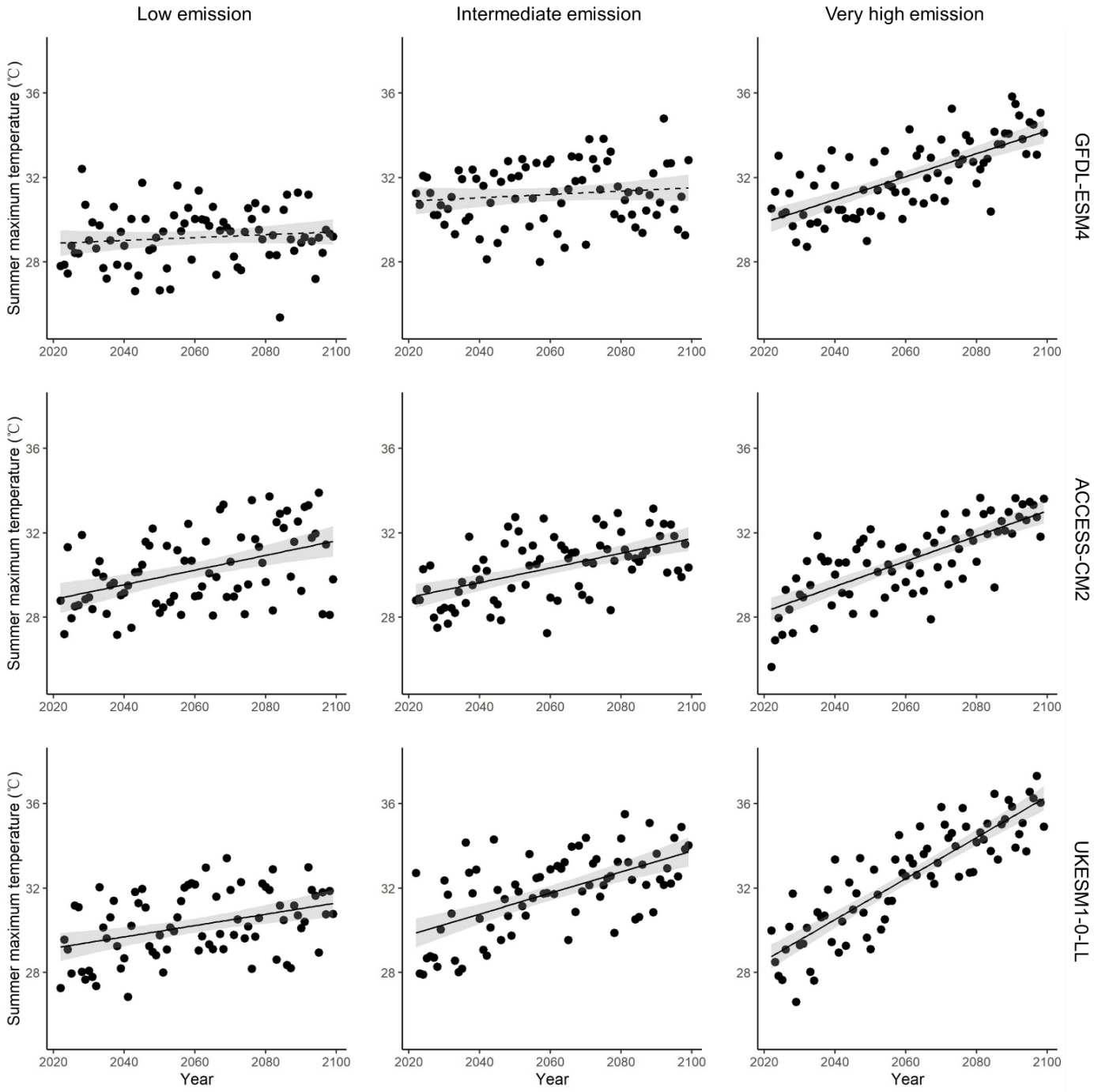

B
Spring rainfall
Summer max. temp.
Winter max. temp.
Winter min. temp.
0.406
-5.69×10-3
-0.017
-0.041
-0.049
9.09×10-3
Probability of males being dominant
Adult survival rate in recruitment phase
Fecundity
r2 = 0.444
Proportion of juvenile females
Adult survival rate in non-breeding phase
r2 = 0.299
Juvenile survival rate in non-breeding phase
r2 = 0.254
Adult survival rate in scramble phase
r2 = 0.067
Juvenile survival rate in scramble phase
Immigration rate in scramble phase
0.495
0.710
0.231
-0.508
0.774
0.422
0.767
0.380
1.000
Population growth rate

