Supplementary Material

Journal: Biodiversity and Conservation

Title: **Climate change and conservation of *Caladenia* orchids in Western Australia**

Authors: Jacopo Calevo, Kingsley W. Dixon, Michael F. Fay, Karl J. Duffy

Appendix S1.

The simulations were run using ten different models, namely the Beijing Climate Center Climate System Model (BCC-CSM2-MR), which is a fully coupled model with ocean, land surface, atmosphere, and sea-ice components (Wu et al. 2019); the Canadian Earth System Model version 5 (CanESM5), that is comprised of three-dimensional atmosphere and ocean general circulation models, a sea-ice model, a land surface scheme, and explicit land and ocean carbon cycle models (Swart et al. 2019); the National Center for Meteorological Research Climate Model Version 6 (CNRM-CM6.1), which was improved from the previous version (Voldoire et al. 2013) in the representation of atmospheric and land processes (Voldoire et al. 2019); the Earth System Model (CNRM-ESM2.1) that derives from the physical-dynamical core of the previously mentioned ocean-atmosphere coupled climate model CNRM-CM6-1, and provides a first attempt to bound the global carbon cycle by resolving the exchange of carbon not only between the atmosphere, land and ocean but also between land and ocean though the aquatic continuum (Séférian et al. 2016; 2019); the third Hadley Centre Global Environment Model in the Global Coupled configuration 3.1 (HadGEM3-GC3.1) which consists of coupled atmosphere, ocean, sea ice, and land models (Andrews et al. 2020); the Institut Pierre-Simon Laplace climate model version 6 (IPSL-CM6A-LR), comprising in particular radiation, temperature, precipitation, and wind models (Boucher et al. 2020); the sixth version of the Model for Interdisciplinary Research on Climate (MIROC6), which is mainly composed by the three sub-models atmosphere, land, and sea ice-ocean (Tatebe et al. 2019); the Earth system model MIROC-ES2L (Hajima et al. 2020), which embeds a terrestrial biogeochemical component with explicit carbon–nitrogen interaction to account for soil nutrient control on plant growth and the land carbon sink; the Meteorological Research Institute Earth System Model version 2.0 (MRI-ESM2.0), that was improved for various model components from previous version such as vertical resolution enhancement of the atmospheric, oceanic, and chemical models (Yukimoto et al. 2019); and the U.K. Earth System Model (UKESM1) which is an improvement of the HadGEM2-ES, and couples between the ocean, land, and atmosphere physical climate and biogeochemical cycles (Sellar et al. 2019).

Table S1. Information about the number of occurrence records used in the models, distribution, conservation status ad GBIF occurrence data of the 26 study species.

SPECIES	N. records	Distribution	Conservation status	GBIF reference
Caladenia abbreviata Hopper & A.P.Br.	8	Narrow	Priority 3	https://doi.org/10.15468/dl.ycw2y3
Caladenia arenicola Hopper & A.P.Br.	33	Narrow	-	https://doi.org/10.15468/dl.6kzrsy
Caladenia christineae Hopper & A.P.Br.	25	Narrow	Threatened	https://doi.org/10.15468/dl.bbtqeh
Caladenia citrina Hopper & A.P.Br.	10	Narrow	-	https://doi.org/10.15468/dl.j4zqfx
Caladenia crebra A.S.George	25	Narrow	-	https://doi.org/10.15468/dl.z76xr5
Caladenia discoidea Lindl.	161	Wide	-	https://doi.org/10.15468/dl.xchp6m
Caladenia doutchiae O.H.Sarg.	45	Wide	-	https://doi.org/10.15468/dl.dssucd
Caladenia excelsa Hopper & A.P.Br.	8	Narrow	Threatened	https://doi.org/10.15468/dl.xunrjt
Caladenia falcata (Nicholls) M.A.Clem. & Hopper	153	Wide	-	https://doi.org/10.15468/dl.9svft2
Caladenia flava R.Br.	871	Wide	-	https://doi.org/10.15468/dl.njn97w
Caladenia footeana Hopper & A.P.Br.	62	Wide	-	https://doi.org/10.15468/dl.4g2waw
Caladenia georgei Hopper & A.P.Br.	22	Narrow	-	https://doi.org/10.15468/dl.fgakcx
Caladenia harringtoniae Hopper & A.P.Br.	24	Narrow	Threatened	https://doi.org/10.15468/dl.aytf97
Caladenia hirta Lindl.	65	Wide	-	https://doi.org/10.15468/dl.v4j5tg
Caladenia huegelii Rchb.f.	20	Narrow	Threatened	https://doi.org/10.15468/dl.tkdetp
Caladenia infundibularis A.S.George	19	Narrow	-	https://doi.org/10.15468/dl.javjxg
Caladenia latifolia R. Br.	210	Wide	-	https://doi.org/10.15468/dl.ufmugs
Caladenia longicauda Lindl.	463	Wide	-	https://doi.org/10.15468/dl.34jtym
Caladenia lorea Hopper & A.P.Br.	12	Narrow	-	https://doi.org/10.15468/dl.4saeed
Caladenia macrostylis Fitzg.	136	Wide	-	https://doi.org/10.15468/dl.8jxuw9
Caladenia nana Endl.	121	Wide	-	https://doi.org/10.15468/dl.ef6v45
Caladenia nobilis Hopper & A.P.Br.	39	Wide	-	https://doi.org/10.15468/dl.nbhpce
Caladenia paludosa Hopper & A.P.Br.	40	Wide	-	https://doi.org/10.15468/dl.dpnj46
Caladenia pectinata R.S.Rogers	84	Wide	-	https://doi.org/10.15468/dl.b98ywk
Caladenia thinicola Hopper & A.P.Br.	9	Narrow	-	https://doi.org/10.15468/dl.jgbc69
Caladenia varians Hopper & A.P.Br.	68	Wide	-	https://doi.org/10.15468/dl.8usv9c

Table S2. Information about the herbarium specimens of the 11 hybridizing taxa combinations.

Hybridising species	Perth Herbarium Accession(s)
C. christineae × *C. longicauda*	PERTH00271330! PERTH00307017!
C. christineae × *C. pectinata*	PERTH00249882! PERTH00249890!
C. christineae × *C. harringtoniae*	PERTH05216362!
C. christineae × *C. hirta*	PERTH00307017
C. harringtoniae × *C. christineae*	PERTH00249882!
C. harringtoniae × *C. latifolia*	PERTH06906265!
C. harringtoniae × *C. longicauda*	PERTH01828908! PERTH06043917!
C. huegelii × *C. arenicola*	PERTH04421191! PERTH00249866!
C. huegelii × *C. georgei*	PERTH00905380! PERTH00255998!
C. huegelii × *C. longicauda*	PERTH05415403!
C. huegelii × *C. paludosa*	PERTH03050289!

