Modeling Potential Impacts of Climate Change on the Distributions of 6 GGBN Priority Plants

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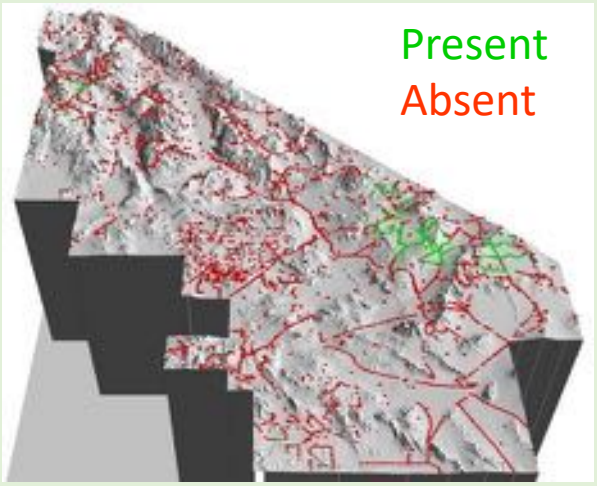
Climate Change & Range Shifts

- Impacts of CC on biodiversity increasingly evident
- Altered climate conditions can exceed species' tolerances
  - Climatically suitable habitat may increase, decline, or shift
  - Persistence ~ dispersal & establishment to suitable habitat
- Changes in climate suitability will be species-specific
  - Not uniform across communities or current ranges.
- Maps delineating current & future habitat suitability needed:
  - Targeted monitoring
  - Scenario planning
  - Potential refugia protection
  - Proactive and adaptive management and decision making

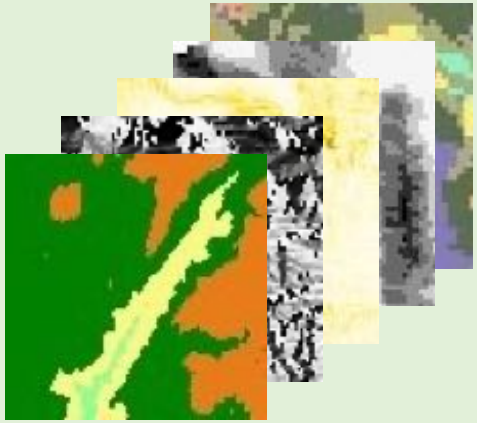
US Forest Service illustration by Savannah Halleaux

Species Distribution Models (SDMs)

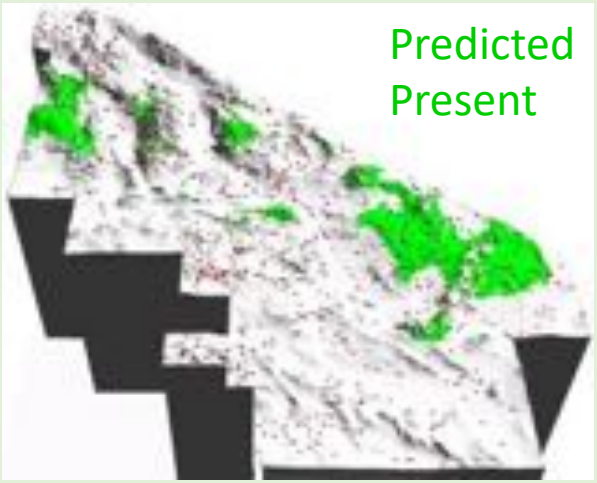
- Models of species-environment relationships
- Interpolate biological survey data in space
  - Statistical and machine learning methods
- Predict occurrence for locations where survey data are lacking



Survey Data



Environmental Data



Prediction Map

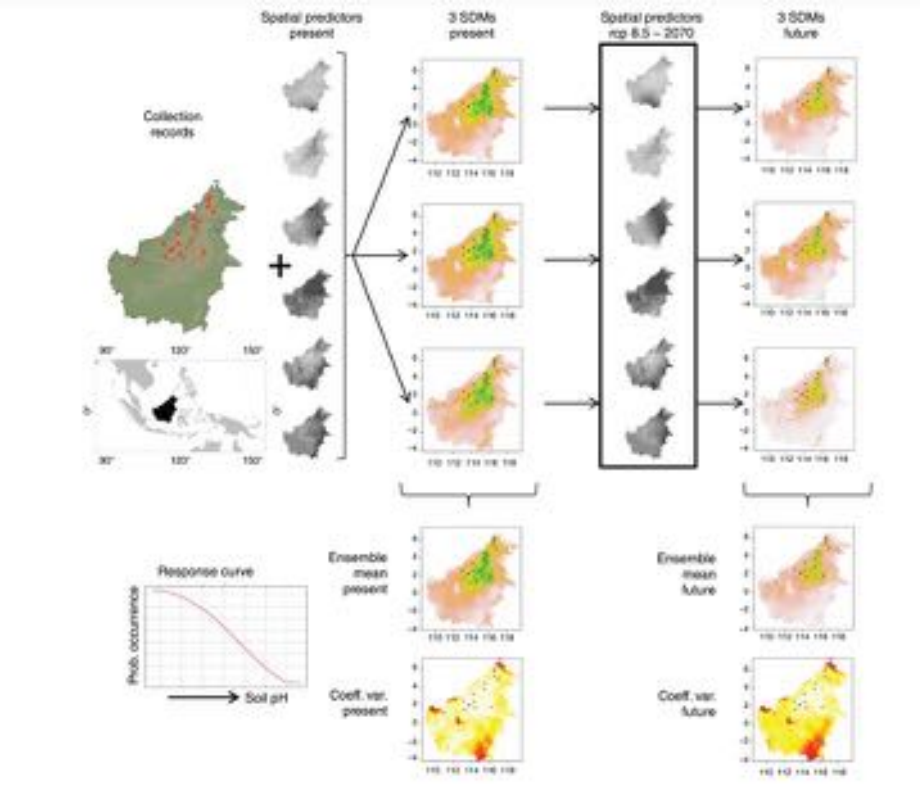
Species distribution=f(environmental data)→Prediction

SDM Limitations

- Data issues
  - *E.g., sample size, resolution, appropriate predictors*
- May not account for biotic interactions or disturbance agents
  - *E.g., competition, facilitation, fire, disease, pests*
- Accuracy varies by species traits
  - *E.g., rarity, range size, body size, mobility*
- No demographic processes
  - *E.g., dispersal, fecundity, mortality, carrying capacity*
- Methodological uncertainty
  - *Model algorithm found to be biggest source*
  - *Can be compounded with other sources of uncertainty such as climate models and data bias, etc.*

Ensemble SDMs

- ‘Fusion’ of predictions from multiple SDM model types
- Decreases prediction uncertainty
- Highlights agreement among different model outputs
- Often more robust & reliable than single model predictions



A Modeling Framework to Estimate and Project Species Distributions in Space and Time

Niels Raes[1] and Jesús Aguirre-Gutiérrez[1,2,3]

Objective

Use ensemble SDM to evaluate climate change effects on distribution and occurrence of 6 priority GGBN plant species

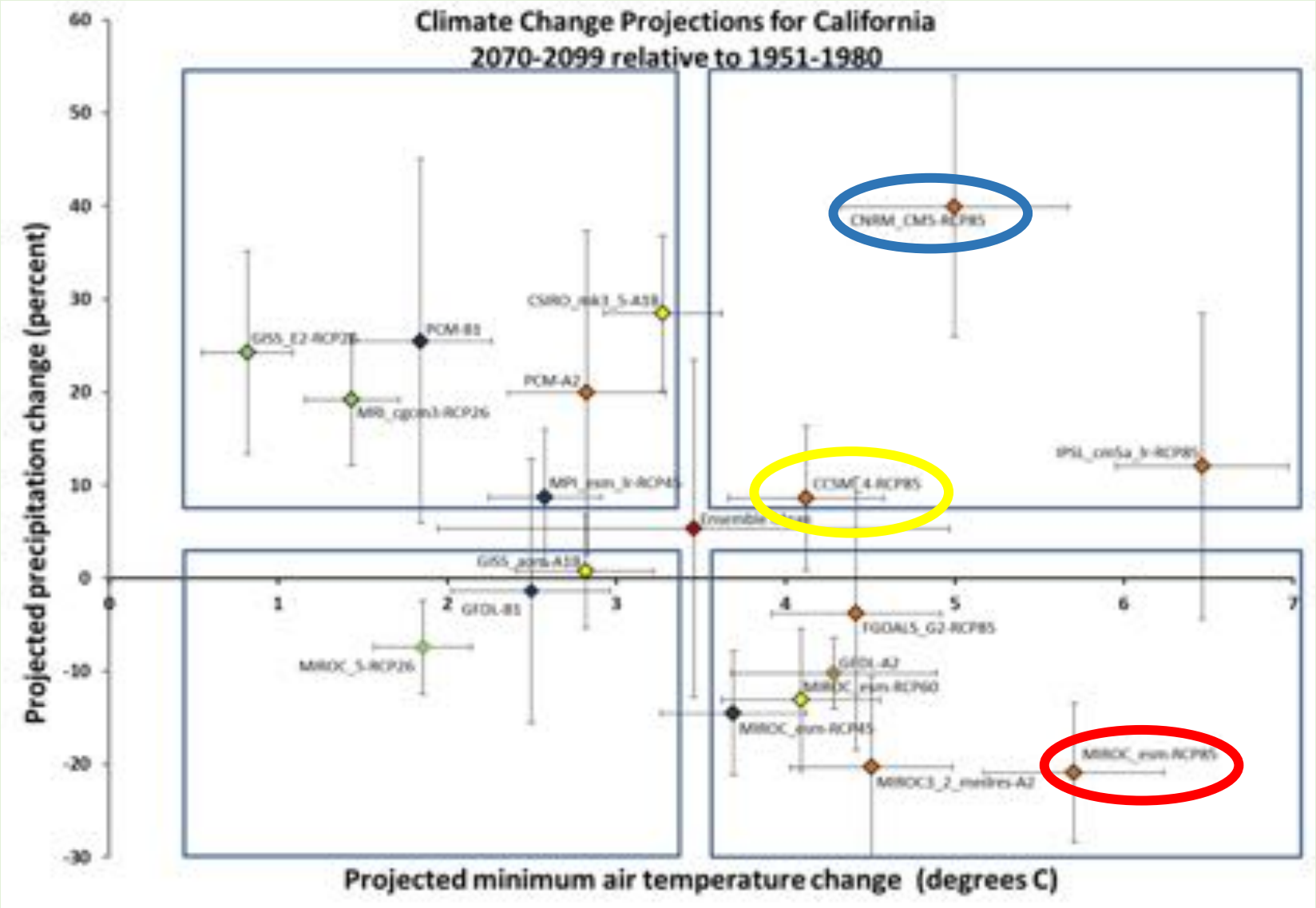
For each species:

- Model baseline distributions at regional scales;
- Identify important drivers of distributions;
- Project potential future (2070-2099) habitat under 3 GCMs;
- Produce mapped predictions for baseline and future in the GGBN;
- Evaluate potential impacts of climate by quantifying area likely to:
  - Persist (remain suitable),
  - Expand (become suitable),
  - Contract (become unsuitable)

GGBN Priority Trees and Shrubs

Species	Lifeform Description	Distribution/Associated Communities
Chamise (*Adenostoma fasciculatum*)	Shade-intolerant evergreen shrub	Most common chaparral species statewide
Coyote Brush (*Baccharis pilularis*)	Shade-intolerant evergreen shrub	Outer Coast Ranges from northern Mex. to OR. Dominant shrub in northern coastal scrub communities
Douglas Fir (*Pseudotsuga menziesii*)	Long-lived, large, coniferous, evergreen tree	Adapted to moist, mild climate, grows from BC to central CA
Coast Live Oak (*Quercus agrifolia*)	Drought-resistant, broadleaf evergreen tree	Occurs in CA and northern Mex., lower-elevation oak woodlands of CA
California Black Oak (*Quercus kelloggii*)	Highly drought-tolerant deciduous tree	Occurs in OR and CA, most common in ponderosa pine and mixed-conifer forests, also mixed-oak woodlands
Coast Redwood (*Sequoia sempervirens*)	Long-lived, large, shade-tolerant, monoecious evergreen tree	Found in coastal northern CA and southwestern OR. Limited to fog belt zone or high moisture areas

Climate Scenarios



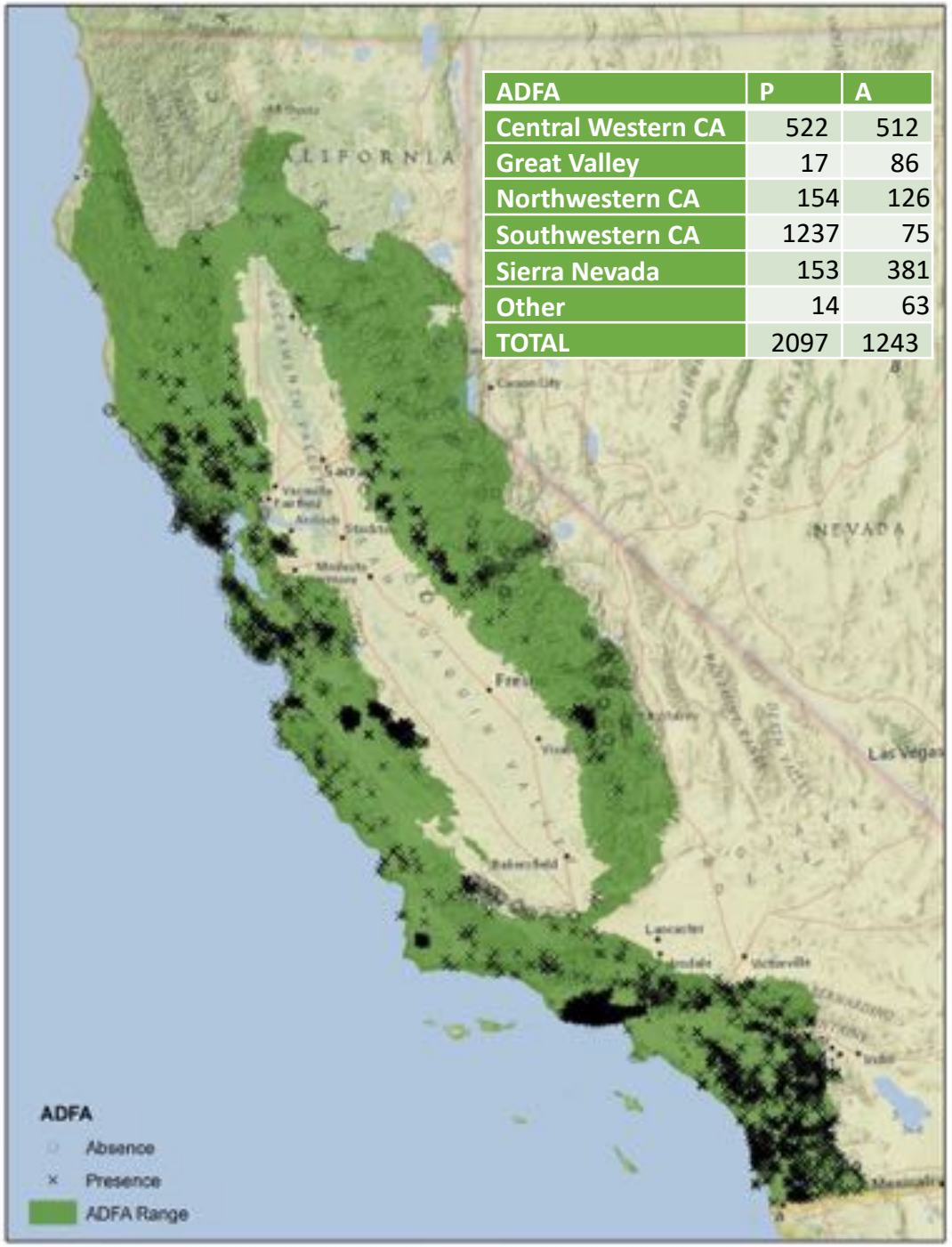
Model Extents, Inputs, & Methods

- Model extents: 5 km buffer of ranges within CA Floristic Province
- Presence-absence data - 1980-2023 (CDFW, CCH, Calflora)
- Environmental predictor layers:
  - Climate and Hydrology (1921-1950/1951-1980/1981-2010)
  - Topography
  - Soils
- 6 presence-absence SDM algorithms (fit in flexSDM R package):
  - Generalized additive (GAM),
  - Generalized boosted regression (BRT),
  - Generalized linear (GLM),
  - Neural networks (ANN),
  - Random forest (RF), and
  - Support vector machine (SVM) models