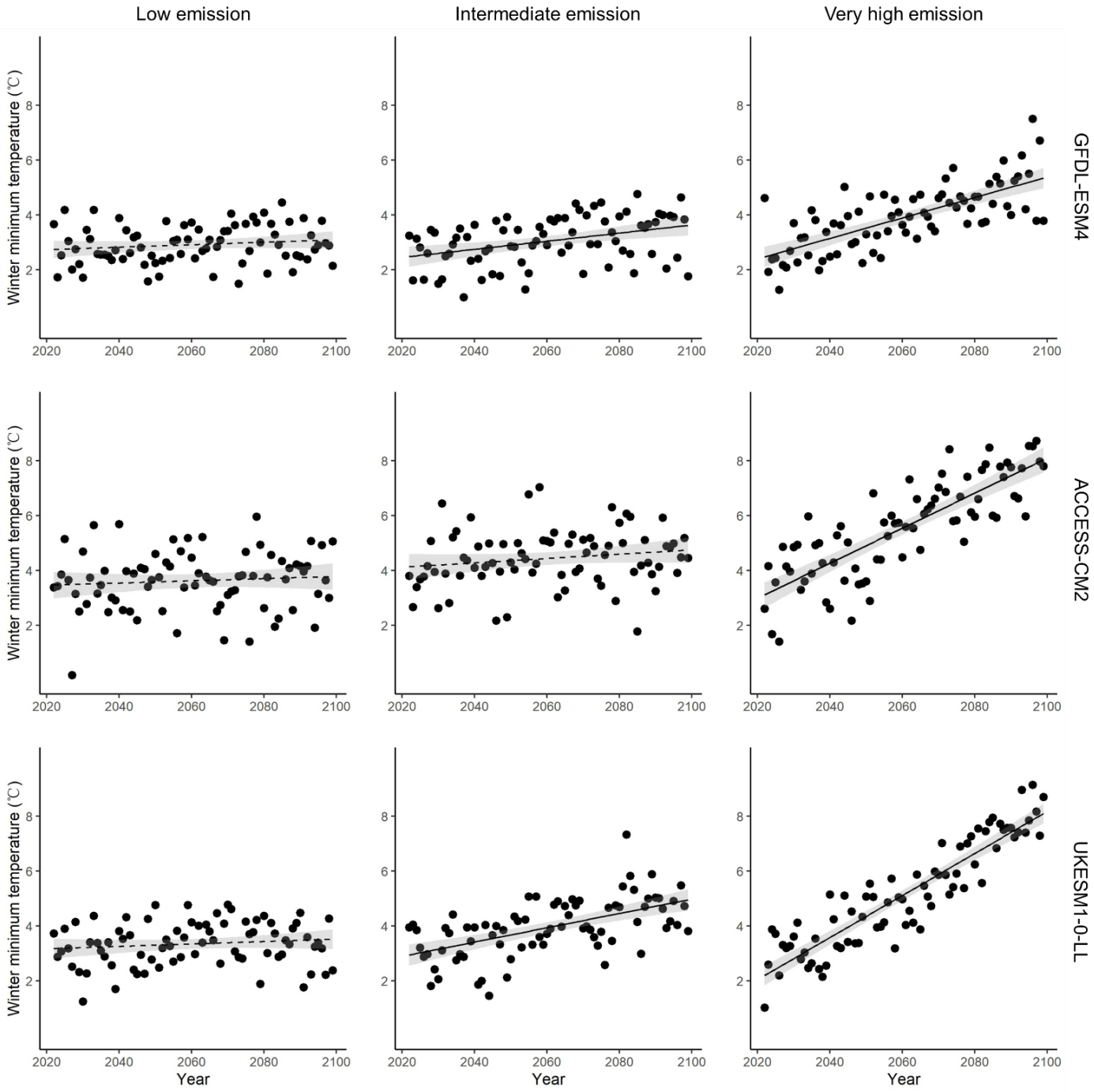
Extended Data Fig. 4 | The path analyses of the effects of climate/density variables on population growth rate via vital rates of female (A) and male (B) superb fairy-wrens. The path coefficients for the strength of association between the climate/density variables and the vital rates are estimates from Gaussian linear models (the female: N=7 models; the male: N=4 models). Negative associations are in red and positive are in black. Significant associations (where the 95% credible interval does not overlap with zero) are given in bold. By contrast, the path coefficients between vital rates and population growth rates are calculated directly (see materials and methods). r^2 values (within boxes) refer to the proportions of the variance of each vital rate explained by the relevant climate/density variables in the Gaussian linear model. The magnitude of a particular demographic pathway is the product of the path coefficient from a given climate/density variable to a given vital rate and of the path coefficient from that vital rate to population growth rate (these are shown in Fig. 3 in the main text).