Table S3. Climatic niche overlap between current and future conditions for *Caladenia* species, as assessed via PCAenv analysis and Schoener's D. The analysis, based on current distribution data and an exemplar future climate scenario (CAN-ESM5, SSP5-8.5), considered key variables (bio1= annual mean temperature, bio12= annual precipitation, bio15 = precipitation seasonality (coefficient of variation), bio16= precipitation of wettest quarter, and bio17= precipitation of driest quarter) representing the most ecologically impactful climatic factors during the growing season. D values range from 0 (no overlap) to 0.661 (highest overlap), with an average niche overlap of D = 0.356.

Species	**overlap_D**
C. flava	0,661
C. footeana	0,659
C. latifolia	0,652
C. longicauda	0,649
C. nobilis	0,645
C. macrostylis	0,626
C. hirta	0,624
C. pectinata	0,623
C. varians	0,622
C. nana	0,528
C. discoidea	0,523
C. falcata	0,515
C. doutchiae	0,451
C. harringtoniae	0,394
C. thinicola	0,315
C. christineae	0,221
C. paludosa	0,198
C. lorea	0,168
C. crebra	0,154
C. arenicola	0,016
C. infundibularis	0,007
C. abbreviata	0
C. citrina	0
C. excelsa	0
C. georgei	0
C. huegelii	0

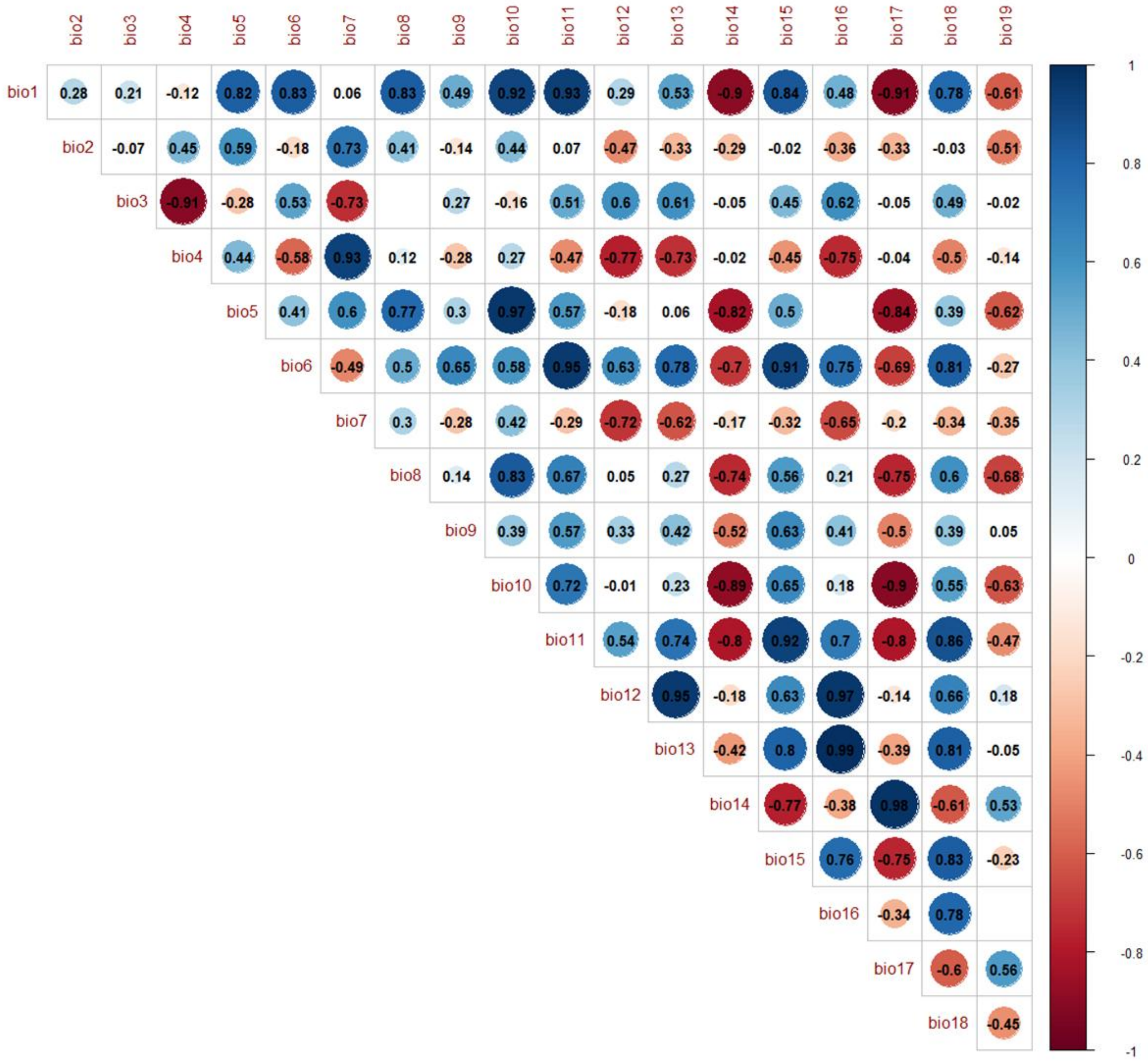

Fig. S1. Correlation plot of the 19 WorldClim variables. Bio1 = annual mean temperature; bio2 = mean diurnal range (mean of monthly (max temp - min temp)); bio3 = isothermality (bio2/bio7) (×100); bio4 = temperature seasonality (standard deviation ×100); bio5 = max temperature of warmest month; bio6 = min temperature of coldest month; bio7 = temperature annual range (bio5-bio6); bio8 = mean temperature of wettest quarter; bio9 = mean temperature of driest quarter; bio10 = mean temperature of warmest quarter; bio11 = mean temperature of coldest quarter; bio12 = annual precipitation; bio13 = precipitation of wettest month; bio14 = precipitation of driest month; bio15 = precipitation seasonality (coefficient of variation); bio16 = precipitation of wettest quarter; bio17 = precipitation of driest quarter; bio18 = precipitation of warmest quarter; bio19 = precipitation of coldest quarter.