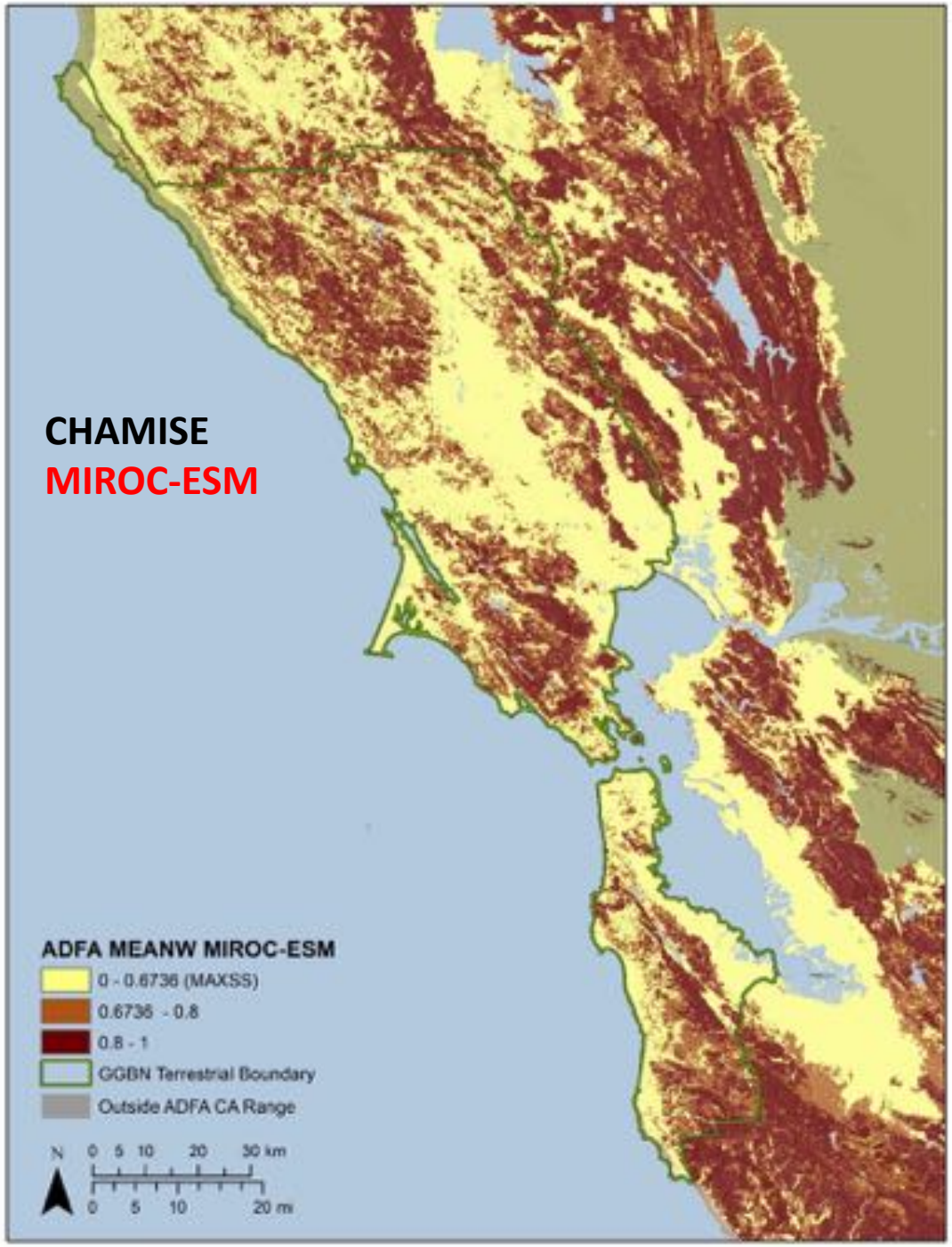
Modeling Details

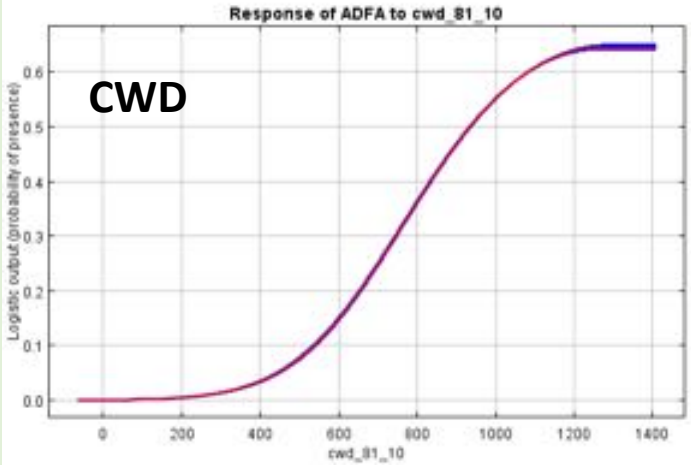
Chamise *(Adenostoma fasciculatum)*

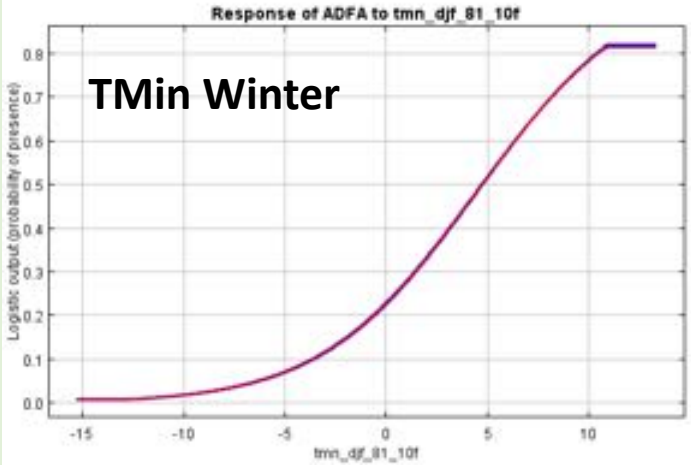
Predictors
Winter Minimum Temperature (◦C; 1981-2010)
Climatic Water Deficit (mm; 1981-2010)
Actual Evapotranspiration (mm; 1981-2010)
Annual Runoff (mm; 1981-2010)
Southwest Index
Solar Insolation Index
Topographic Wetness Index
Terrain Ruggedness
Soil Thickness
Soil pH
Percent Clay
Percent Sand
Soil Porosity
Productivity Index
Drainage Index

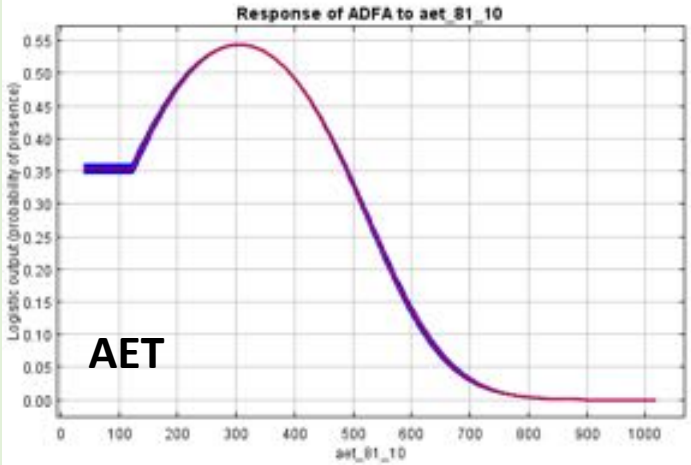


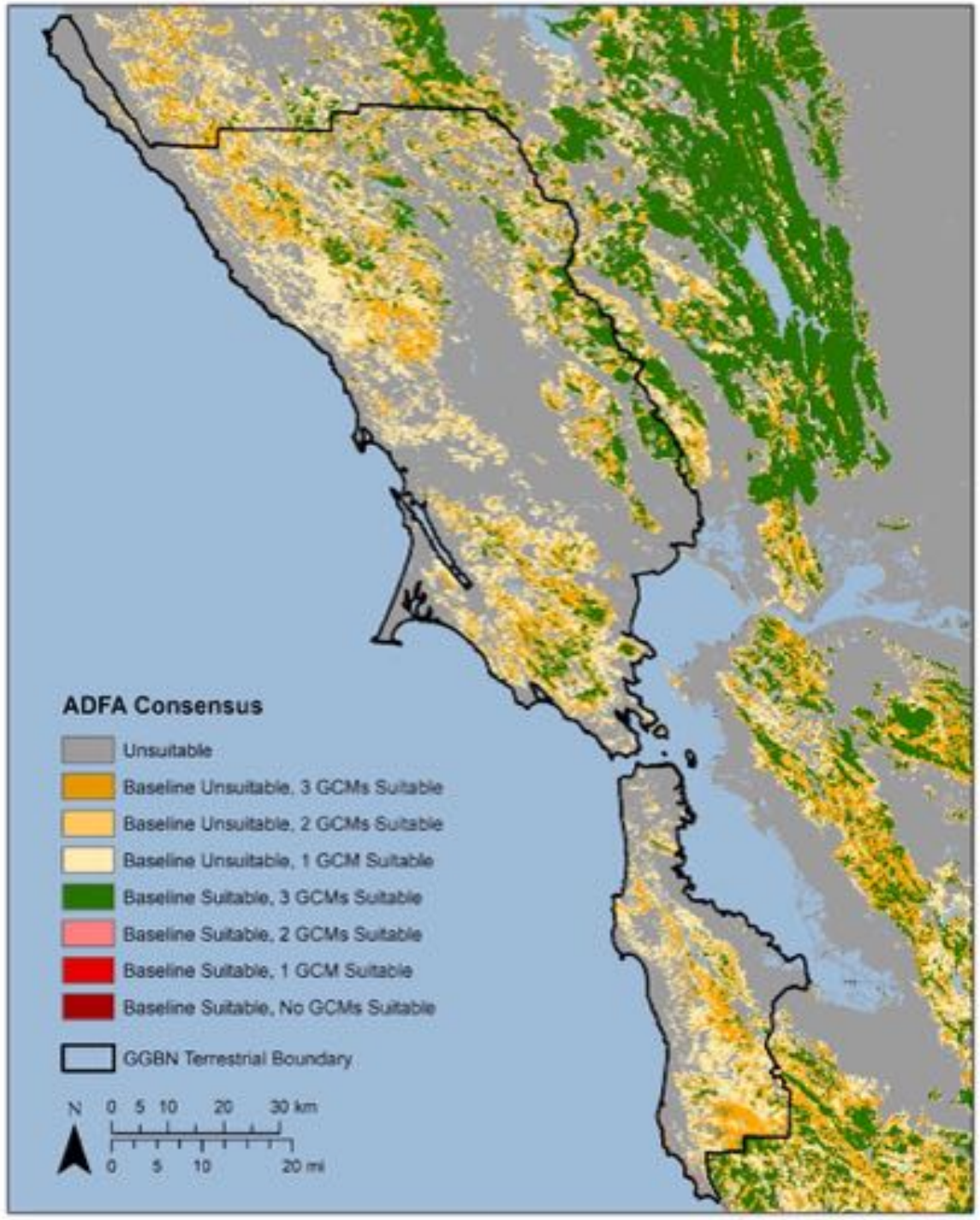
ADFA	P	A
Central Western CA	522	512
Great Valley	17	86
Northwestern CA	154	126
Southwestern CA	1237	75
Sierra Nevada	153	381
Other	14	63
TOTAL	2097	1243


CHAMISE
MIROC-ESM
ADFA MEANW MIROC-ESM
0 - 0.6736 (MAXSS)
0.6736 - 0.8
0.8 - 1
GGBN Terrestrial Boundary
Outside ADFA CA Range
N
0 5 10 20 30 km
0 5 10 20 mi

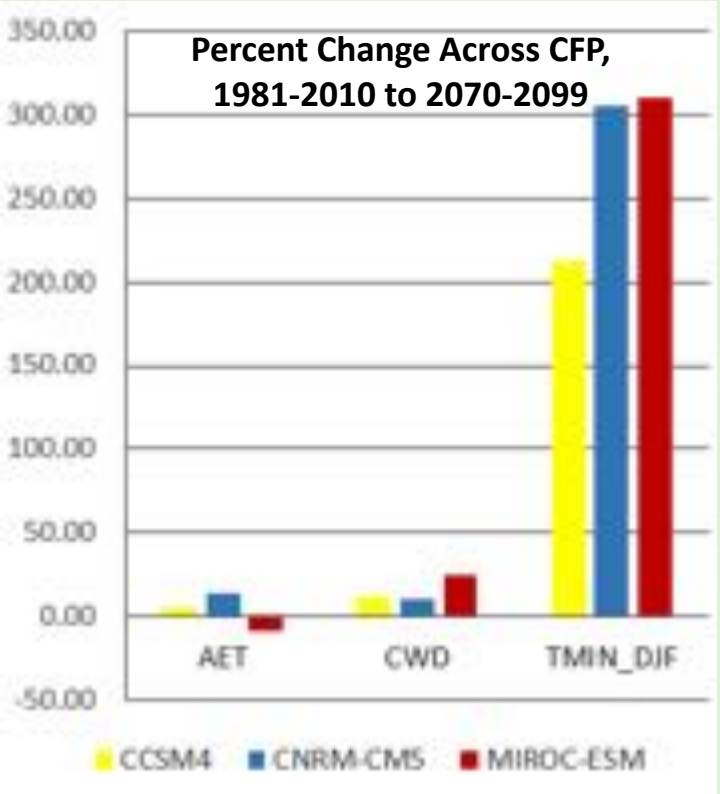

Response of ADFA to cwd_81_10
CWD
Logistic output (probability of presence)
cwd_81_10


