Ecography

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Supplementary material

Appendix 1

Canopy cover measurements

We compared canopy cover recorded with the CanopyApp (UNH Earth Systems Research Center; https://itunes.apple.com/us/app/canopyapp/id926943048?mt=8) at the point of the sensor with canopy cover collected with a densitometer across 20 points in a ~20 m diameter plot centered on the sensor. The number of points in the plot where canopy intersected the densitometer reading were divided by the total number of points (20) and multiplied by 100 to obtain percent canopy cover. These measures of canopy cover at two different scales (point scale and stand scale) were correlated (R^2=0.84; Fig. A1).

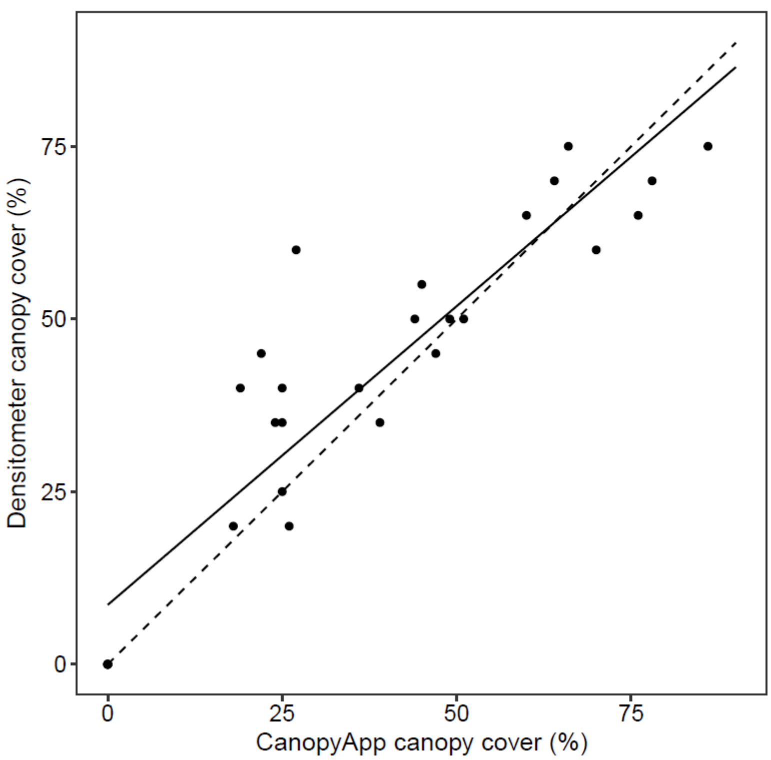

Figure A1. Comparison of canopy cover measured with the CanopyApp at the point of the sensor with canopy cover measured with a densitometer and averaged across a ~314 m^2 plot centered on the sensor. The solid line is the fitted line from a linear regression and the dashed line is the 1:1 line.

We also compared measurements of canopy cover with a spherical densiometer to those recorded with the CanopyApp. Points were located haphazardly across two sites to cross a gradient of canopy cover. Ten points were recorded at the Lubrecht Experimental Forest (one of the main study sites). Twenty additional points were recorded at Pattee Canyon Recreation Area just east of Missoula, MT. The two measurements were highly correlated with R^2=0.87 and a slope of 0.92 (95% confidence interval: 0.78-1.07). The spherical densiometer tended to produce a higher estimate of canopy cover than the app by 15.7% (95% confidence interval: 7.97-23.4).