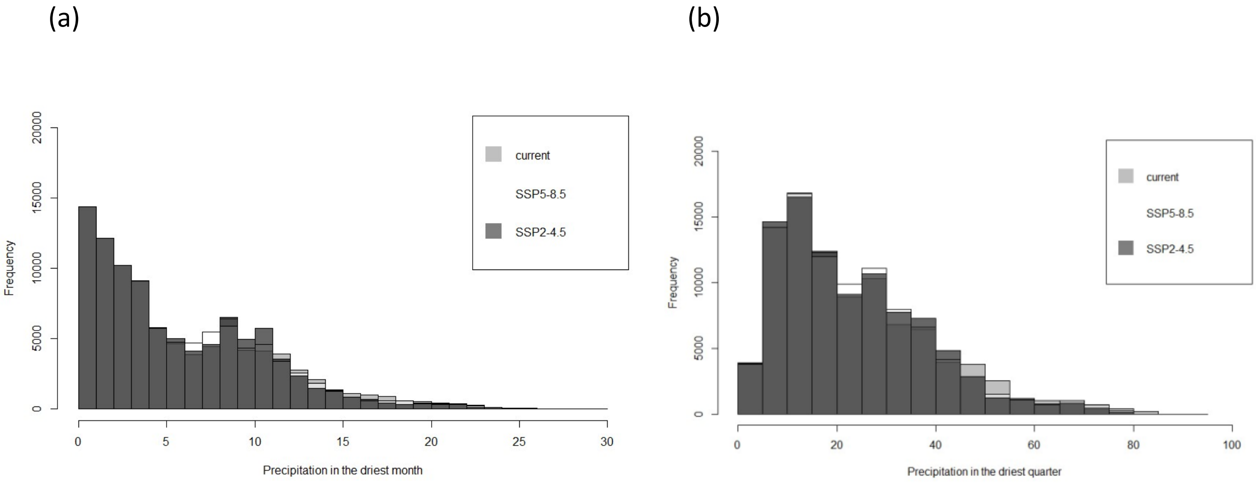

Fig. S2. Example of frequency histograms of (a) precipitation in the driest month and (b) precipitation in the driest quarter of the HadGEM3-GC31-LL scenarios. Height of each bar corresponds to the proportional area in Western Australia with the corresponding precipitation level in the present (grey), future SSP2-4.5 (white) or future SSP5-8.5 (dark grey).

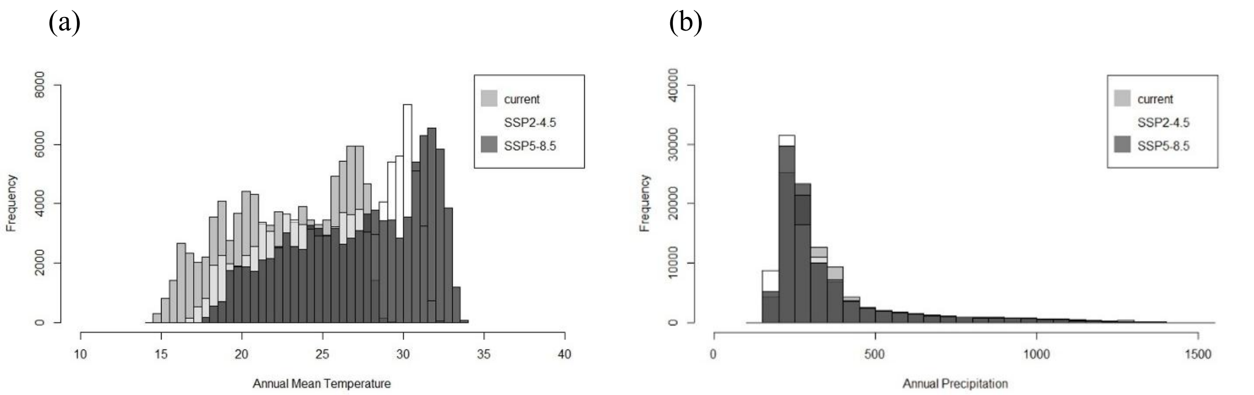

Fig. S3. Example of frequency histograms of (a) annual mean temperature and (b) annual mean precipitation of the HadGEM3-GC31-LL scenarios. Height of each bar corresponds to the proportional area in Western Australia with the corresponding temperature or precipitation level in the present (grey), future SSP2-4.5 (white) or future SSP5-8.5 (dark grey).

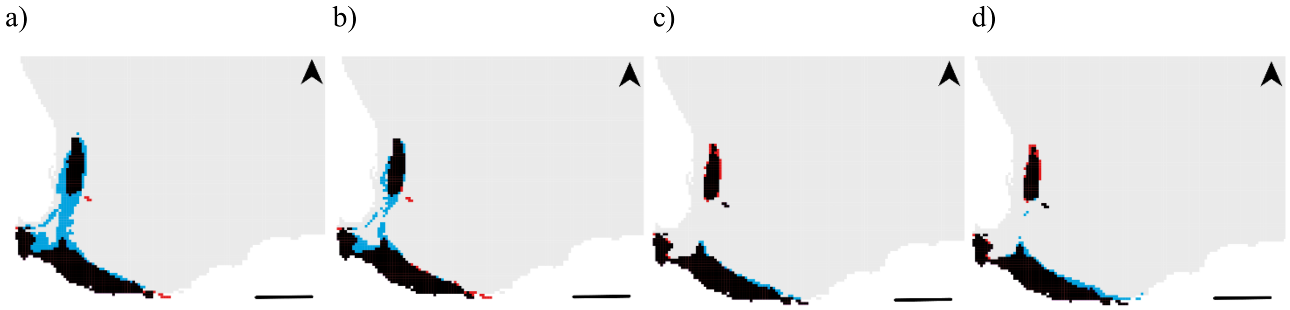

Fig. S4. Shifting ranges under climate change for *Caladenia abbreviata*. Species range under a) LIG; b) HCO c) SSP2-4.5 and d) SPP5-8.5 climatic scenarios are compared with current distribution. Red indicates potential range loss, blue potential range gain, while black indicates no change. Black arrows point North, and scale bars = 100km.