Response of ADFA to tmn_djf_81_10f
TMin Winter
Logistic output (probability of presence)
tmn_djf_81_10f


Response of ADFA to aet_81_10
AET
Logistic output (probability of presence)
aet_81_10



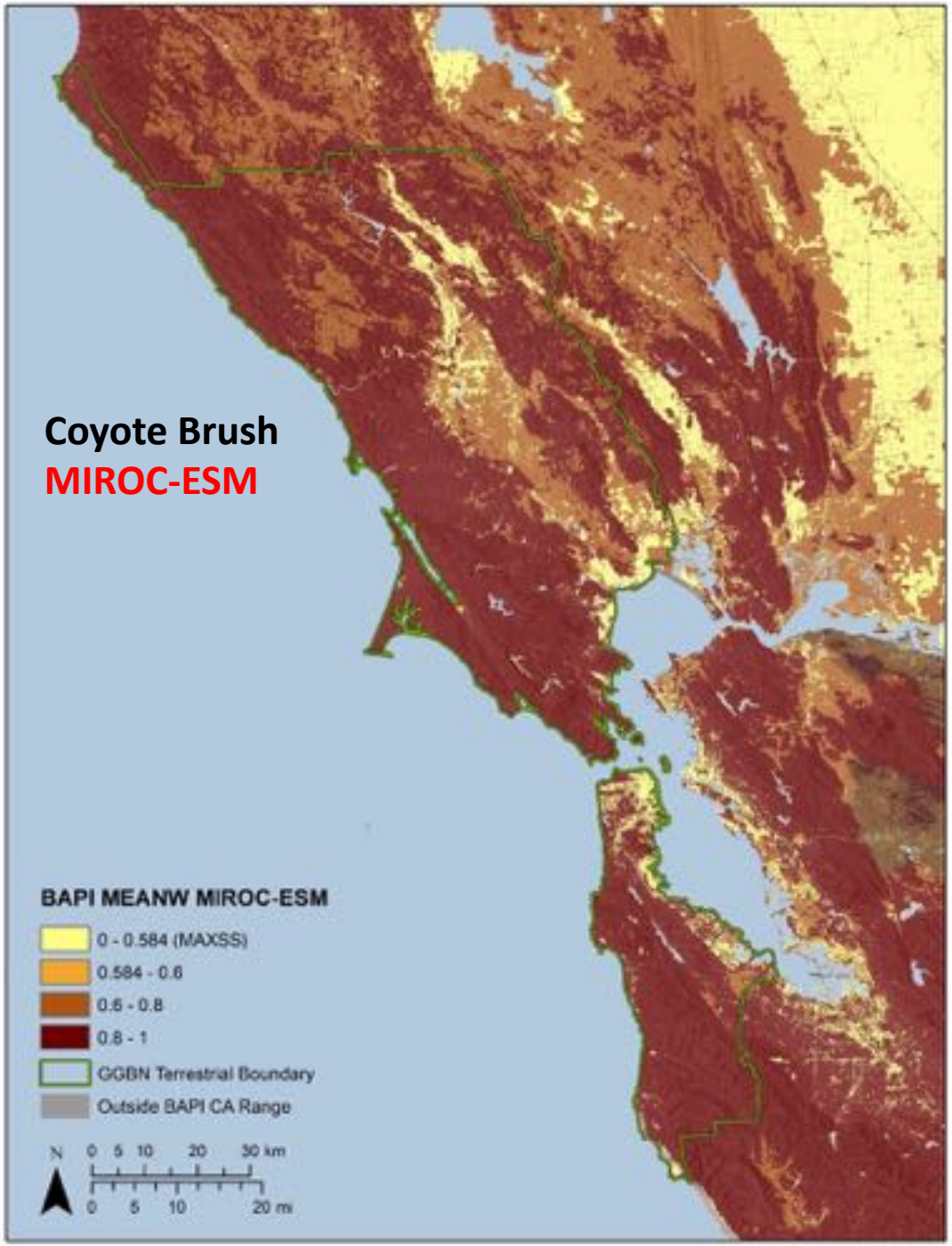
Scenario	GGBN Suitable Area (km²)	Mean Suitability
Baseline	542	0.06
CNRM-CM5	1480	0.17
CCSM4	1501	0.17
MIROC-ESM	3118	0.36

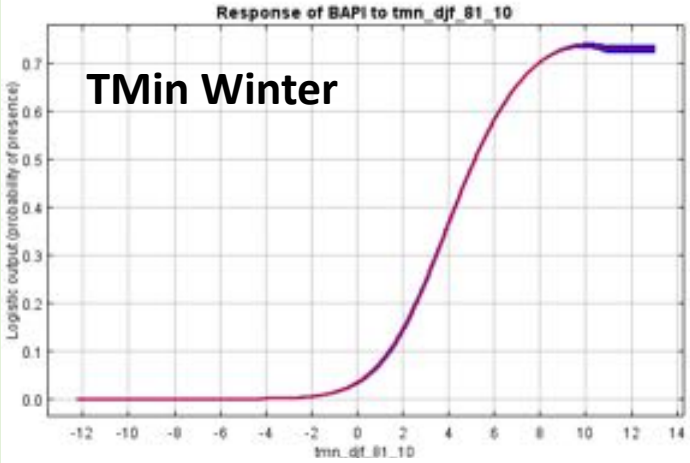


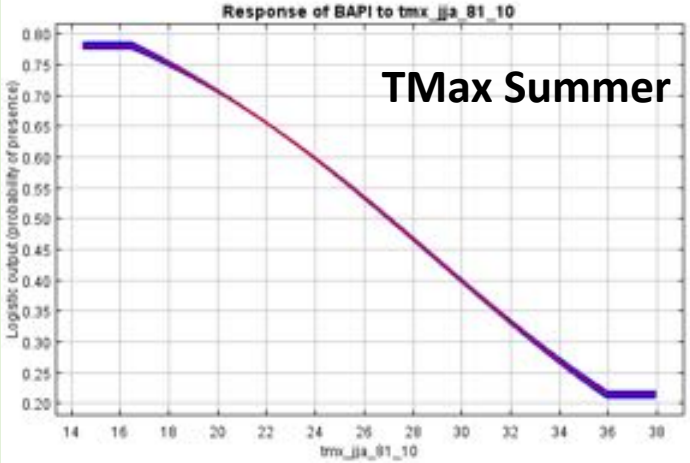
Coyote Brush *(Baccharis pilularis)*

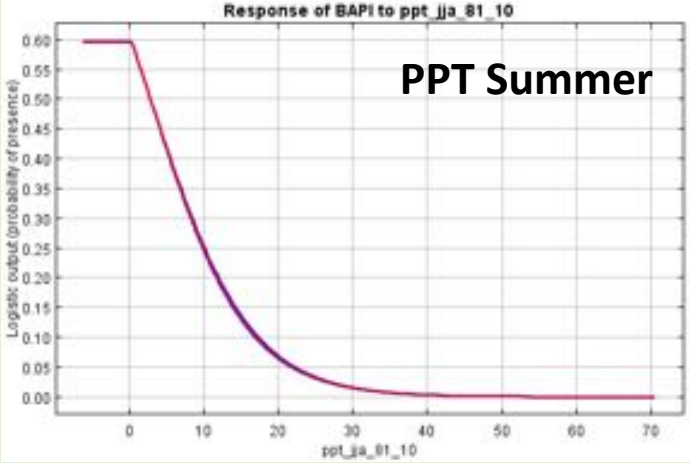
Predictors
Summer Precipitation (mm; 1981-2010)
Summer Max. Temperature (◦C; 1981-2010)
Winter Minimum Temperature (◦C; 1981-2010)
Annual Runoff (mm; 1981-2010)
Terrain Ruggedness
Topographic Heterogeneity
Soil pH
Percent Clay
Drainage Index

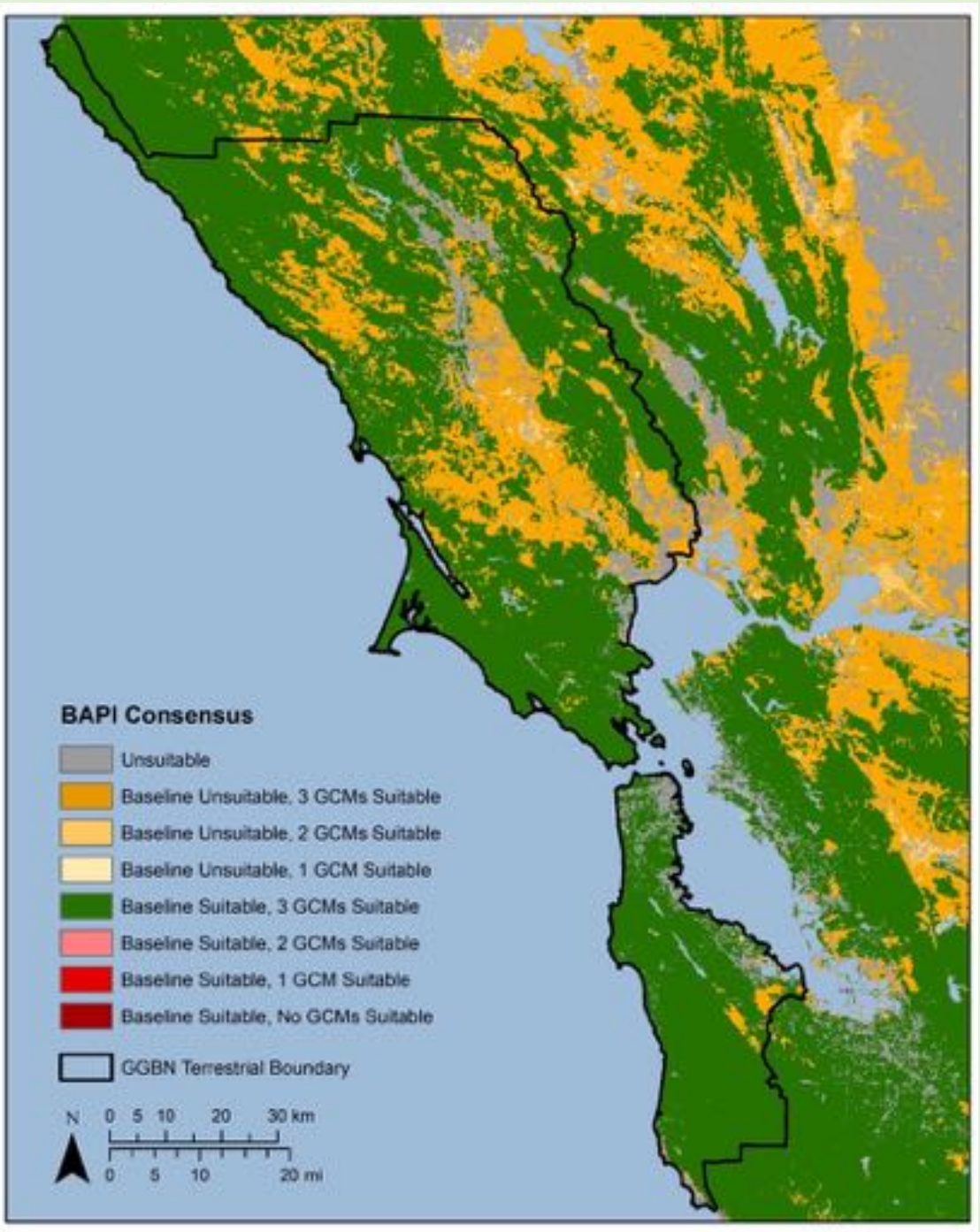
BAPI	P	A
Central Western CA	853	440
Great Valley	89	173
Northwestern CA	218	228
Southwestern CA	532	85
Other	167	57
TOTAL	1859	983


Coyote Brush
MIROC-ESM
BAPI MEANW MIROC-ESM
0 - 0.584 (MAXSS)
0.584 - 0.6
0.6 - 0.8
0.8 - 1
GGBN Terrestrial Boundary
Outside BAPI CA Range
N
0 5 10 20 30 km
0 5 10 20 m

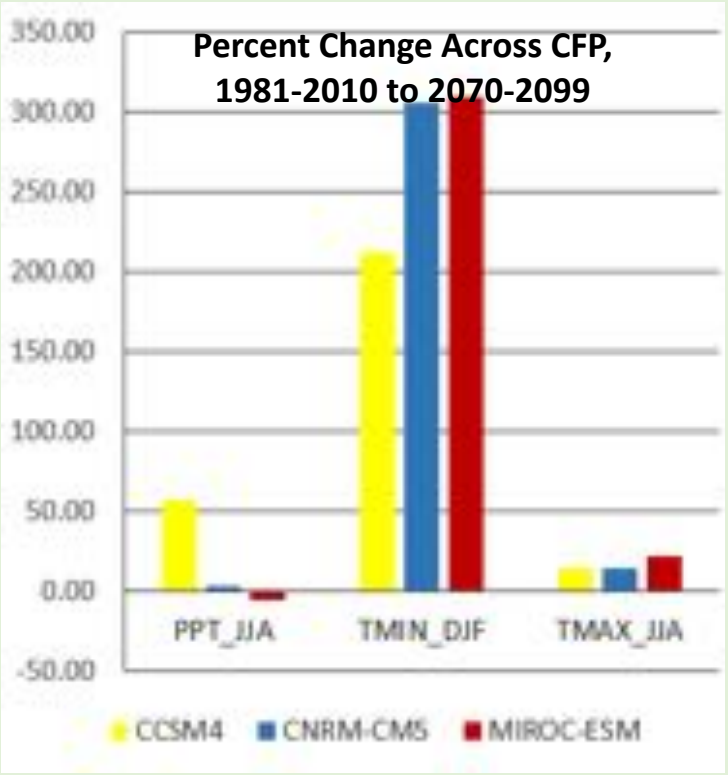

Response of BAPI to tmn_djf_81_10
TMin Winter
Logistic output (probability of presence)
tmn_djf_81_10


Response of BAPI to tmx_jja_81_10
TMax Summer
Logistic output (probability of presence)
tmx_jja_81_10


Response of BAPI to ppt_jja_81_10
PPT Summer
Logistic output (probability of presence)
ppt_jja_81_10