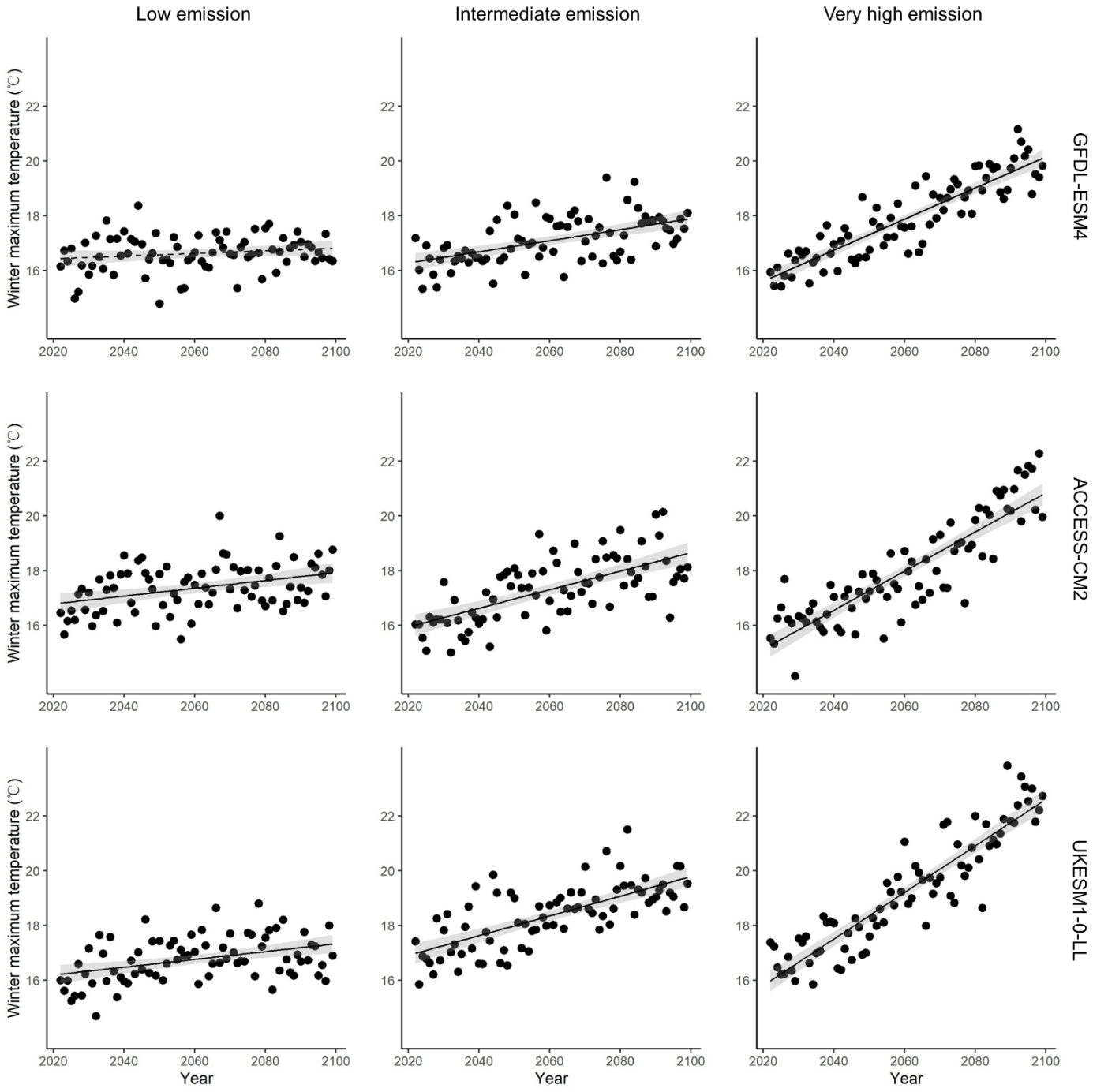


Extended Data Fig. 5 | The changes of forecasted climate variables under the scenario of no further emission-driven climate change.