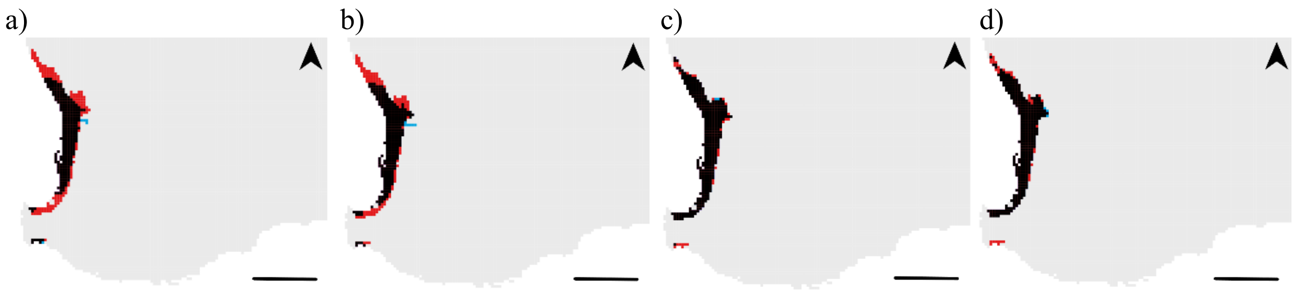

Fig. S5. Shifting ranges under climate change for *Caladenia arenicola*. Species range under a) LIG; b) HCO c) SSP2-4.5 and d) SPP5-8.5 climatic scenarios are compared with current distribution. Red indicates potential range loss, blue potential range gain, while black indicates no change. Black arrows point North, and scale bars = 100km.

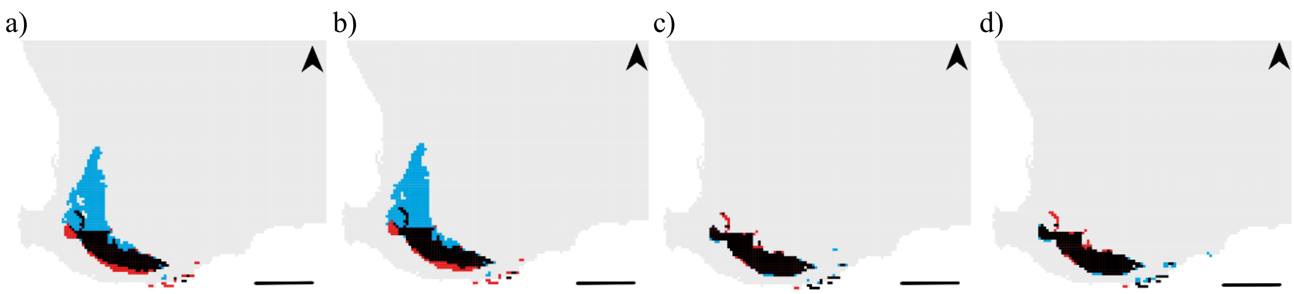

Fig. S6. Shifting ranges under climate change for *Caladenia christineae*. Species range under a) LIG; b) HCO c) SSP2-4.5 and d) SPP5-8.5 climatic scenarios are compared with current distribution. Red indicates potential range loss, blue potential range gain, while black indicates no change. Black arrows point North, and scale bars = 100km.

a) b) c) d)

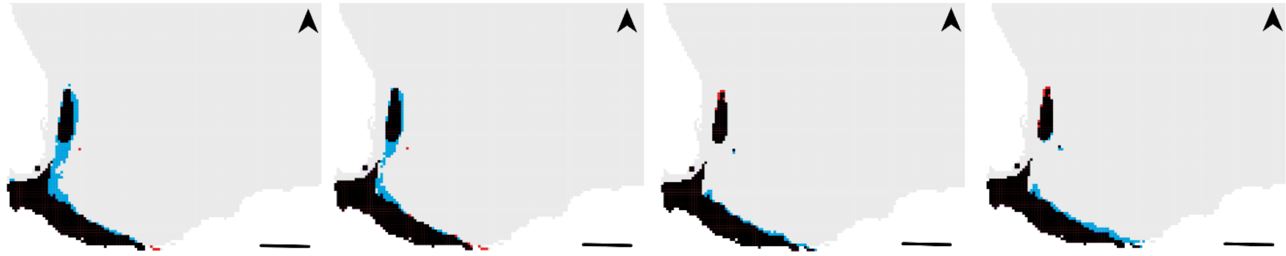

Fig. S7. Shifting ranges under climate change for *Caladenia citrina*. Species range under a) LIG; b) HCO c) SSP2-4.5 and d) SPP5-8.5 climatic scenarios are compared with current distribution. Red indicates potential range loss, blue potential range gain, while black indicates no change. Black arrows point North, and scale bars = 100km.

a) b) c) d)

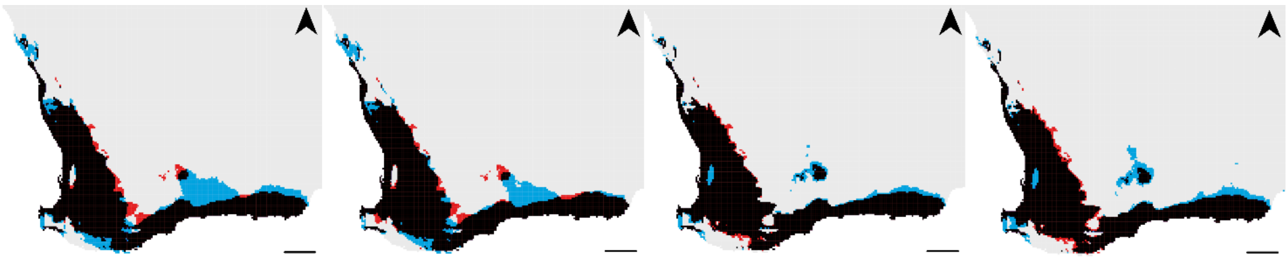

Fig. S8. Shifting ranges under climate change for *Caladenia discoidea*. Species range under a) LIG; b) HCO c) SSP2-4.5 and d) SPP5-8.5 climatic scenarios are compared with current distribution. Red indicates potential range loss, blue potential range gain, while black indicates no change. Black arrows point North, and scale bars = 100km.

a) b) c) d)

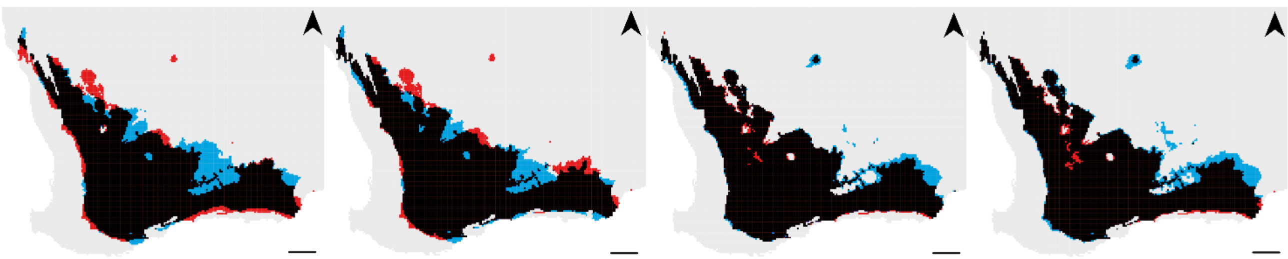

Fig. S9. Shifting ranges under climate change for *Caladenia doutchiae*. Species range under a) LIG; b) HCO c) SSP2-4.5 and d) SPP5-8.5 climatic scenarios are compared with current distribution. Red indicates potential range loss, blue potential range gain, while black indicates no change. Black arrows point North, and scale bars = 100km.