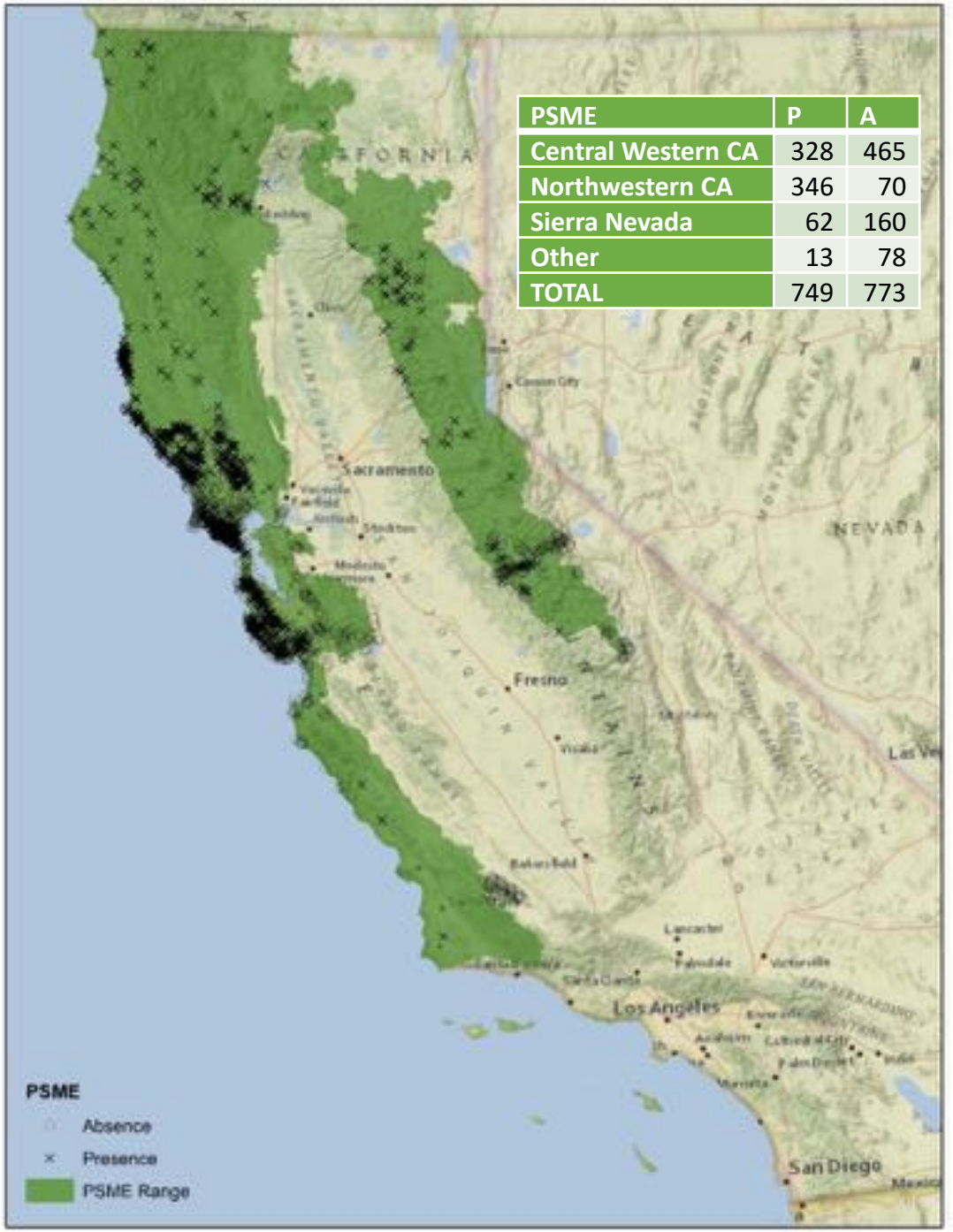
Scenario	GGBN Suitable Area (km^2)	Mean Suitability
Baseline	4848	0.51
CNRM-CM5	6260	0.74
CCSM4	6236	0.76
MIROC-ESM	6267	0.77

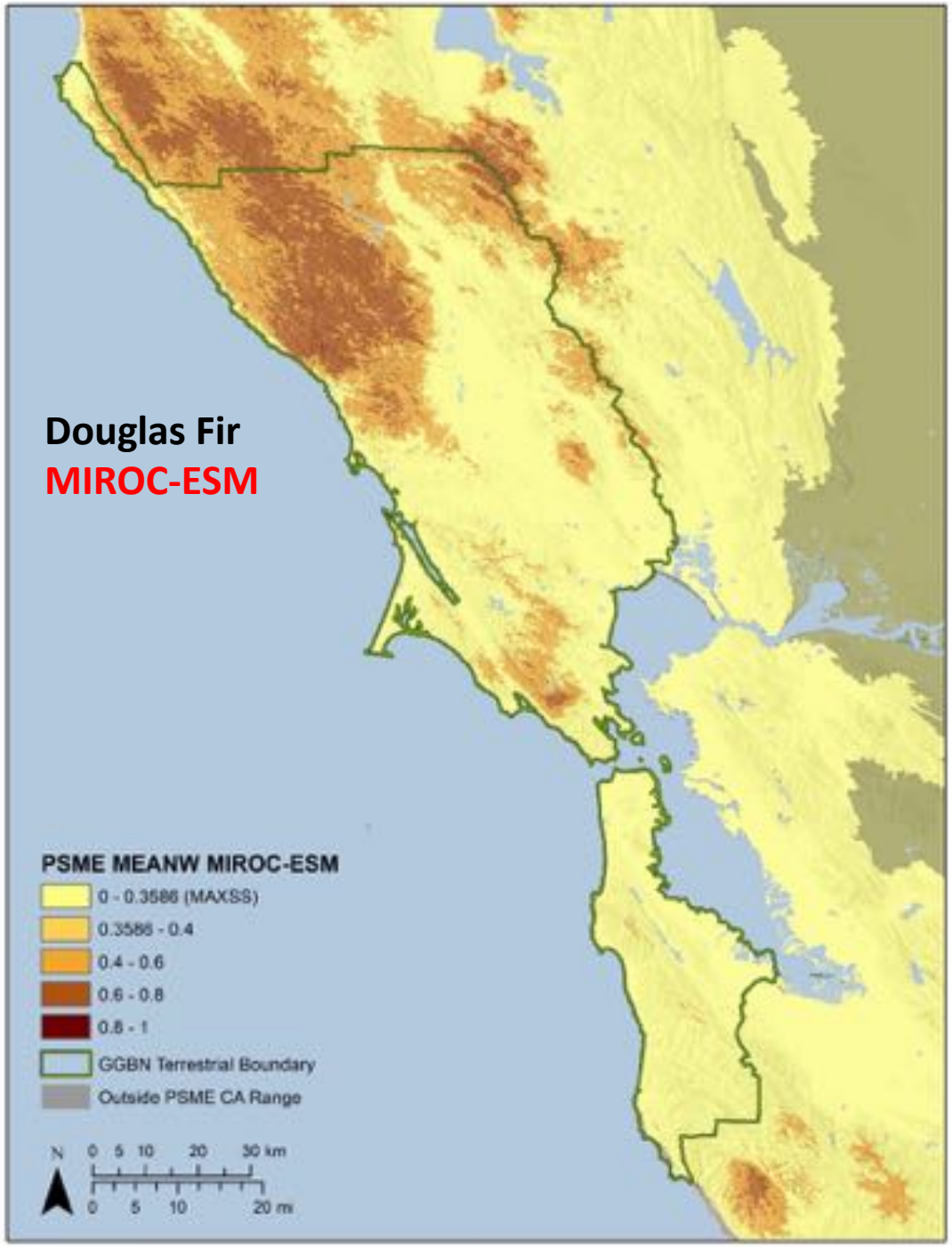


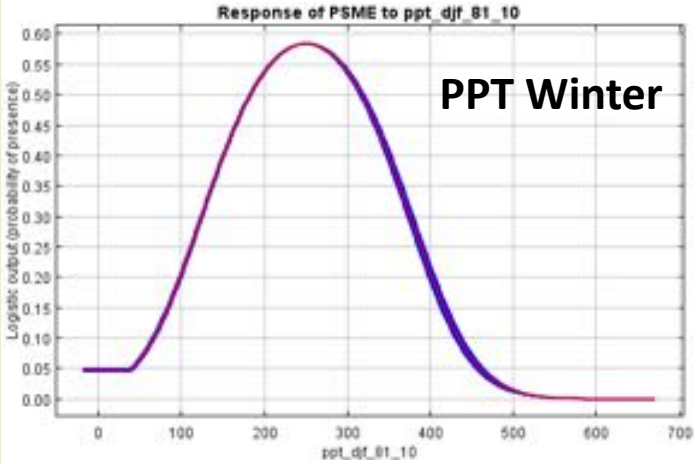
Douglas Fir *(Pseudotsuga menziesii)*

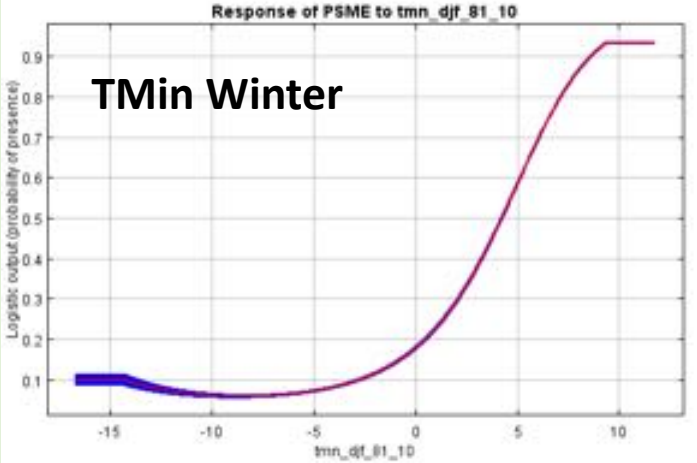
Predictors
Winter Precipitation (mm; 1981-2010)
Summer Max. Temperature (◦C; 1981-2010)
Actual Evapotranspiration (mm; 1981-2010)
Solar Insolation Index
Topographic Wetness Index
Terrain Ruggedness
Available Water Capacity
Percent Clay
Soil Porosity

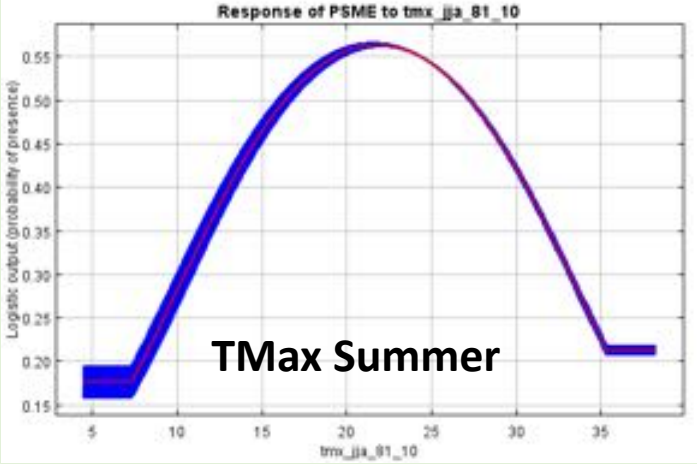
PSME	P	A
Central Western CA	328	465
Northwestern CA	346	70
Sierra Nevada	62	160
Other	13	78
TOTAL	749	773

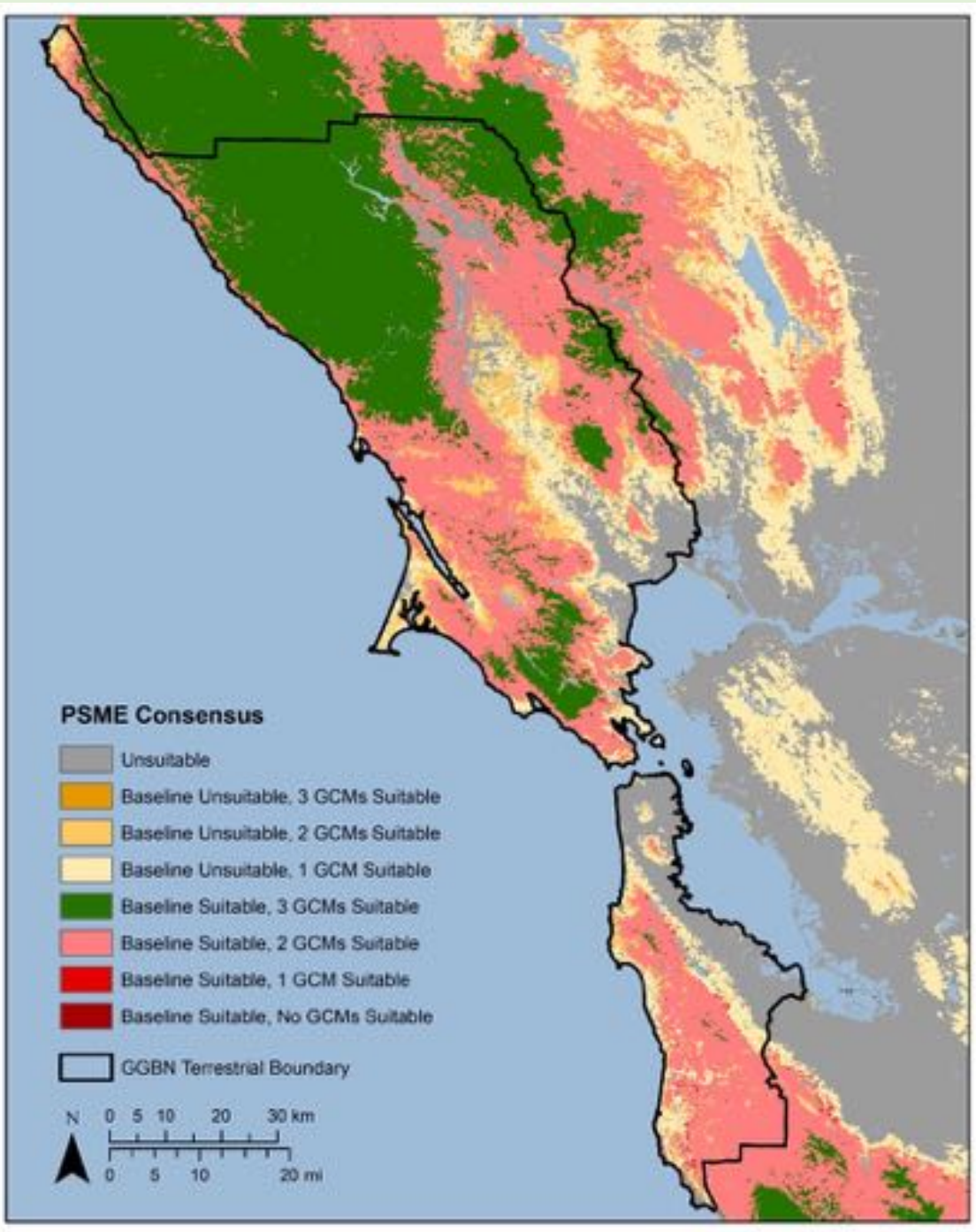



Douglas Fir
MIROC-ESM
PSME MEANW MIROC-ESM
0 - 0.3586 (MAXSS)
0.3586 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1
GGBN Terrestrial Boundary
Outside PSME CA Range
N
0 5 10 20 30 km
0 5 10 20 mi