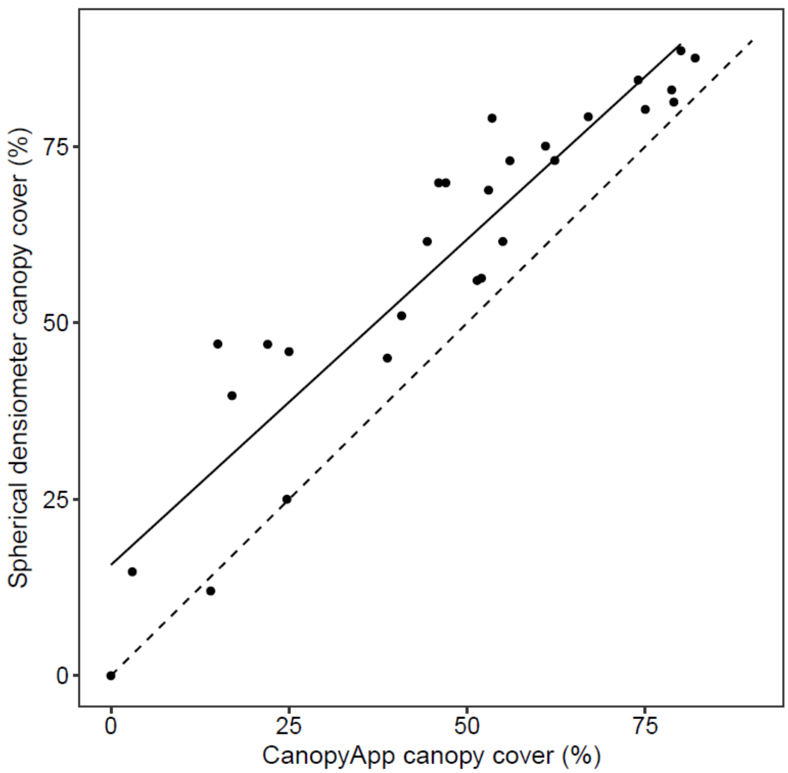

Figure A2. Comparison of canopy cover measured with the CanopyApp with canopy cover measured with a spherical densiometer. The solid line is the fitted line from a linear regression and the dashed line is the 1:1 line.

Daily differences in temperature and VPD from 10 cm in forest to 2 m in open

The difference between the low sensors in the forest and the high sensors in the clearing represents the potential difference between gridded climate data (based on 2 m sensors in clearings) and the microclimate conditions experienced by organisms near ground level. This difference for maximum temperature and VPD was best explained by soil moisture, canopy cover, solar radiation, and the interaction between solar radiation and canopy cover (Fig. A3). These models represent the tradeoff between higher microclimate variability at the ground level and less microclimate variability under forest cover. At low levels of solar radiation, predicted ΔMXT.LH and ΔVPD.LH were negative (cooler, moister in forest) once canopy cover surpassed approximately 30%. However, at higher levels of solar radiation, very high levels of canopy cover were necessary before it was cooler and/or moister at 10 cm in the forest than at 2 m in the clearing. Our model suggests that canopy cover is the most important variable in predicting ΔMNT.LH, however the model had considerably less explanatory power than the models for maximum temperature and VPD. Note that we did not compare our forest microclimate measurements to actual gridded climate data.