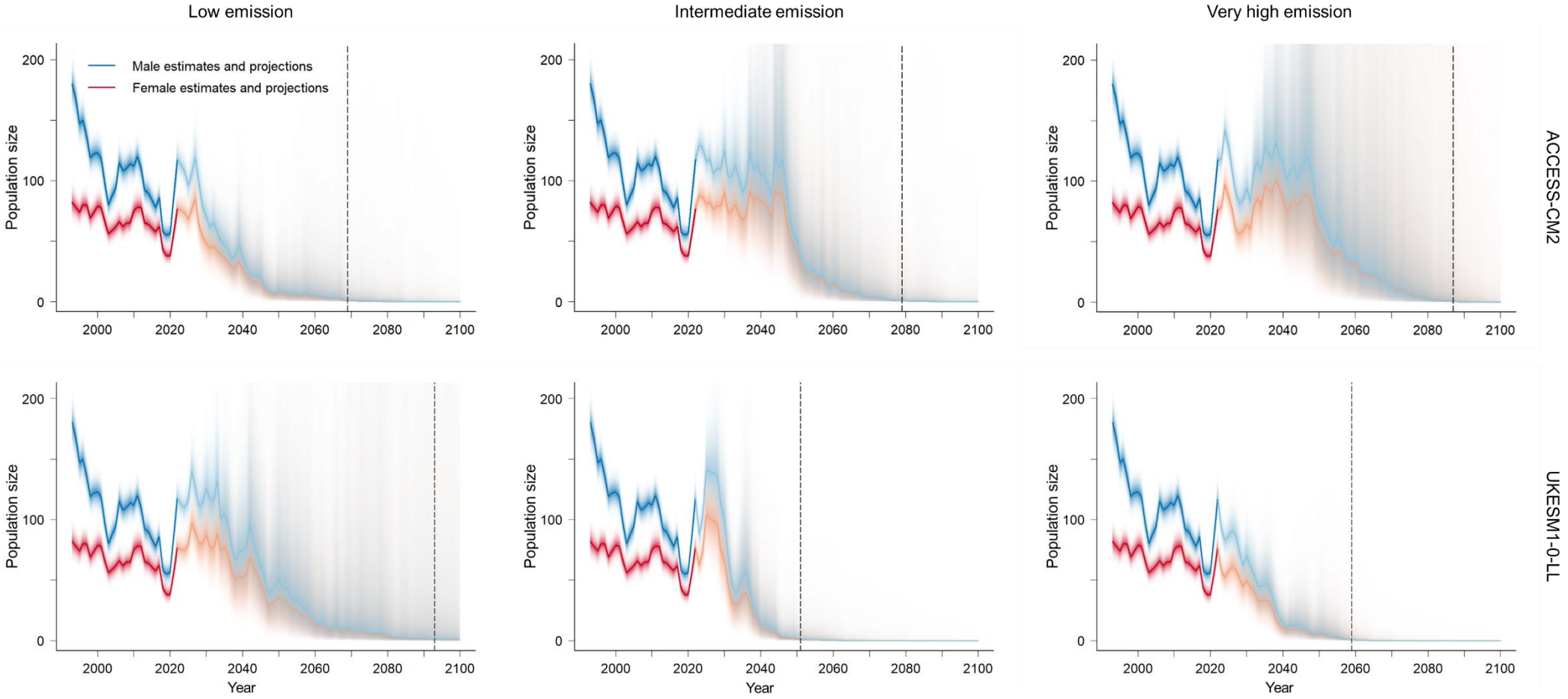

Low emission
Intermediate emission
Very high emission
GFDL-ESM4
ACCESS-CM2
UKESM1-0-LL
Spring rainfall (mm)
Year
0
1
2
3
4
2020
2040
2060
2080
2100


Low emission
Intermediate emission
Very high emission
GFDL-ESM4
ACCESS-CM2
UKESM1-0-LL
Summer maximum temperature (℃)
Year
28
32
36
2020
2040
2060
2080
2100


Low emission
Intermediate emission
Very high emission
GFDL-ESM4
ACCESS-CM2
UKESM1-0-LL
Winter minimum temperature (℃)
Year
2020
2040
2060
2080
2100
2
4
6
8



28 **Extended Data Fig. 6 | The changes of forecasted climate variables under three**
29 **climate change scenarios**: *low*, *intermediate* and *very high* greenhouse gas emission
30 scenarios. The forecasted climate data was obtained from three Coupled Model
31 Intercomparison Project Phase 6 (CMIP6) climate models: GFDL-ESM4, ACCESS-
32 CM2 and UKESM1-0-LL. The solid lines and dashed lines represent statistically
33 significant and non-significant relationships, respectively.



Extended Data Fig. 7 | The estimated historical and projected population sizes of female and male superb fairy-wrens at the end of the scramble phase (15 November) under three climate change scenarios: *low*, *intermediate* and *very high* greenhouse gas emission scenarios. Forecasted climate data were obtained from the Coupled Model Intercomparison Project Phase 6 (CMIP6) climate models ACCESS-CM2 and UKESM1-0-LL. The bold colours represent estimated median number of individuals with corresponding uncertainty gradient (strip) by the