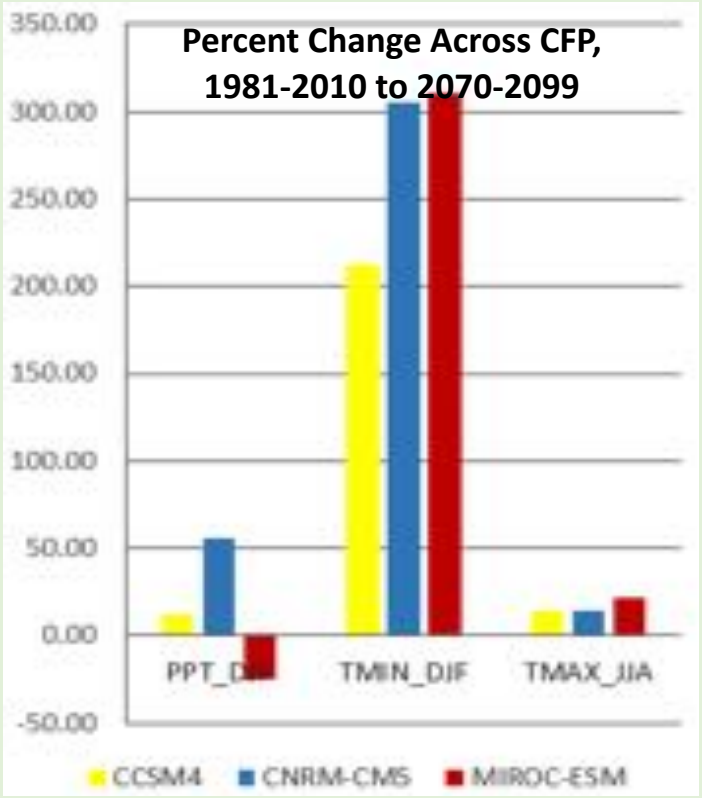

Response of PSME to ppt_djf_81_10
PPT Winter
Logistic output (probability of presence)
ppt_djf_81_10


Response of PSME to tmn_djf_81_10
TMin Winter
Logistic output (probability of presence)
tmn_djf_81_10


Response of PSME to tmx_jja_81_10
TMax Summer
Logistic output (probability of presence)
tmx_jja_81_10



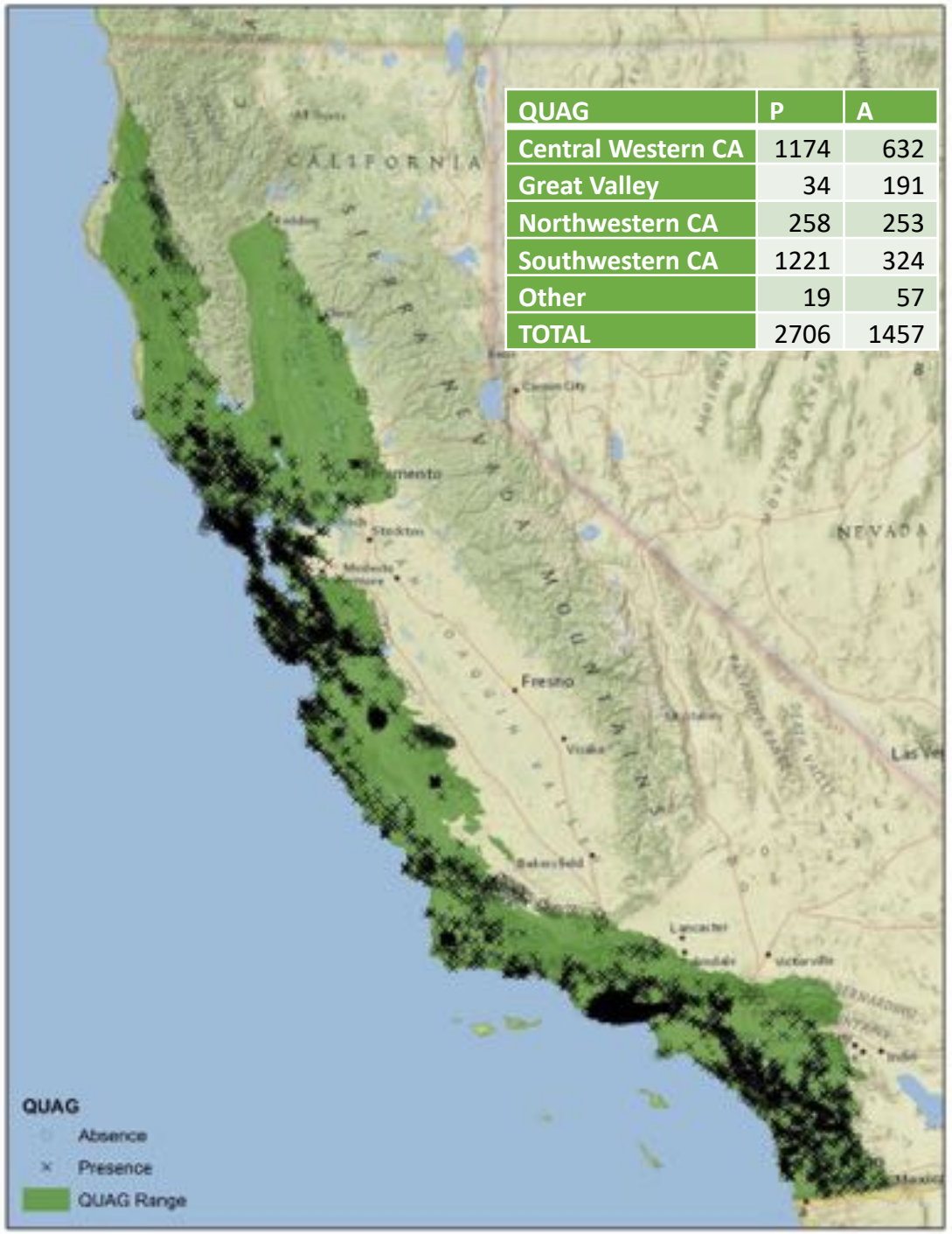
Scenario	GGBN Suitable Area (km²)	Mean Suitability
Baseline	4719	0.49
CNRM-CM5	5845	0.63
CCSM4	5195	0.54
MIROC-ESM	2203	0.18

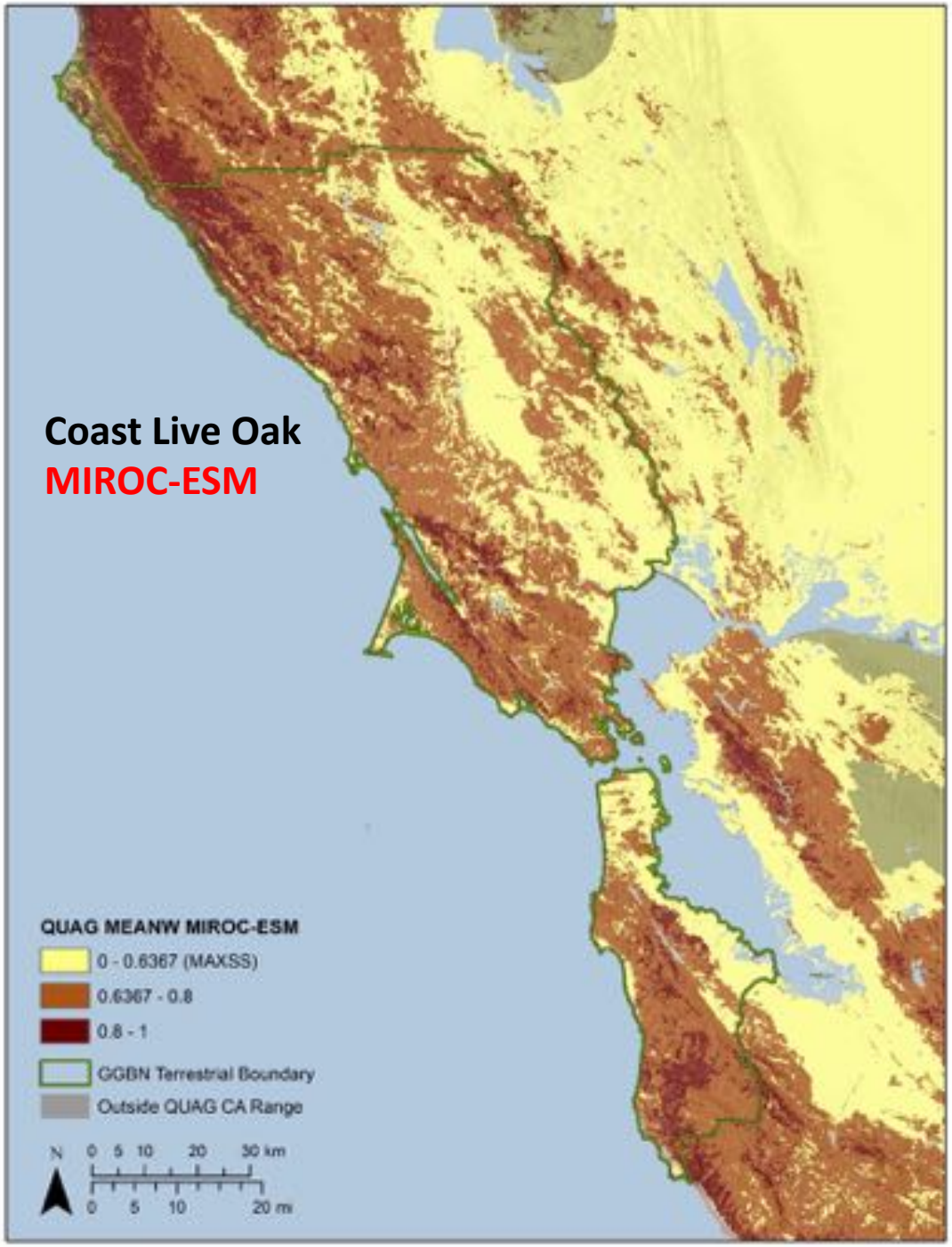


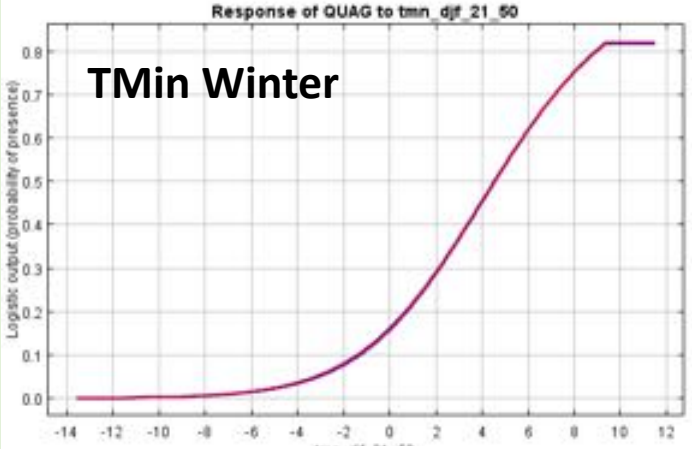
Coast Live Oak *(Quercus agrifolia)*

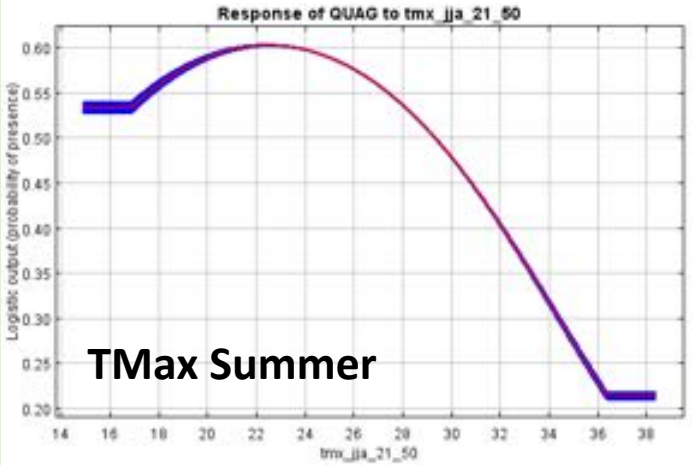
Predictors
Summer Precipitation (mm; 1921-1950)
Summer Max. Temperature (◦C; 1921-1950)
Winter Minimum Temperature (◦C; 1921-1950)
Annual Runoff (mm; 1921-1950)
Slope (%)
Southwest Index
Terrain Ruggedness
Soil Thickness
Soil pH
Available Water Capacity
Percent Clay
Percent Sand
Soil Porosity
Drainage Index

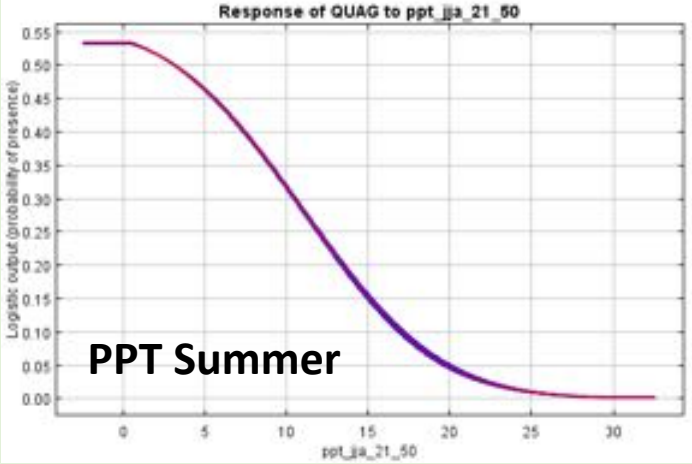
QUAG	P	A
Central Western CA	1174	632
Great Valley	34	191
Northwestern CA	258	253
Southwestern CA	1221	324
Other	19	57
TOTAL	2706	1457