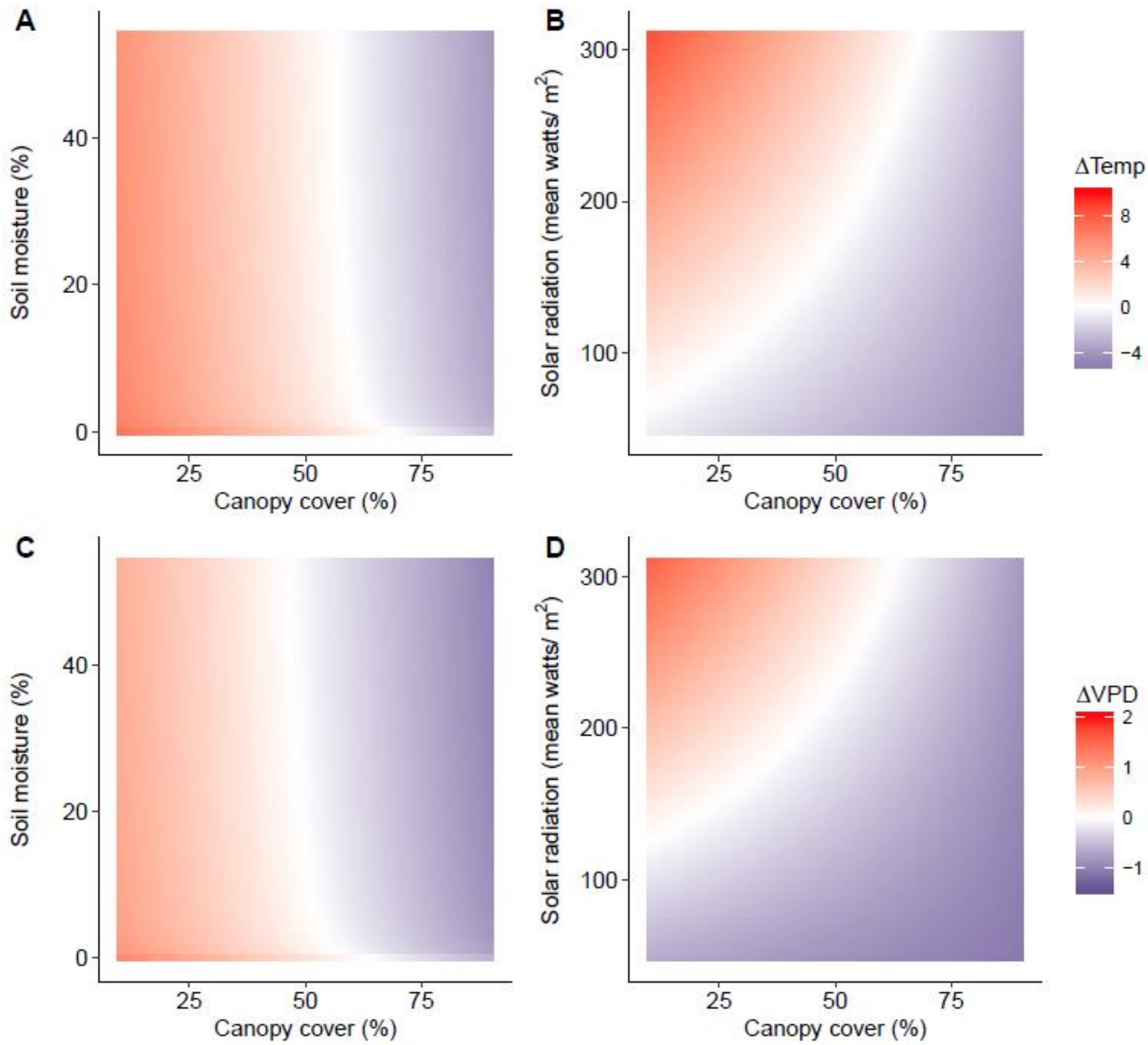

Figure A3. Difference in maximum temperature (ΔMXT.LH; A & B) and maximum VPD (ΔVPD.LH; C & D) between sensors under the canopy at ground level and the reference sensor in the open at 2 m. Temperature differences are in degrees C and VPD differences in kPa. Both ΔMXT.LH and ΔVPD.LH were most strongly related to soil moisture, canopy cover, daily mean solar radiation, and the interaction between daily mean solar radiation and canopy cover. Models for ΔMNT (not shown) were less explanatory than for ΔMXT.LH and ΔVPD.LH but suggest that canopy cover is the most important variable. These differences between the low sensors in the forest and the high sensors in the clearing represents the potential difference between gridded climate data (based on 2 m sensors in clearings) and the microclimate conditions experienced by organisms near ground level in forests.

Table A1. Global climate models used to predict future water balance metrics (2040-2069).

Modelling Center or Group	Model
Beijing Climate Center, China Meteorological Administration	BCC_Csm1_1_m
	BCC_Csm1_1
College of Global Change and Earth System Science, Beijing Normal University	BNU_Esm
National Center for Atmospheric Research	CCsm4
Centre National de Recherches Météorologiques / Centre Européen de Recherche et Formation Avancée en Calcul Scientifique	CNRM_CM5
Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence	CSIRO_Mk3_6_0
NOAA Geophysical Fluid Dynamics Laboratory	GFDL_Esm2G
	GFDL_Esm2M
Met Office Hadley Centre	HadGEM2_CC
	HadGEM2_ES
Institute for Numerical Mathematics	INM-CM4
Institut Pierre-Simon Laplace	IPSL_CM5A_LR
	IPSL_CM5A_MR
	IPSL_CM5B_LR
Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	MIROC_Esm_CHEM
	MIROC_Esm
Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	MIROC5
Meteorological Research Institute	MRI_CGCM3
Norwegian Climate Centre	NorEsm1_M