a) b) c) d)

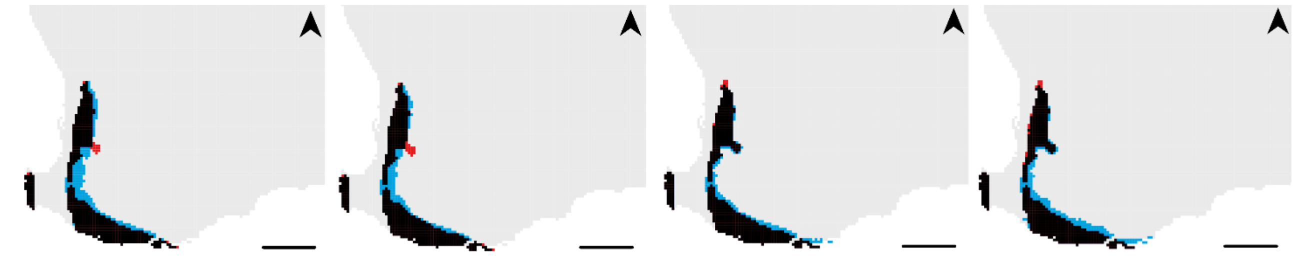

Fig. S10. Shifting ranges under climate change for *Caladenia excelsa*. Species range under a) LIG; b) HCO c) SSP2-4.5 and d) SPP5-8.5 climatic scenarios are compared with current distribution. Red indicates potential range loss, blue potential range gain, while black indicates no change. Black arrows point North, and scale bars = 100km.

a) b) c) d)

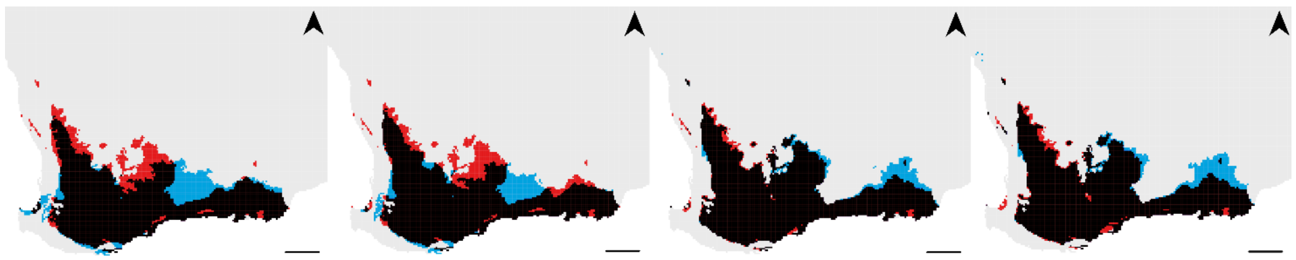

Fig. S11. Shifting ranges under climate change for *Caladenia falcata.* Species range under a) LIG; b) HCO c) SSP2-4.5 and d) SPP5-8.5 climatic scenarios are compared with current distribution. Red indicates potential range loss, blue potential range gain, while black indicates no change. Black arrows point North, and scale bars = 100km.

a) b) c) d)

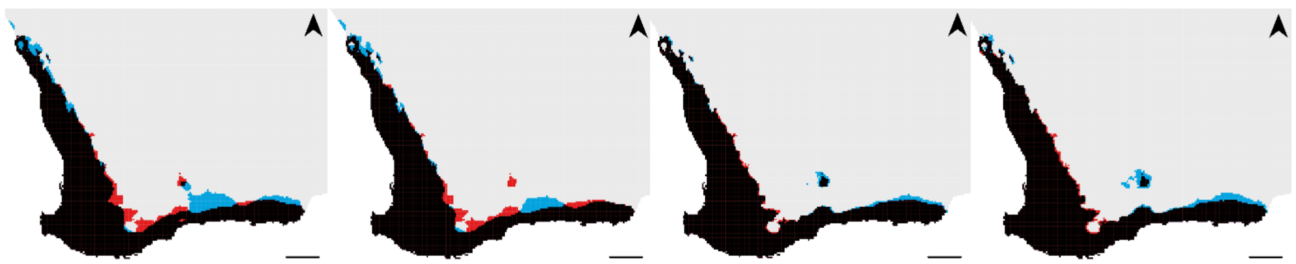

Fig. S12. Shifting ranges under climate change for *Caladenia flava.* Species range under a) LIG; b) HCO c) SSP2-4.5 and d) SPP5-8.5 climatic scenarios are compared with current distribution. Red indicates potential range loss, blue potential range gain, while black indicates no change. Black arrows point North, and scale bars = 100km.

a) b) c) d)

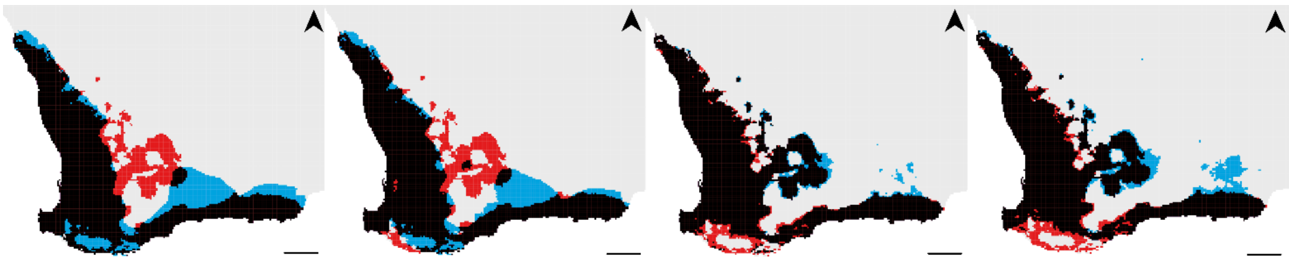

Fig. S13. Shifting ranges under climate change for *Caladenia footeana.* Species range under a) LIG; b) HCO c) SSP2-4.5 and d) SPP5-8.5 climatic scenarios are compared with current distribution. Red indicates potential range loss, blue potential range gain, while black indicates no change. Black arrows point North, and scale bars = 100km.