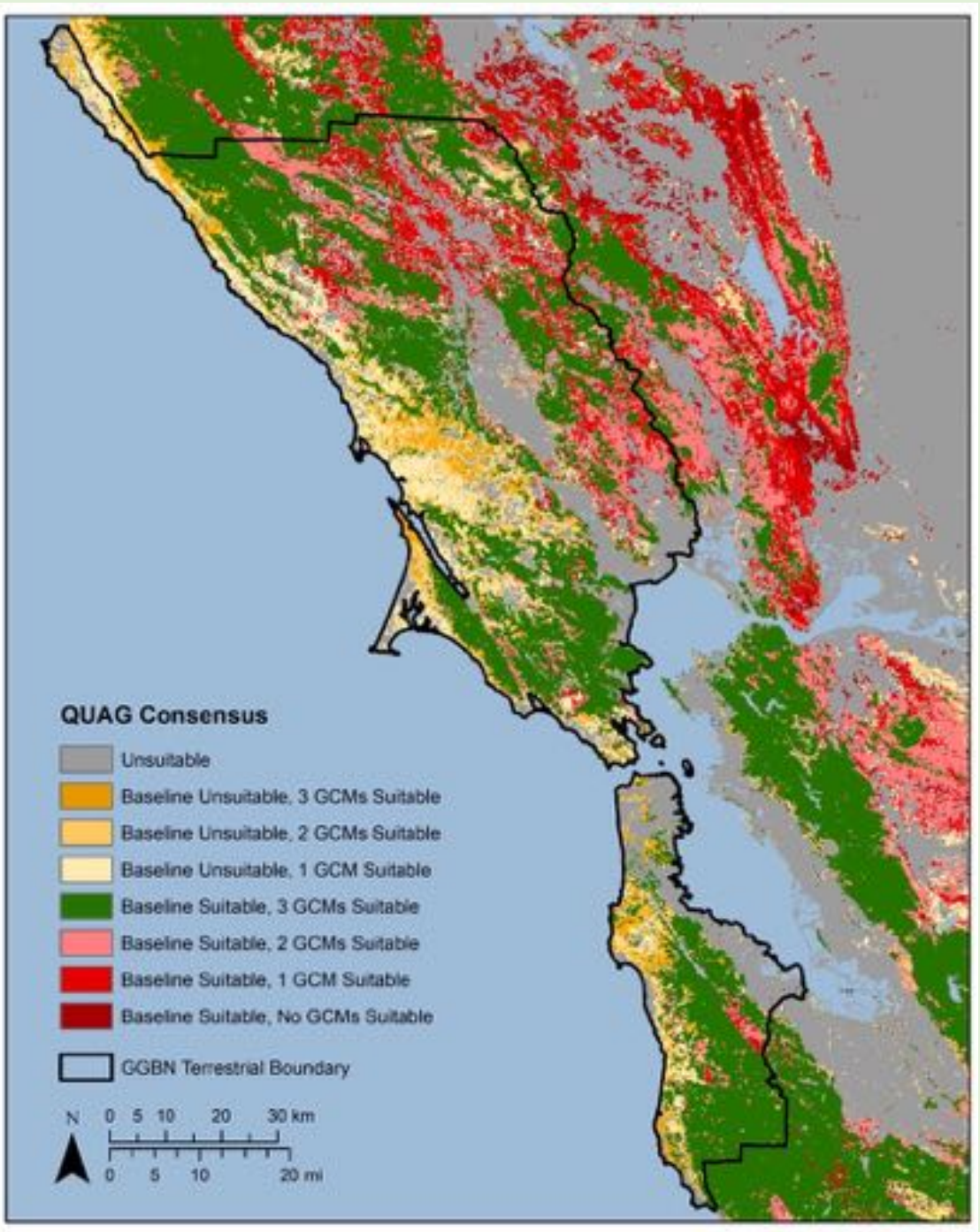



Coast Live Oak
MIROC-ESM
QUAG MEANW MIROC-ESM
0 - 0.6367 (MAXSS)
0.6367 - 0.8
0.8 - 1
GGBN Terrestrial Boundary
Outside QUAG CA Range
N
0 5 10 20 30 km
0 5 10 20 mi

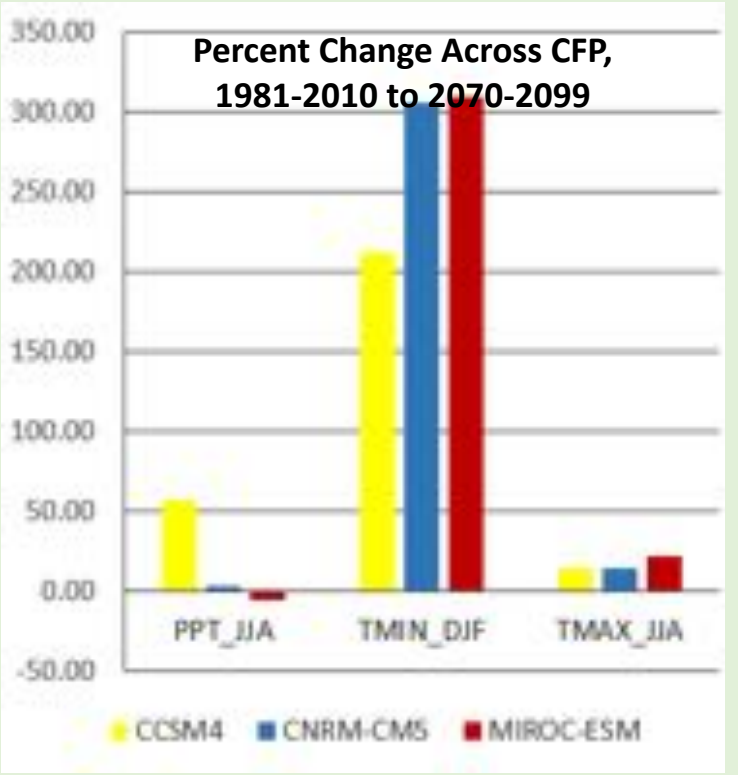

Response of QUAG to tmn_djf_21_50
TMin Winter
Logistic output (probability of presence)


Response of QUAG to tmx_jja_21_50
TMax Summer
Logistic output (probability of presence)
tmx_jja_21_50


Response of QUAG to ppt_jja_21_50
PPT Summer
Logistic output (probability of presence)
ppt_jja_21_50



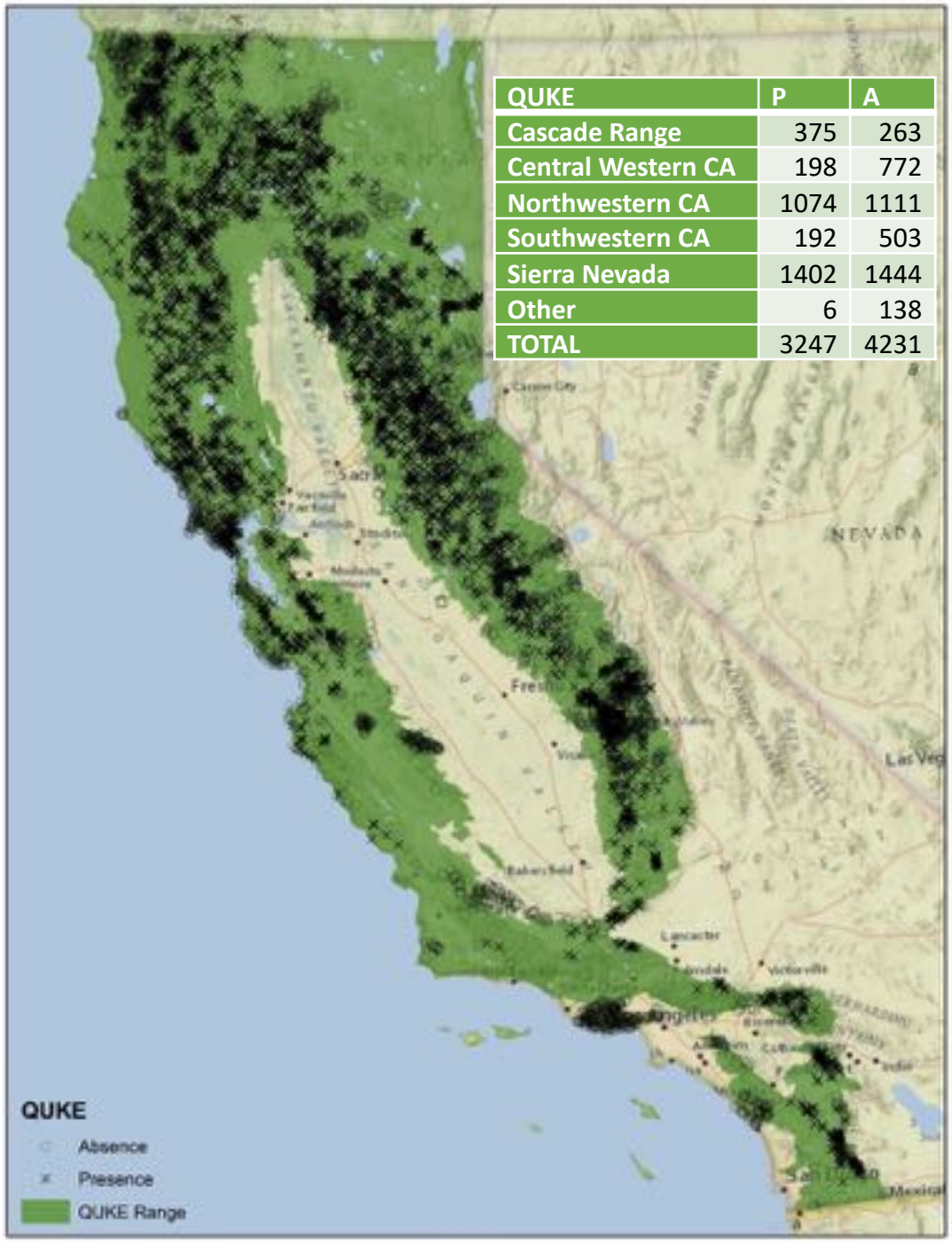
Scenario	GGBN Suitable Area (km²)	Mean Suitability
Baseline	3847	0.43
CNRM-CM5	3343	0.36
CCSM4	4581	0.51
MIROC-ESM	4401	0.48



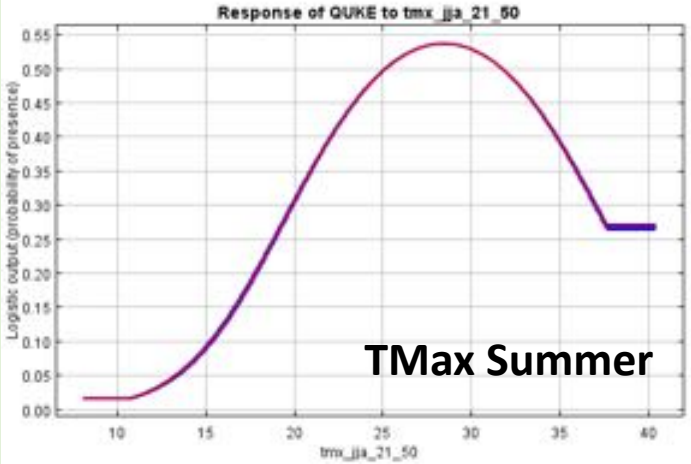
California Black Oak *(Quercus kelloggii)*

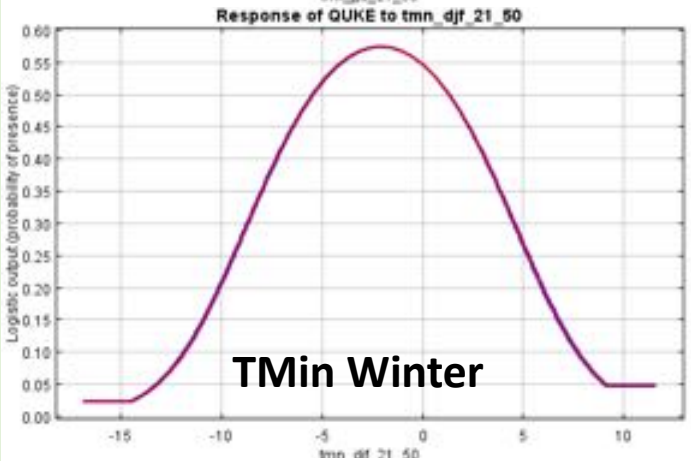
Predictors
Summer Precipitation (mm; 1921-1950)
Summer Max. Temperature (◦C; 1921-1950)
Winter Minimum Temperature (◦C; 1921-1950)
Actual Evapotranspiration (mm; 1921-1950)
Annual Runoff (mm; 1921-1950)
Southwest Index
Solar Insolation Index
Topographic Wetness Index
Terrain Ruggedness
Soil Thickness
Soil pH
Available Water Capacity
Percent Clay
Percent Sand
Soil Porosity

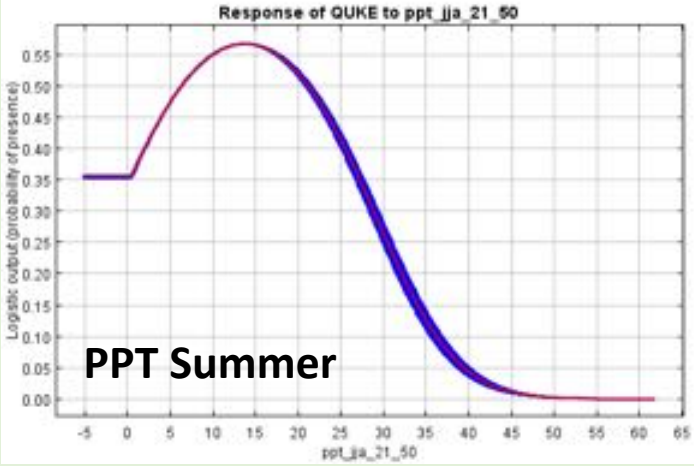
QUKE	P	A
Cascade Range	375	263
Central Western CA	198	772
Northwestern CA	1074	1111
Southwestern CA	192	503
Sierra Nevada	1402	1444
Other	6	138
TOTAL	3247	4231