Table A2. Top ranked daily models for each response variable and their RMSE from 6-fold cross validation spatially stratified by site. Marginal R^2 corresponds to just the fixed effects and conditional R^2 includes the fixed and random effects. Response abbreviations described in Methods. Low are sensors placed at 10 cm above the ground, high are 2 m sensors, and LH represents the difference from low sensors in the forest to high sensors in the clearing. "sm" is soil moisture, "srad" solar radiation, and "MinRH" minimum relative humidity.

Response	Top model	RMSE	Marginal R^2	Conditional R^2
ΔMXT low	poly(srad)*Canopy+Wind	3.81	0.29	0.64
ΔMNT low	minRH*wind	1.97	0.17	0.52
ΔVPD low	poly(srad)*Canopy+Wind	0.93	0.20	0.49
ΔMXT high	poly(sm)*Canopy	1.84	0.17	0.56
ΔMNT high	Canopy	1.45	0.02	0.69
ΔVPD high	poly(sm)*Canopy	0.47	0.11	0.28
ΔMXT.LH	Canopy*srad + sm	3.88	0.33	0.67
ΔMNT.LH	Canopy	2.21	0.06	0.64
ΔVPD.LH	Canopy*srad + sm	1.07	0.21	0.52

Table A3. Direction of significant relationships between the absolute value of the daily differences and the predictor variables. Positive values indicate a larger absolute difference between the forest and the clearing and negative values indicate the opposite. "sm" is soil moisture, "srad" solar radiation, and "MinRH" minimum relative humidity. "n.s." signifies that the variable was not selected by cross validation to be part of the final model. We did not include minimum RH in VPD models because RH was used to calculate VPD.

Variable	Canopy	sm	srad	Wind	MinRH
ΔMXT low	+	n.s.	+/-	-	n.s.
ΔMNT low	n.s.	n.s.	n.s.	-	-
ΔVPD low	+	n.s.	+/-	-	NA
ΔMXT high	+	+	n.s.	n.s.	n.s.
ΔMNT high	+	n.s.	n.s.	n.s.	n.s.
ΔVPD high	+	+	n.s.	n.s.	NA

Table A4. Standardized coefficients from top ranked daily models for each response variable. Response abbreviations described in Methods. Low are sensors placed at 10 cm above the ground, high are 2 m sensors, and LH represents the difference from low sensors in the forest to high sensors in the clearing. “sm” is soil moisture, “srad” solar radiation, and “MinRH” minimum relative humidity.

	Response								
Predictor	ΔMXT low	ΔMNT low	ΔVPD low	ΔMXT high	ΔMNT high	ΔVPD high	ΔMXT .LH	ΔMNT .LH	ΔVPD. LH
Canopy	-0.513	-	-0.405	-0.426	0.164	-0.263	-0.144	0.254	-0.015
Wind	0.085	0.129	0.077	-	-	-	-	-	-
minRH	-	-0.267	-	-	-	-	-	-	-
srad	-	-	-	-	-	-	0.549	-	0.516
poly(srad)1	0.307	-	0.270	-	-	-	-	-	-
poly(srad)2	0.086	-	0.087	-	-	-	-	-	-
sm	-	-	-	-	-	-	-0.073	-	-0.072
poly(sm)1	-	-	-	0.112	-	0.032	-	-	-
poly(sm)2	-	-	-	-0.073	-	0.062	-	-	-
Canopy* poly(srad)1	-0.287	-	-0.382	-		-	-	-	-
Canopy* poly(srad)2	-0.015	-	-0.038	-	-	-	-	-	-
Canopy* poly(sm)1	-	-	-	-0.182	-	-0.059	-	-	-
Canopy* poly(sm)2	-	-	-	-0.051	-	-0.261	-	-	-
Wind* minRH	-	-0.229	-	-	-	-	-	-	-
srad* Canopy	-	-	-	-	-	-	-0.470	-	-0.460