a) b) c) d)

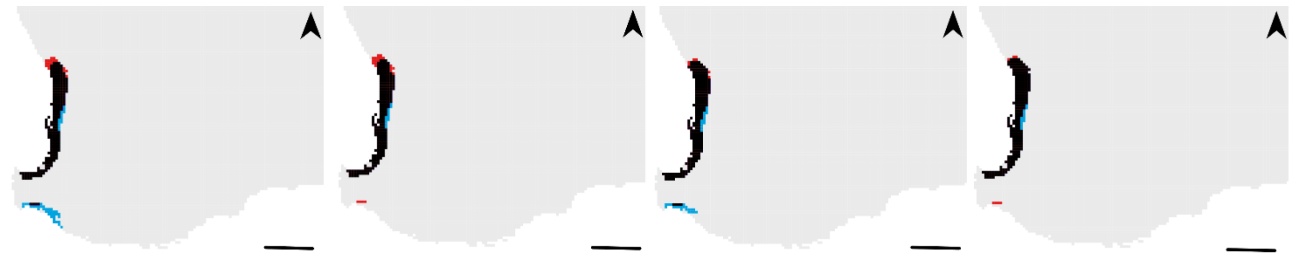

Fig. S14. Shifting ranges under climate change for *Caladenia georgei*. Species range under a) LIG; b) HCO c) SSP2-4.5 and d) SPP5-8.5 climatic scenarios are compared with current distribution. Red indicates potential range loss, blue potential range gain, while black indicates no change. Black arrows point North, and scale bars = 100km.

a) b) c) d)

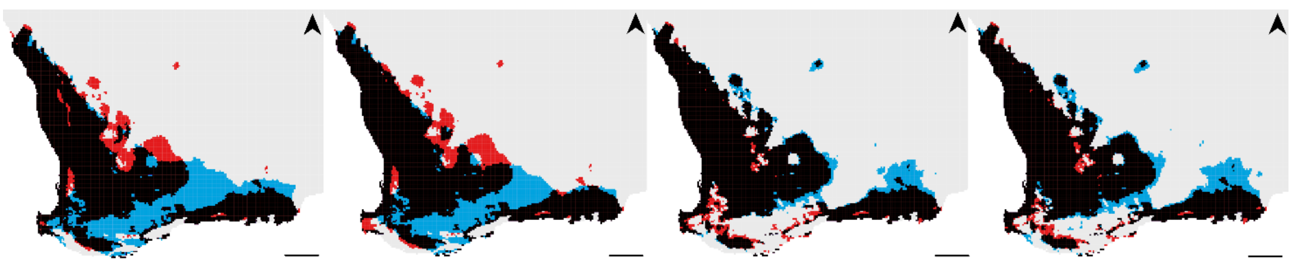

Fig. S15. Shifting ranges under climate change for *Caladenia hirta*. Species range under a) LIG; b) HCO c) SSP2-4.5 and d) SPP5-8.5 climatic scenarios are compared with current distribution. Red indicates potential range loss, blue potential range gain, while black indicates no change. Black arrows point North, and scale bars = 100km.

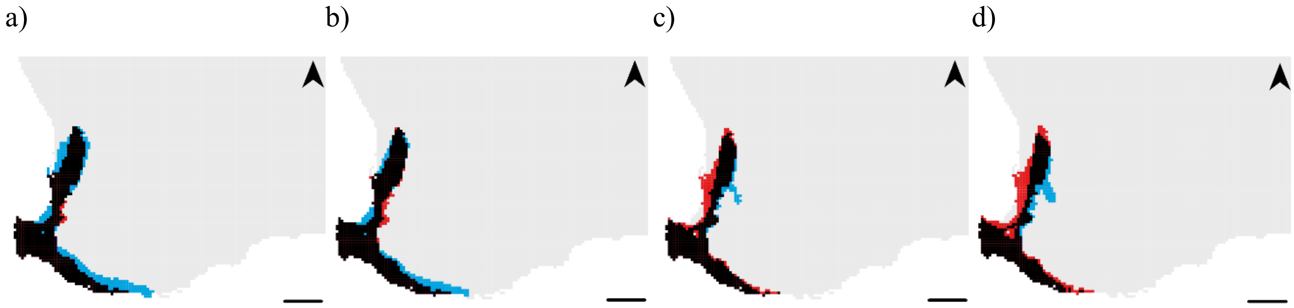

Fig. S16. Shifting ranges under climate change for *Caladenia infundibularis*. Species range under a) LIG; b) HCO c) SSP2-4.5 and d) SPP5-8.5 climatic scenarios are compared with current distribution. Red indicates potential range loss, blue potential range gain, while black indicates no change. Black arrows point North, and scale bars = 100km.

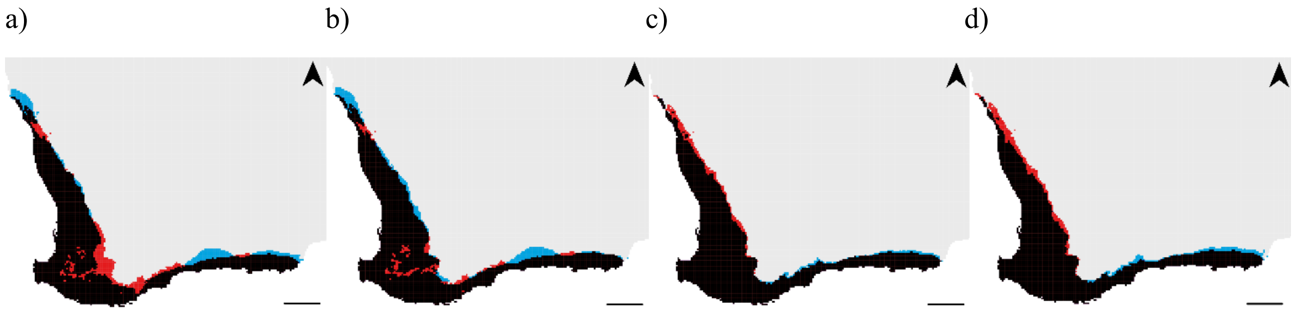

Fig. S17. Shifting ranges under climate change for *Caladenia latifolia*. Species range under a) LIG; b) HCO c) SSP2-4.5 and d) SPP5-8.5 climatic scenarios are compared with current distribution. Red indicates potential range loss, blue potential range gain, while black indicates no change. Black arrows point North, and scale bars = 100km.