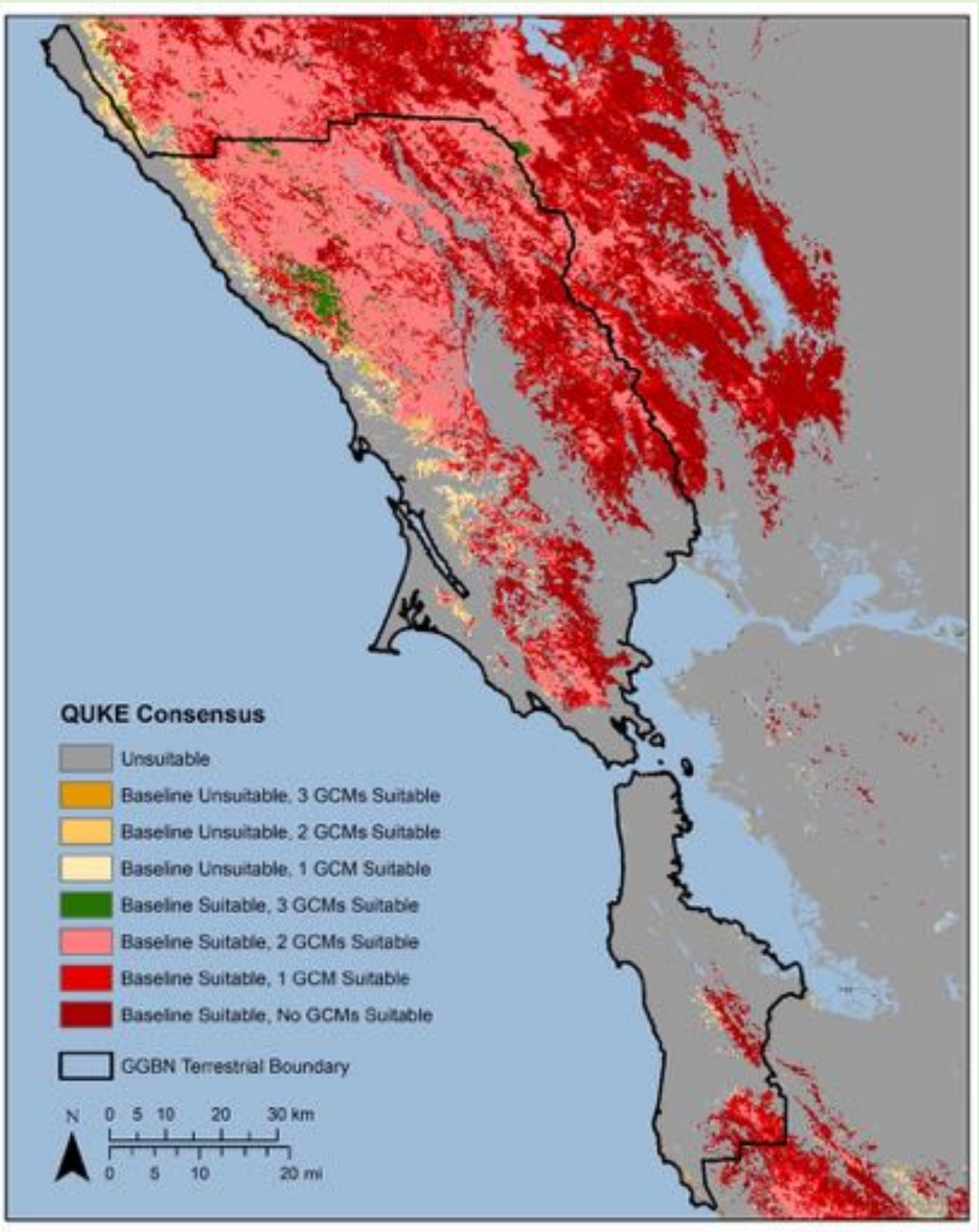



CA Black Oak
MIROC-ESM
QUKE MEANW MIROC-ESM
0 - 0.4212 (MAXSS)
0.4212 - 0.6
0.6 - 0.8
0.8 - 1
GGBN Terrestrial Boundary
Outside QUKE CA Range
N
0 5 10 20 30 km
0 5 10 20 mi

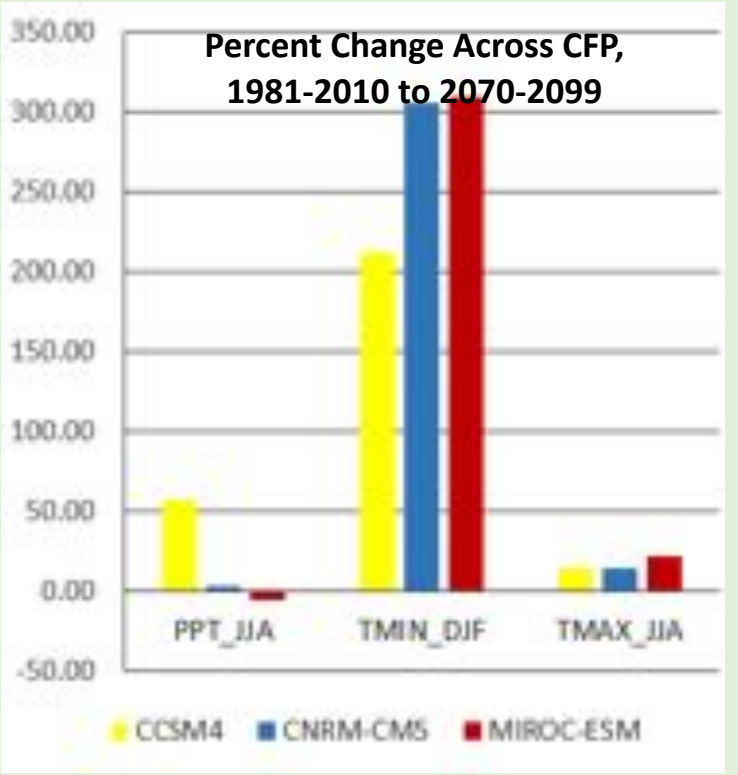

Response of QUKE to tmx_jja_21_50
Logistic output (probability of presence)
tmx_jja_21_50
TMax Summer


Response of QUKE to tmn_djf_21_50
Logistic output (probability of presence)
TMin Winter


Response of QUKE to ppt_jja_21_50
Logistic output (probability of presence)
ppt_jja_21_50
PPT Summer

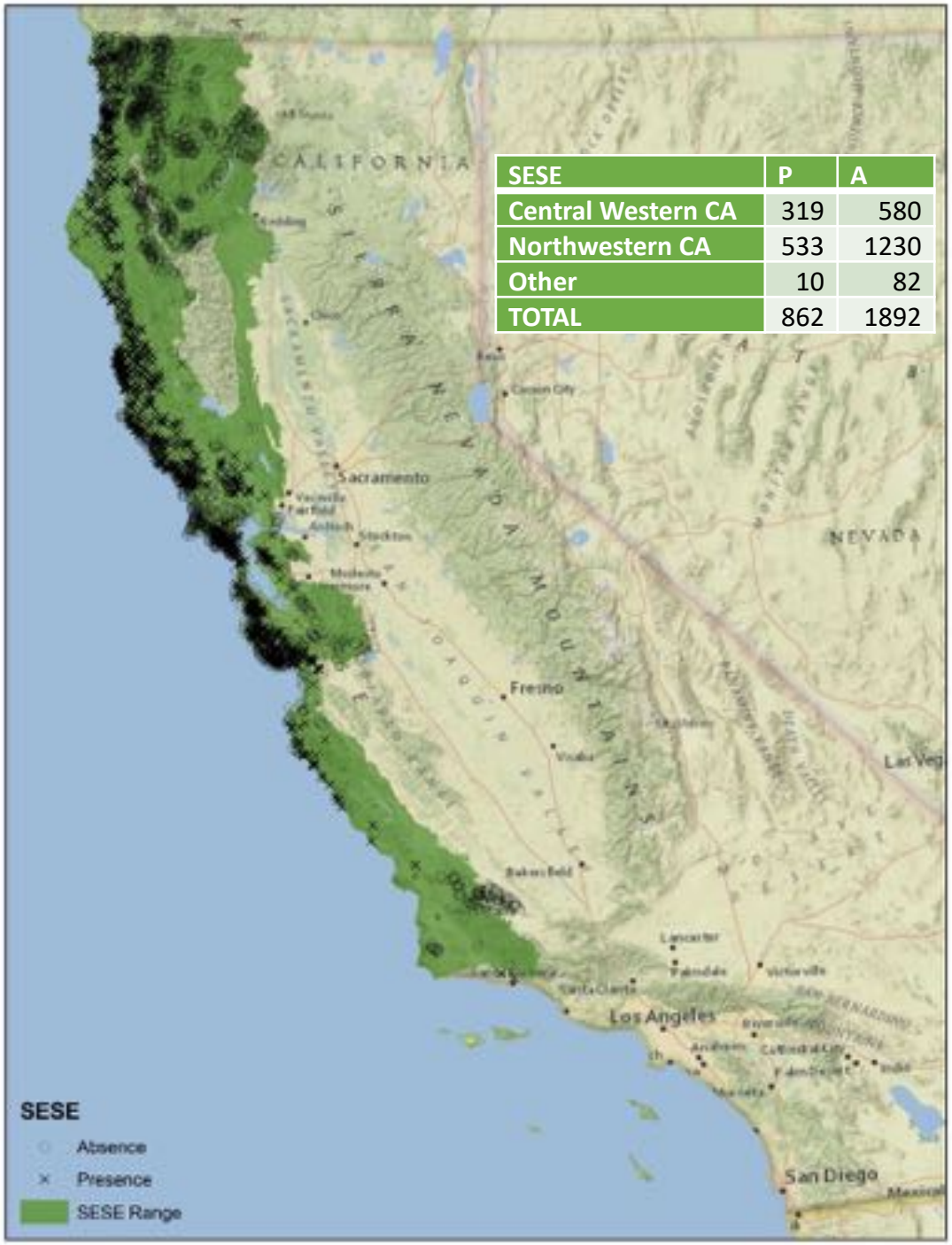


Scenario	GGBN Suitable Area (km²)	Mean Suitability
Baseline	3195	0.30
CNRM-CM5	1923	0.14
CCSM4	2368	0.18
MIROC-ESM	123	0.01