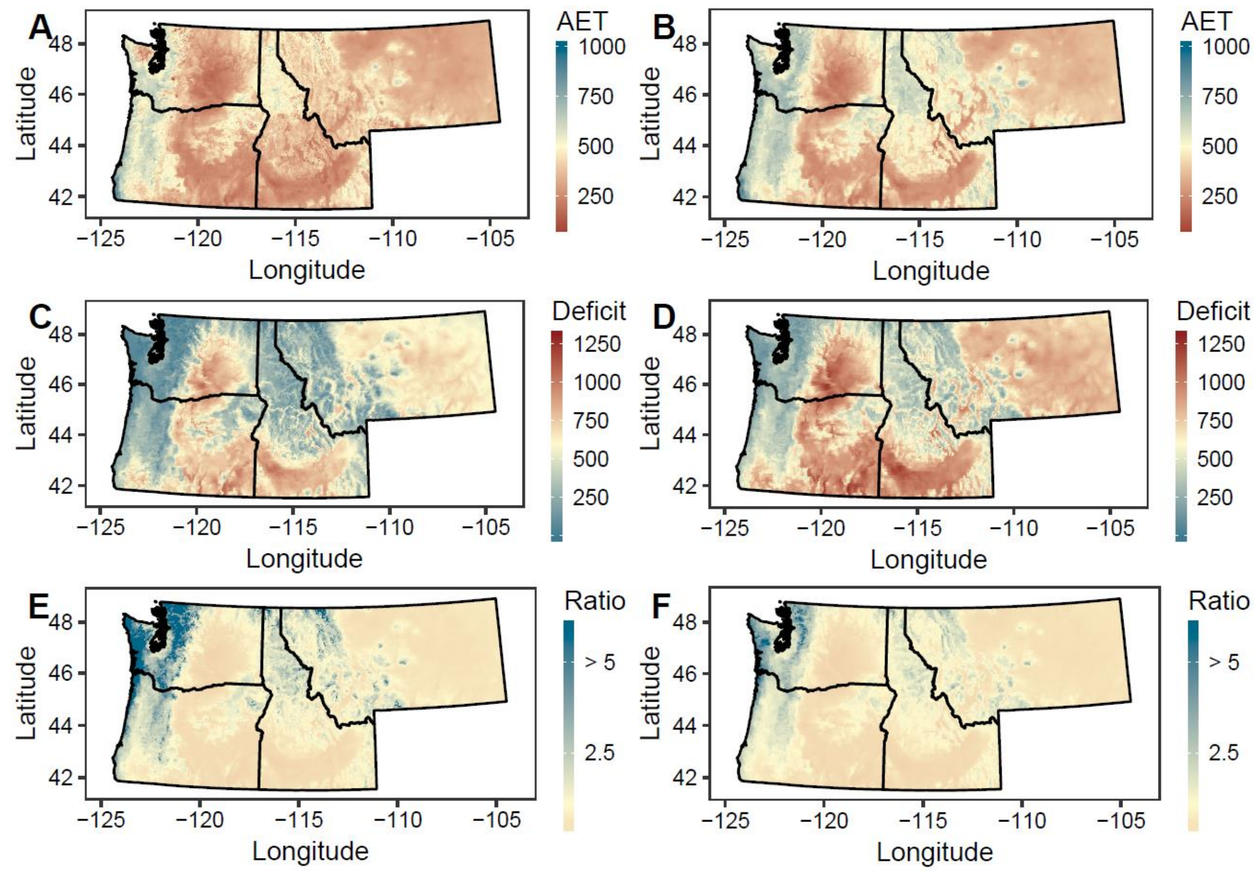

Figure A4. Current (1980-2009; A, C, E) and future (2040-2069; B, D, F) predictions of AET (A & B), deficit (C & D), and their ratio (AET/deficit; E & F) for the northwestern USA. Future conditions are the mean from 20 global climate models.