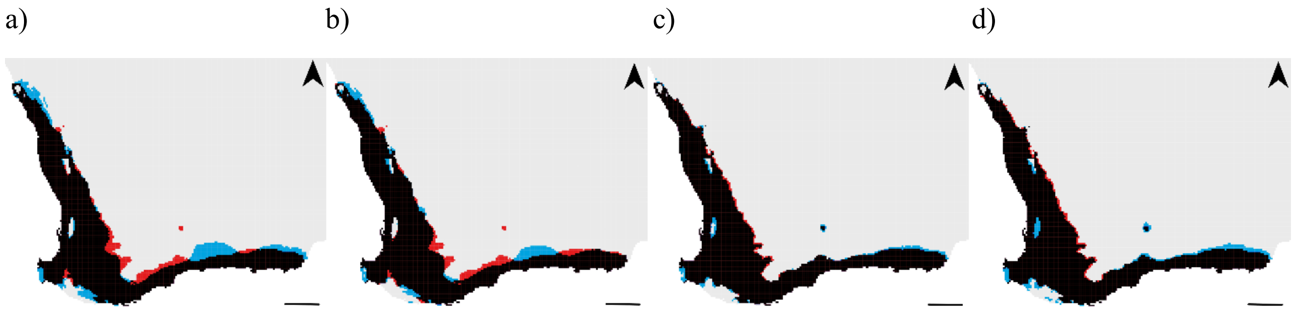

Fig. S18. Shifting ranges under climate change for *Caladenia longicauda*. Species range under a) LIG; b) HCO c) SSP2-4.5 and d) SPP5-8.5 climatic scenarios are compared with current distribution. Red indicates potential range loss, blue potential range gain, while black indicates no change. Black arrows point North, and scale bars = 100km.

a) b) c) d)

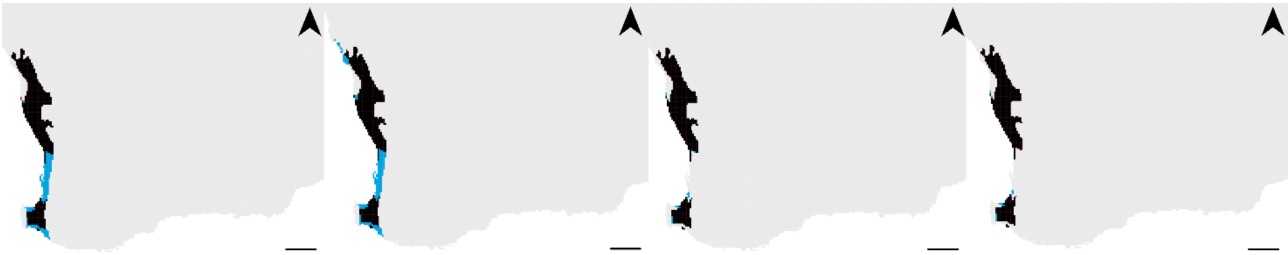

Fig. S19. Shifting ranges under climate change for *Caladenia lorea*. Species range under a) LIG; b) HCO c) SSP2-4.5 and d) SPP5-8.5 climatic scenarios are compared with current distribution. Red indicates potential range loss, blue potential range gain, while black indicates no change. Black arrows point North, and scale bars = 100km.

a) b) c) d)

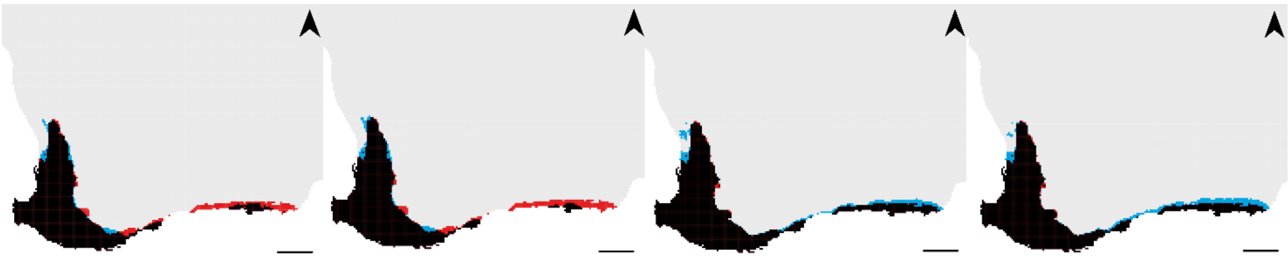

Fig. S20. Shifting ranges under climate change for *Caladenia macrostylis*. Species range under a) LIG; b) HCO c) SSP2-4.5 and d) SPP5-8.5 climatic scenarios are compared with current distribution. Red indicates potential range loss, blue potential range gain, while black indicates no change. Black arrows point North, and scale bars = 100km.

a) b) c) d)

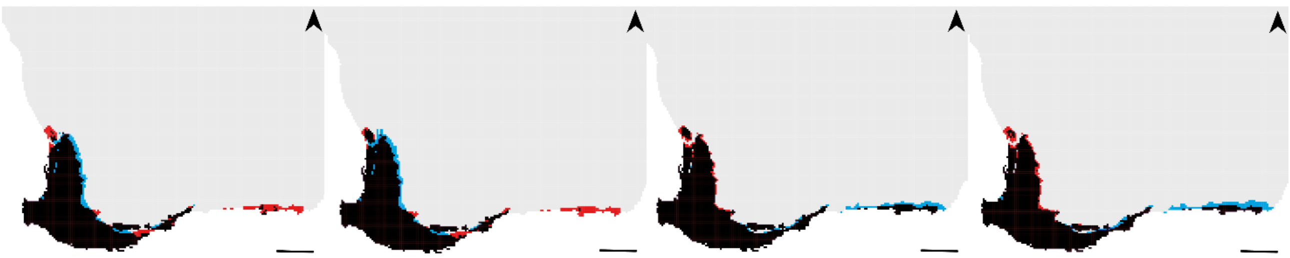

Fig. S21. Shifting ranges under climate change for *Caladenia nana*. Species range under a) LIG; b) HCO c) SSP2-4.5 and d) SPP5-8.5 climatic scenarios are compared with current distribution. Red indicates potential range loss, blue potential range gain, while black indicates no change. Black arrows point North, and scale bars = 100km.

a) b) c) d)