integrated population model (IPM) parameterised with the climate and demographic data from 1993 to 2022. The right two thick lines are the projected median population size from 2023 to 2100 with corresponding uncertainty gradient (strip), based on the IPM parameters from 1993 to 2022. The thick dashed line in each panel is the year in which the probability of extinction is 50% (i.e. median population size of the female is less than 1).

Table S1. The increases of temperatures (◦C) from 2022 to 2100 in different climate change scenarios at both global scale and local (Canberra) scale.

Scale	Climate model or source	RCP	Δ annual mean temp.	Δ annual min. temp.	Δ annual max. temp.	Δ summer max. temp.	Δ winter min. temp.	Δ winter max. temp.
Global	IPCC	2.6	0.44 (0.19, 0.87)					
Global	IPCC	4.5	1.47 (1.01, 2.12)					
Global	IPCC	8.5	3.42 (2.39, 4.72)					
Canberra	GFDL-ESM4	2.6		0.24	0.47	0.52	0.35	0.37
Canberra	GFDL-ESM4	4.5		1.16	1.19	0.61	1.14	1.55
Canberra	GFDL-ESM4	8.5		2.91	4.03	4.19	2.87	4.37
Canberra	ACCESS-CM2	2.6		0.57	1.36	2.68	0.31	1.10
Canberra	ACCESS-CM2	4.5		1.63	2.71	2.69	0.61	2.61
Canberra	ACCESS-CM2	8.5		5.28	5.72	4.60	4.91	5.50
Canberra	UKESM1-0-LL	2.6		0.60	1.27	0.96	0.34	1.10
Canberra	UKESM1-0-LL	4.5		2.38	3.39	3.01	2.01	2.77
Canberra	UKESM1-0-LL	8.5		6.16	7.09	6.80	5.90	6.54

Note: Global surface air temperature change are presented with the mean and 95% confidence intervals in patentheses.