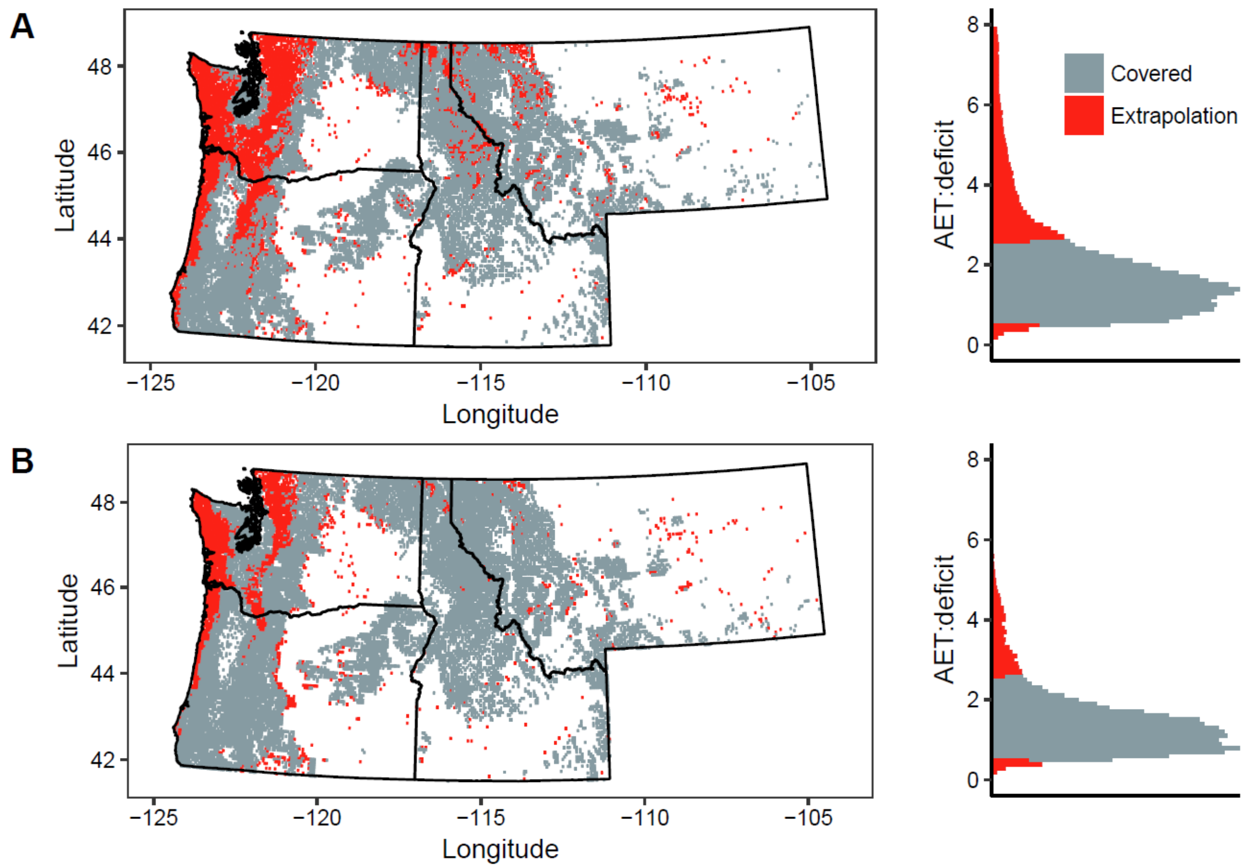

Figure A5. Maps depicting areas with AET-to-deficit ratios outside (extrapolation; red) and within (covered; gray) the range of AET-to-deficit ratios in our study sites for forested (>20% canopy cover) pixels in the northwestern U.S. under mean current (A; 1980-2009) and future (B; 2040-2069) conditions. Histograms to the right of plots display the distribution of cells on the landscape. Extrapolation occurred to 25% of the pixels with current conditions and 14% of the pixels with future conditions.