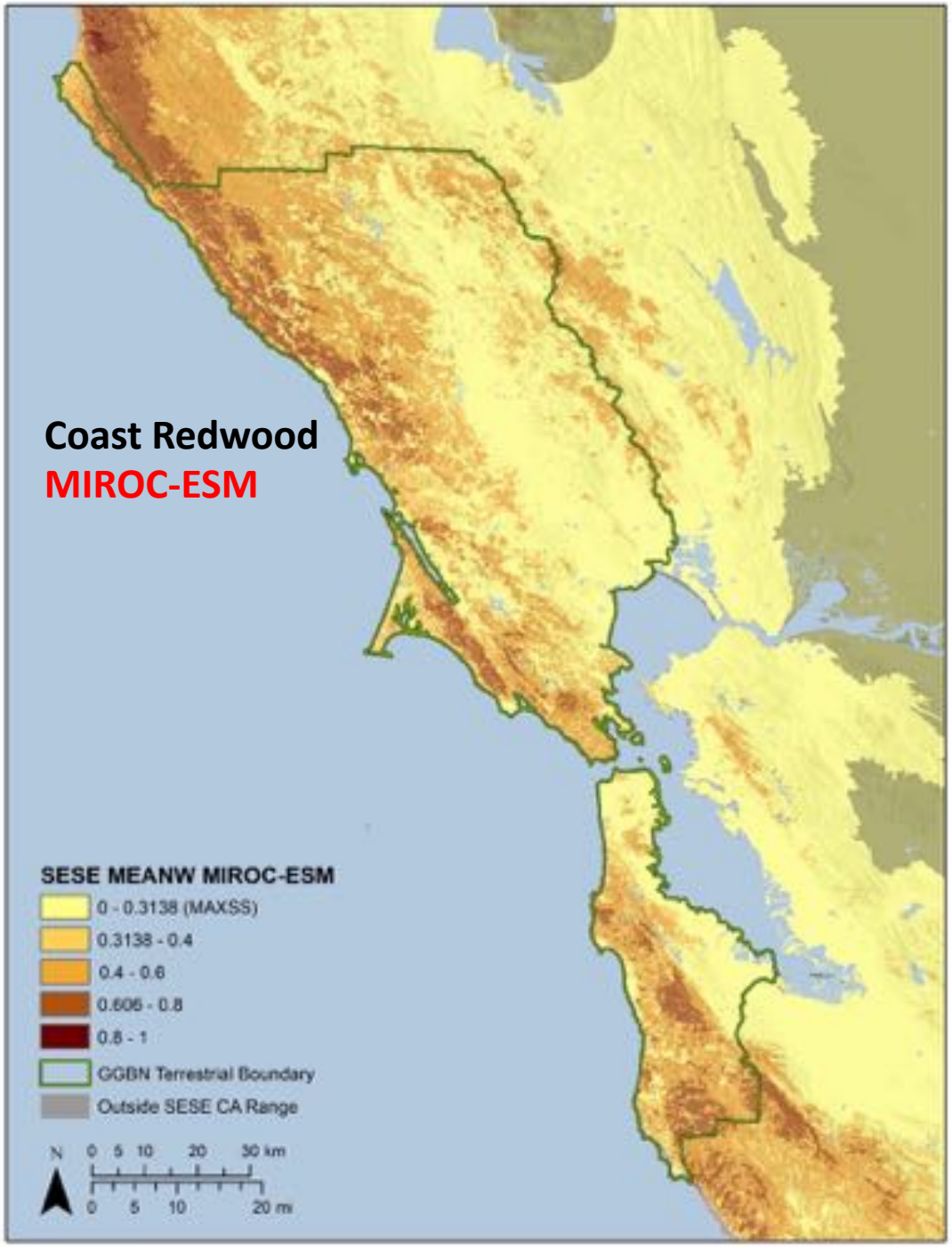


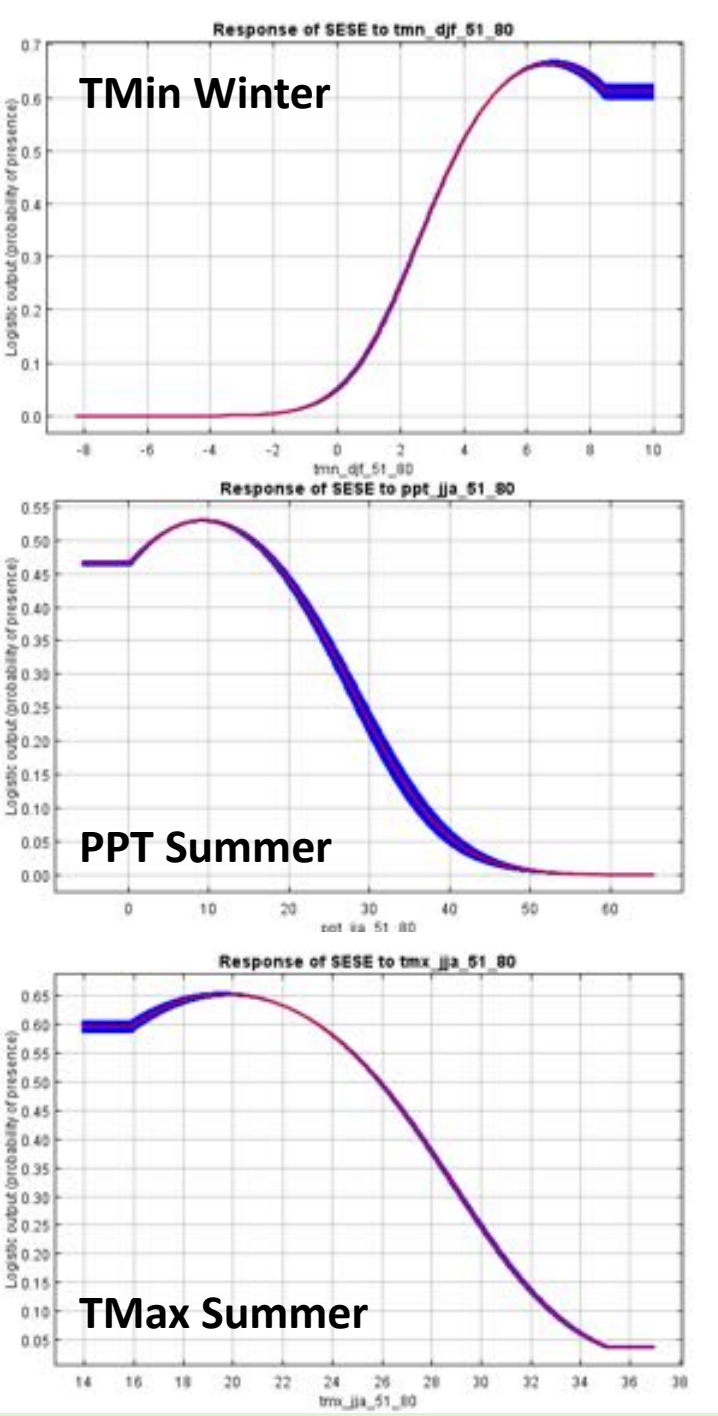
Coast Redwood *(Sequoia sempervirens)*

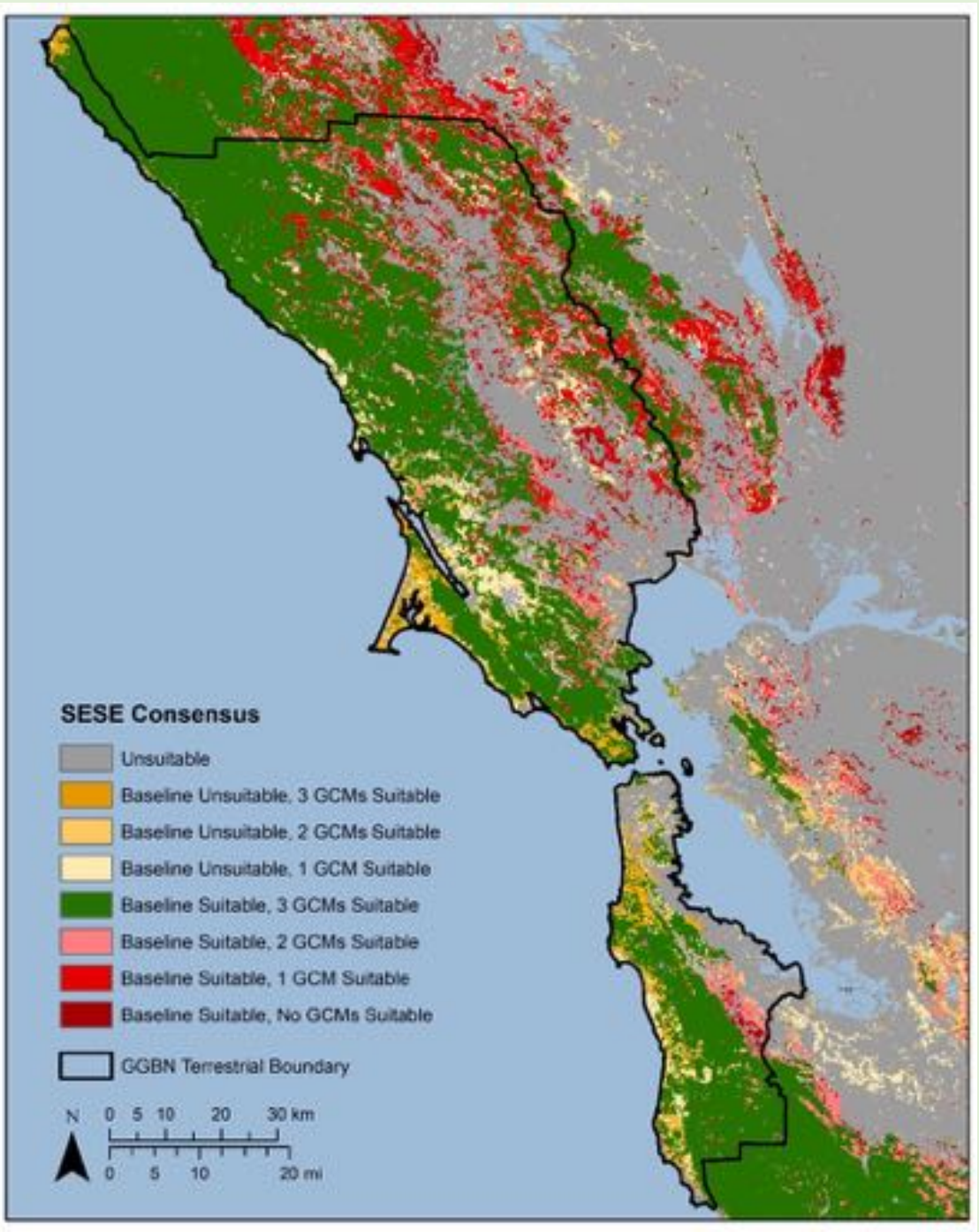
Predictors
Summer Precipitation (mm; 1951-1980)
Summer Max. Temperature (◦C; 1951-1980)
Winter Minimum Temperature (◦C; 1951-1980)
Actual Evapotranspiration (mm; 1951-1980)
Annual Runoff (mm; 1951-1980)
Southwest Index
Topographic Heterogeneity
Soil Thickness
Soil pH
Available Water Capacity
Percent Clay
Percent Sand
Soil Porosity
Drainage Index



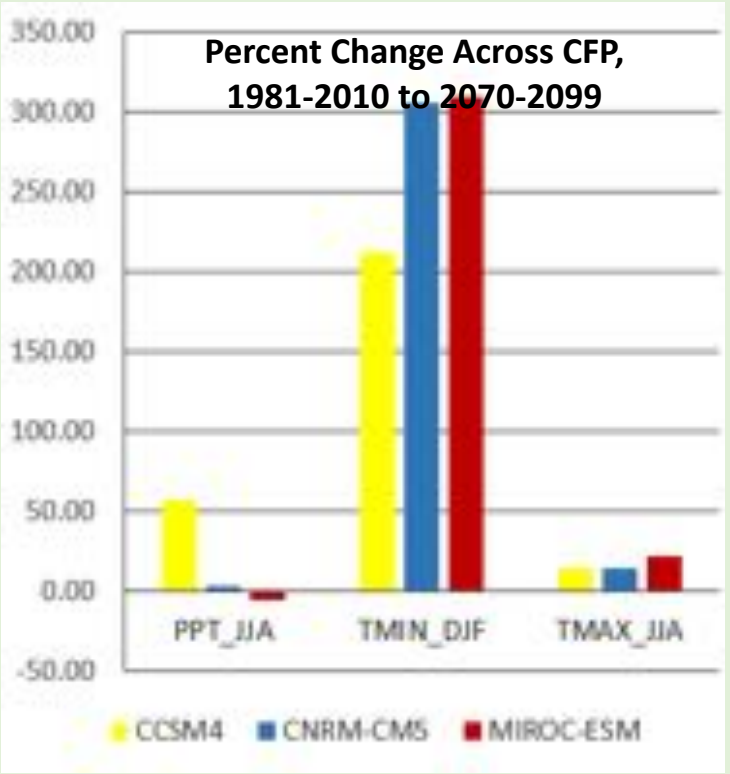
SESE	P	A
Central Western CA	319	580
Northwestern CA	533	1230
Other	10	82
TOTAL	862	1892


Coast Redwood
MIROC-ESM
SESE MEANW MIROC-ESM
0 - 0.3138 (MAXSS)
0.3138 - 0.4
0.4 - 0.6
0.606 - 0.8
0.8 - 1
GGBN Terrestrial Boundary
Outside SESE CA Range
N
0 5 10 20 30 km
0 5 10 20 mi


Response of SESE to tmn_djf_51_80
TMin Winter
Logistic output (probability of presence)
tmn_djf_51_80
Response of SESE to ppt_jja_51_80
PPT Summer
Logistic output (probability of presence)
Response of SESE to tmx_jja_51_80
TMax Summer
Logistic output (probability of presence)
tmx_jja_51_80



Scenario	GGBN Suitable Area (km²)	Mean Suitability
Baseline	4418	0.42
CNRM-CM5	4000	0.30
CCSM4	5062	0.45
MIROC-ESM	3805	0.27



- Thanks to Danny Franco, Alison Forrestel, Laura Hilberg, & Kai Henifin
- Questions?

Model Evaluation

Species	Sens. (TPR)	Spec. (TNR)	AUC	TSS	Boyce	Jaccard	Sorensen
Chamise	0.80	0.81	0.88	0.61	0.96	0.72	0.83
Coyote Brush	0.77	0.65	0.77	0.42	0.94	0.64	0.78
Douglas Fir	0.84	0.68	0.83	0.52	0.91	0.64	0.77
Coast Live Oak	0.82	0.62	0.75	0.44	0.89	0.68	0.80
California Black Oak	0.84	0.78	0.87	0.63	0.99	0.66	0.80
Coast Redwood	0.85	0.87	0.94	0.72	0.97	0.67	0.80

TPR: True Positive Rate (Sensitivity), proportion of observed positives that were predicted to be positive, 0-1

TNR: True Negative Rate (Specificity), proportion of observed negatives that were predicted to be negatives, 0-1

AUC: Area Under ROC (receiver operating characteristic) Curve, measure of performance across all possible thresholds, 0-1
0.5–0.7 = low performance, 0.7–0.9 moderate, and > 0.9 high

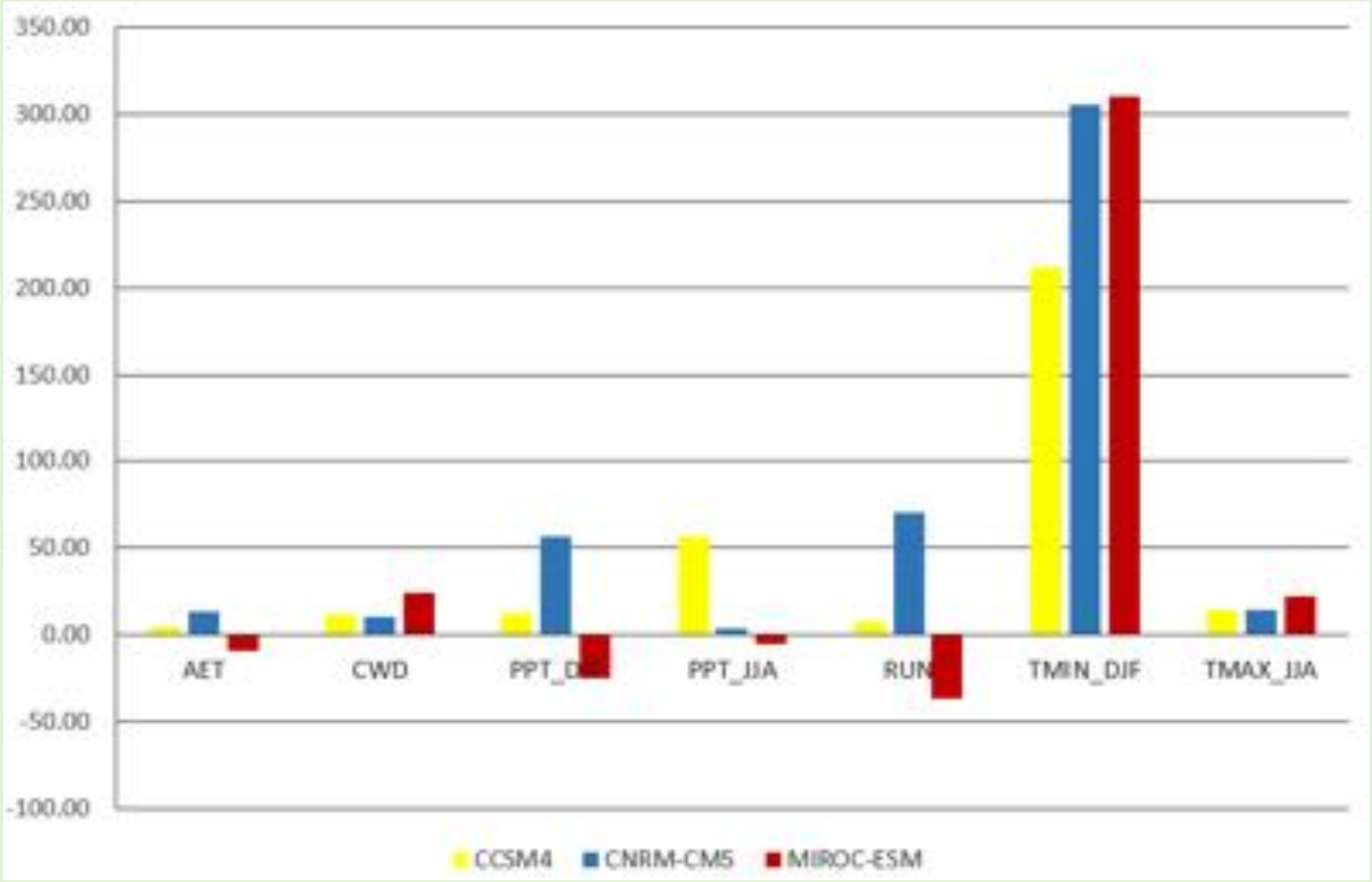
TSS: True Skill Statistic, {1 – maximum(sensitivity + specificity)} where sensitivity and specificity are calculated based on the probability threshold for which their sum is maximized, -1-1, values close to 0 or negative indicate poor performance, +1 = perfect match between observed and predicted distributions

Boyce: Continuous Boyce Index, intended for presence-only data, here using presence-absence, Spearman rank correlation coefficient between proportion of sites in each prediction class and expected proportion of predictions in each prediction class based on proportion of landscape in that class, -1 to 1. Values > 0 indicate the model's output is positively correlated with true probability of presence. Values < 0 indicate it is negatively correlated with the true probability of presence

Jaccard: Jaccard index or similarity coefficient, 0-1, higher values indicate more similarity

Sorensen: Sorensen similarity index, similar to Jaccard, 0-1, higher values indicate more similarity

Percent Change Across CFP, 1981-2010 to 2070-2099



Predictors

Type	Predictor	Source
Climate and Hydrology (Historical 30-year Summaries: 1921-1950, 1951-1980, 1981-2010)	Annual Precipitation (mm)	2014 California Basin Characterization Model (BCM)
	Summer Precipitation (mm)	
	Winter Precipitation (mm)	
	Summer Maximum Temperature (◦C)	
	Winter Minimum Temperature (◦C)	
	Climatic Water Deficit (mm)	
	Actual Evapotranspiration (mm)	
	Annual Runoff (mm)	
Topography	Slope (%)	USGS LANDFIRE Topographic Product
	Southwest Index	Derived from USGS LANDFIRE Topographic Products
	Solar Insolation Index	
	Topographic Wetness Index	
	Heat Load index	
	Terrain Ruggedness	USGS – Welty and Jeffries 2018
	Topographic Heterogeneity	NatureServe
Soils	Soil Thickness	Gridded National Soil Survey Geographic Database (gNATSGO), USDA NRCS
	Soil pH	
	Available Water Capacity	
	Percent Clay	
	Percent Sand	
	Soil Porosity	California Basin Characterization Model (BCM) v8 Input
	Productivity Index	USDA U.S. Forest Service
	Drainage Index	