Table S2 | Vital rates and annual population growth rate of female or male superb fairy-wrens. The median values with 95% credible intervals for each vital rate were estimated by the integrated population model.

	Symbol	Median	95% credible interval
Female:			
Fecundity	γ_t	1.247	0.770 - 2.464
Offspring sex ratio	τ_t	0.386	0.330 - 0.444
Natal philopatry rate	π_t	0.889	0.797 - 0.951
Adult survival rate in the recruitment phase	$\varphi_{F,\ I,t}$	0.862	0.774 - 0.924
Adult survival rate in the non-breeding phase	$\varphi_{F,\ II,t}$	0.845	0.574 - 0.945
Adult survival rate in the scramble phase	$\varphi_{F,III,t}$	0.811	0.757 - 0.859
Natal juvenile survival rate in the non-breeding phase	$\varphi_{L,\ II,t}$	0.805	0.535 - 0.952
Natal juvenile survival rate in the scramble phase	$\varphi_{L,III,t}$	0.311	0.204 - 0.443
Non-natal juvenile survival rate in the non-breeding phase	$\varphi_{O,\ II,t}$	0.836	0.434 - 0.976
Non-natal juvenile survival rate in the scramble phase	$\varphi_{O,III,t}$	0.775	0.667 - 0.863
Immigration rate in the recruitment phase	$\delta_{F,\ I,t}$	0.226	0.062 - 0.533
Immigration rate in the scramble phase	$\delta_{F,III,t}$	0.158	0.097 - 0.244
Male:			
Probability of males being the dominant in their territory	ψ_t	0.635	0.475 - 0.758
Adult survival rate in the recruitment phase	$\varphi_{M,\ I,t}$	0.918	0.843 - 0.957
Adult survival rate in the non-breeding phase	$\varphi_{M,\ II,t}$	0.852	0.675 - 0.929
Adult survival rate in the scramble phase	$\varphi_{M,III,t}$	0.848	0.762 - 0.915
Juvenile survival rate in the non-breeding phase	$\varphi_{J,\ II,t}$	0.752	0.465 - 0.897

Juvenile survival rate in the scramble phase	$\varphi_{J,III,t}$	0.820	0.720 - 0.893
Immigration rate in the scramble phase	$\delta_{M,III,t}$	0.033	0.014 - 0.072

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Table S3 | Detection rates of adults and juveniles for female and male superb fairy-wrens conditioning on being alive.

	Recruitment phase	Non-breeding phase	Scramble phase
Female adults	0.938 (0.924, 0.950)	0.996 (0.991, 0.999)	0.990 (0.982, 0.995)
Female natal juveniles		0.822(0.767, 0.869)	0.627 (0.556, 0.696)
Female non-natal juveniles		0.976 (0.957, 0.988)	0.951 (0.922, 0.971)
Male adults	0.994 (0.990, 0.996)	0.998 (0.995, 0.999)	0.996 (0.993, 0.998)
Male juveniles		0.996 (0.991, 0.999)	0.991 (0.983, 0.996)

Note: shown are median values with 95% credible intervals in patentheses. Detection rate of female natal juveniles was underestimated because emigration is not explicitly modelled in our capture mark recapture model, causing detection to be inflated by temporary emigration from the study area for the dispersing sex.

Table S4 | Correlations among historical climate variables and the breeding vacancy availability index (*N*=29).

	Spring rainfall	Summer max. temp.	Winter min. temp.	Winter max. temp.	Breeding vacancy availability index
Spring rainfall	1				
Summer max. temp.	-0.339	1			
Winter min. temp.	**-0.565**	0.249	1		
Winter max. temp.	0.034	0.361	0.066	1	
Breeding vacancy availability index	**-0.678**	0.288	0.206	-0.010	1

Note: significant Pearson correlations are shown in bold.