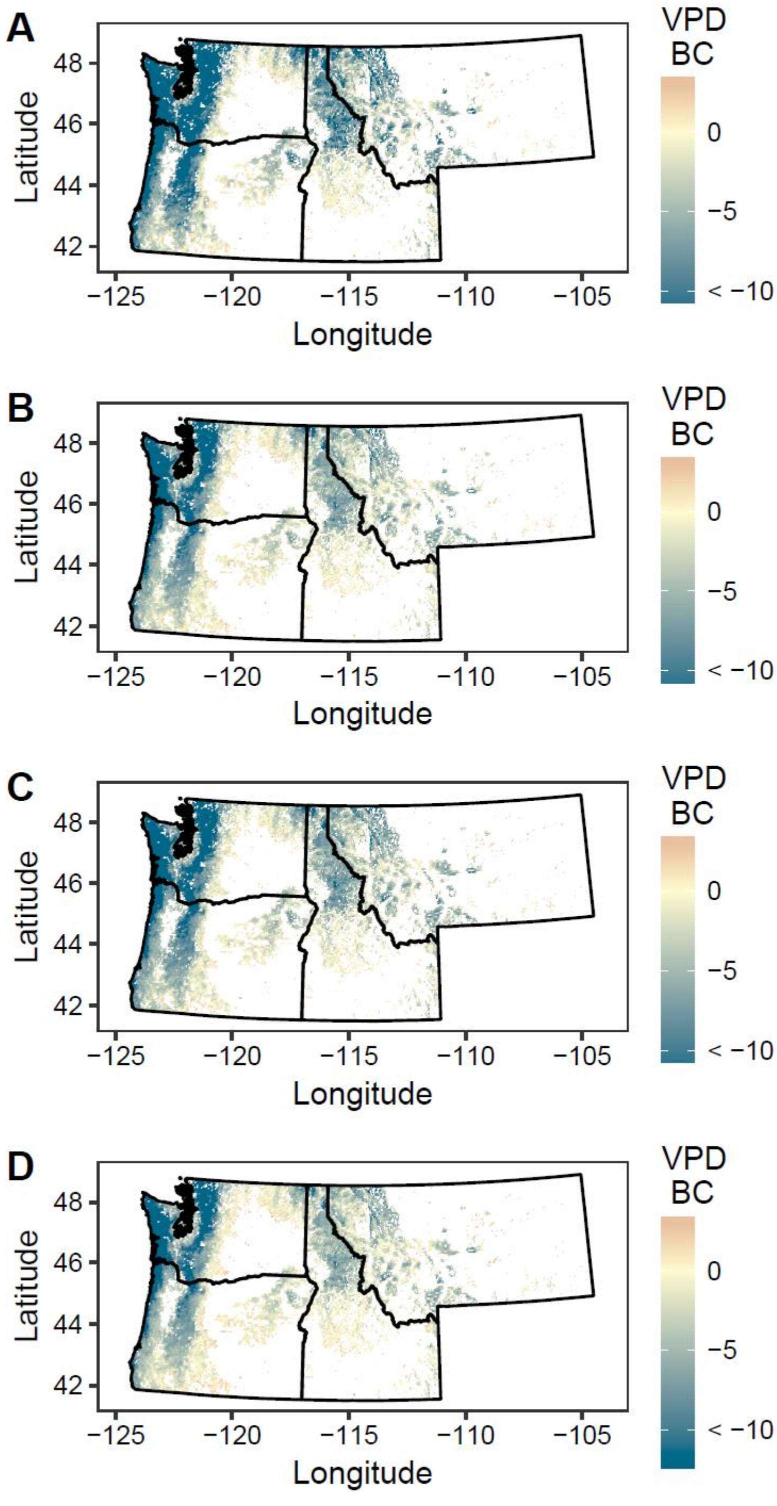

Figure A6. Microclimatic buffering capacity near the ground surface for maximum VPD under current conditions (1980-2009; A); or future climate conditions (2040-2069) and no change in canopy cover (B); a 10% increase in canopy cover (C); or a 10% decrease in canopy cover (D). Blue indicates microclimatic buffering by forests, yellow indicates no difference between forest and reference conditions, and red indicates it was drier in the forest. Projections are made in areas with at least 20% canopy cover.