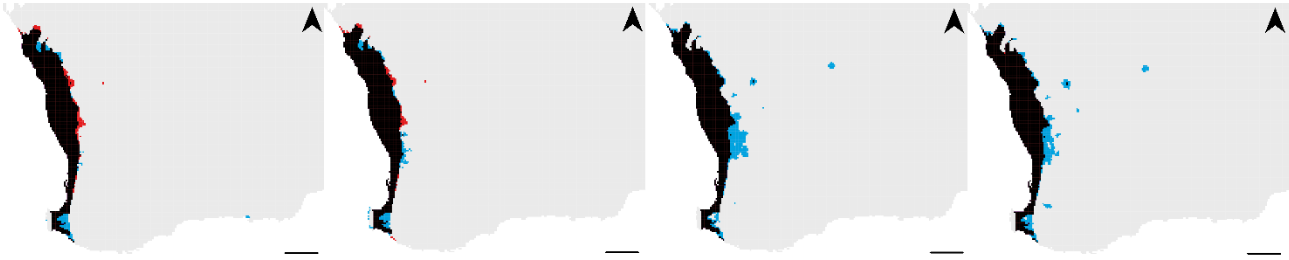

Fig. S22. Shifting ranges under climate change for *Caladenia nobilis*. Species range under a) LIG; b) HCO c) SSP2-4.5 and d) SPP5-8.5 climatic scenarios are compared with current distribution. Red indicates potential range loss, blue potential range gain, while black indicates no change. Black arrows point North, and scale bars = 100km.

a) b) c) d)

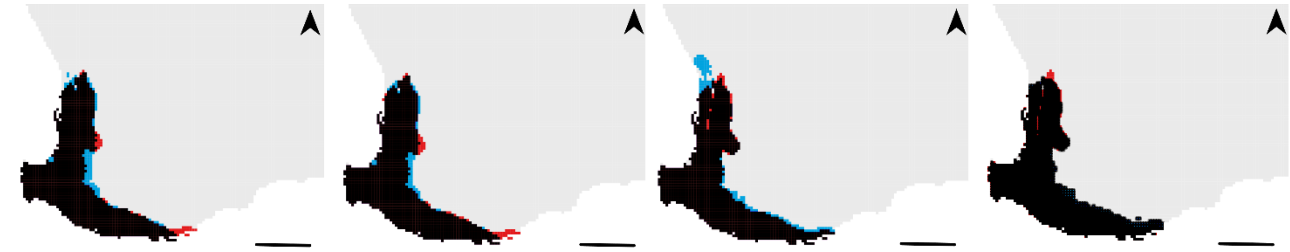

Fig. S23. Shifting ranges under climate change for *Caladenia thinicola*. Species range under a) LIG; b) HCO c) SSP2-4.5 and d) SPP5-8.5 climatic scenarios are compared with current distribution. Red indicates potential range loss, blue potential range gain, while black indicates no change. Black arrows point North, and scale bars = 100km.

a) b) c) d)

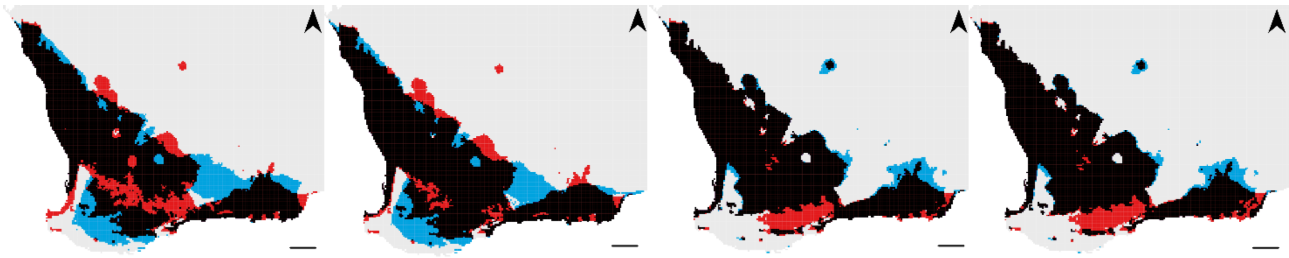

Fig. S24. Shifting ranges under climate change for *Caladenia varians.* Species range under a) LIG; b) HCO c) SSP2-4.5 and d) SPP5-8.5 climatic scenarios are compared with current distribution. Red indicates potential range loss, blue potential range gain, while black indicates no change. Black arrows point North, and scale bars = 100km.

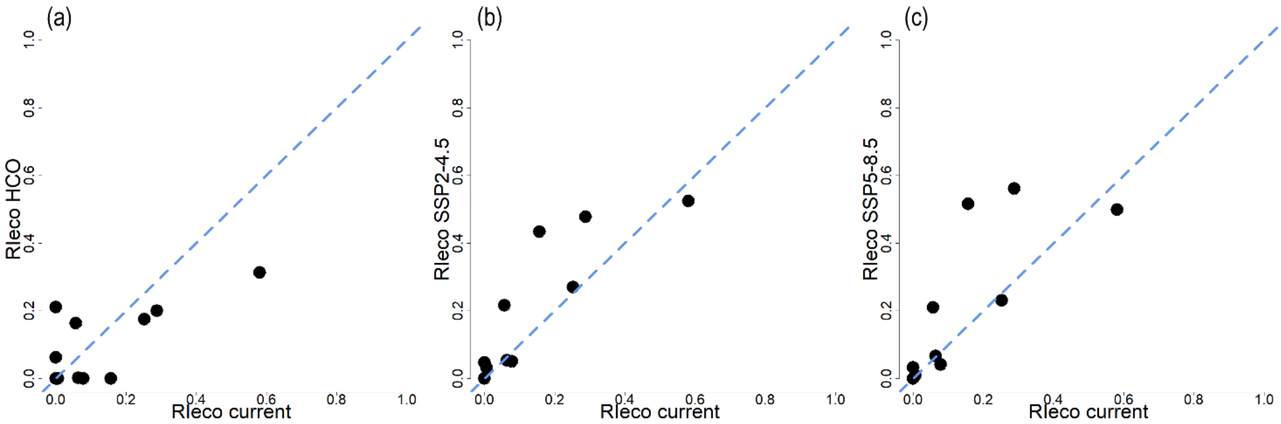

Fig. S25. Mean pairwise values between (a) current ecogeographical isolation (*RIeco*) and *RIeco* during the Mid Holocene (HCO); (b) current *RIeco* and *RIeco* predicted for SSP2-4.5 scenarios; (c) current *RIeco* and *RIeco* predicted for SSP5-8.5 scenarios. Dashed lines indicate no change in the *RIeco*. Values below the line indicate decreased *RIeco*, while values above the dashed line indicate increased *RIeco* from current conditions.