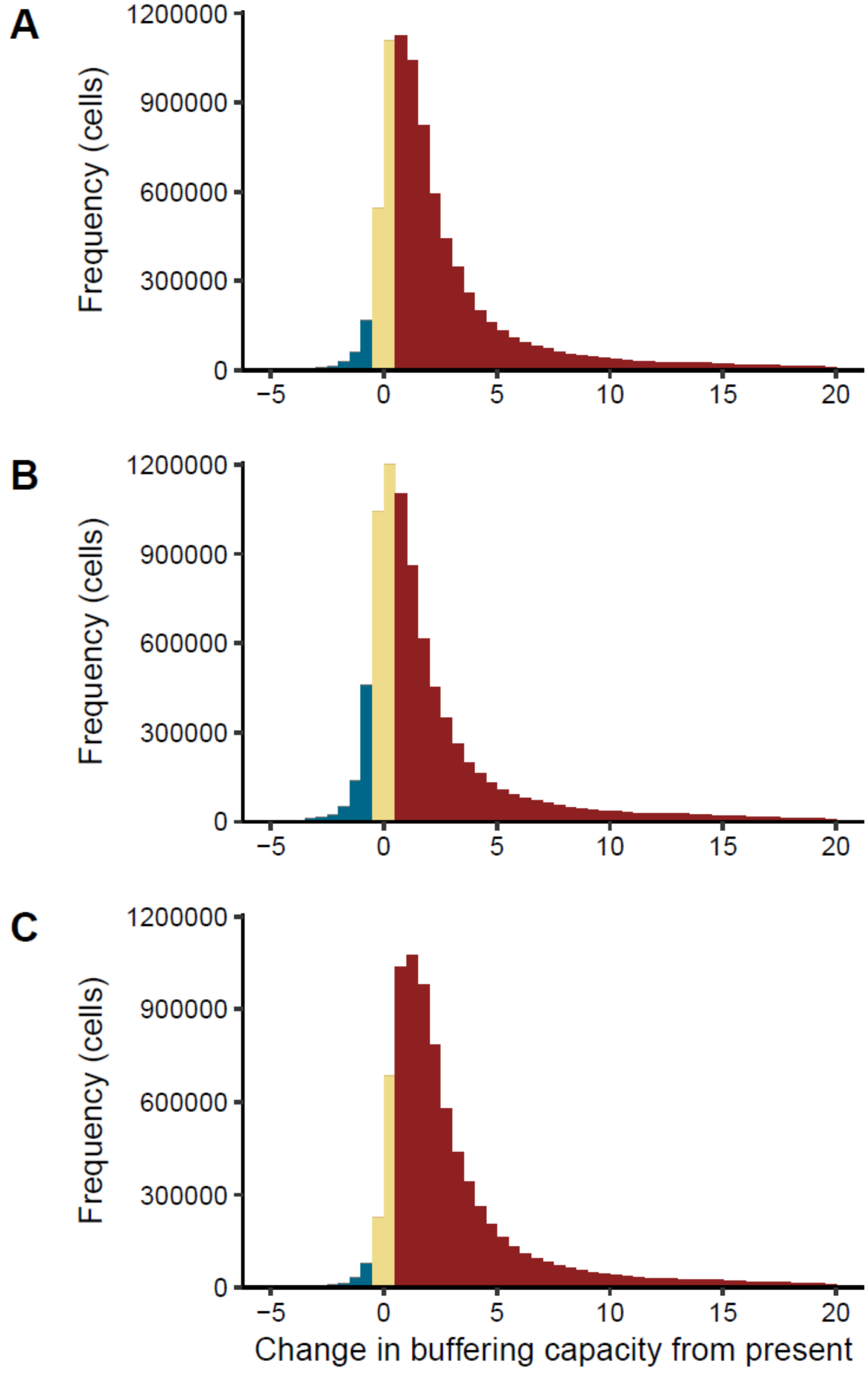

Figure A7. Difference in microclimatic buffering capacity near the ground surface for maximum VPD between current conditions (1980-2009) and future climate conditions (2040-2069) with no change in canopy cover (A); a 10% increase in canopy cover (B); or a 10% decrease in canopy cover (C). Blue indicates a shift to greater microclimatic buffering capacity in the future, yellow indicates no change in buffering capacity over time, and red indicates a shift to reduced buffering capacity in the future. Projections are made in areas with at least 20% canopy cover in Washington, Oregon, Idaho, and Montana (Fig. A5).