Projected Climate Scenarios and Potential Impacts on Vegetation and Fire Vulnerability

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Prepared for Golden Gate Biosphere Network Climate Vulnerability Assessment

December 2023

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Goals

1) Provide a range of viable scientific projections suitable for this vulnerability assessment.
2) Support ongoing conservation planning by partners.
3) Scope potential collaborative climate resilience project opportunities.

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Context

1. Lot of uncertainty about impacts of climate change on watersheds and ecosystems, recommend "ensemble approach" to climate projections.

2. Analyzing scenarios representing different degrees of change in projected temperature and rainfall, each scenario is treated as a distinct physical "simulation”.

3. Scenarios simulate potential change in climate conditions in the future, not intended to project precise timing of how impacts unfold.

4. Models are based on monthly average values; complementary analyses may be required to capture extreme events.

5. The full suite of data is available on Data Basin and ArcGIS Online.

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Approach

1. Identify a subset of scenarios to use that capture end members and central tendency of ensemble.
2. Use most recent models (CMIP 6) but augment with (CMIP5) to include drought scenario.
3. Utilize USGS Basin Characterization Model inputs (PPT and TEMP) to ecologically relevant hydrology indictors: AET (productivity), PET, CWD (drought stress), runoff and recharge (270m).
4. Query vegetation distribution and fire hazard models that build on Basin Characterization Model, outputs or equivalents (30m).

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Outline

1. Review of climate model selection including summaries of downscaled temperature and rainfall trends.
2. Review of hydrology outputs and summaries.
3. Discussion on implications of climate for vegetation, Ackerly model.
4. Discussion on implications of climate for fire hazard.
5. Highlighting landscape-scale and collaborative project opportunities for planning.

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Overview and Methods

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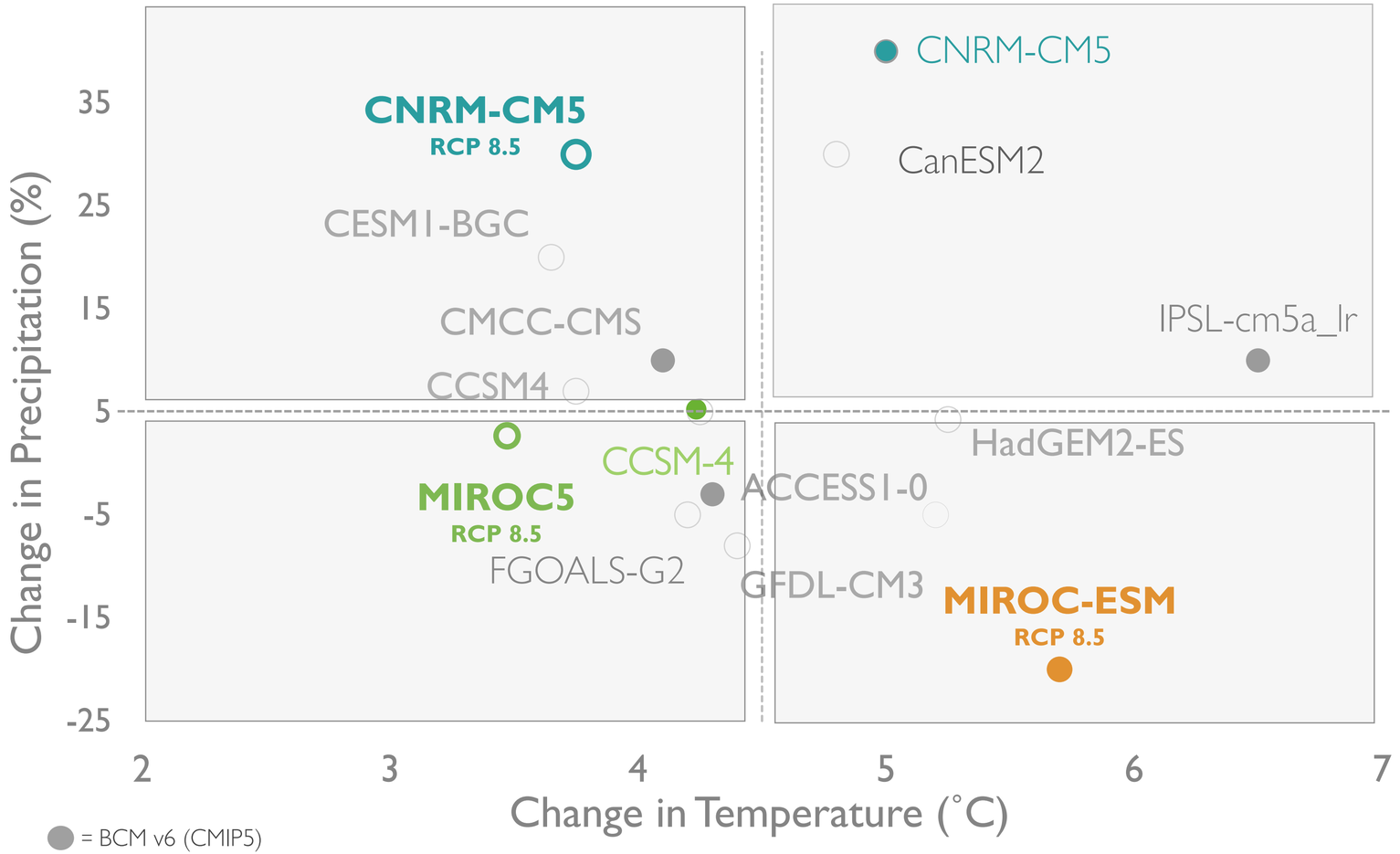
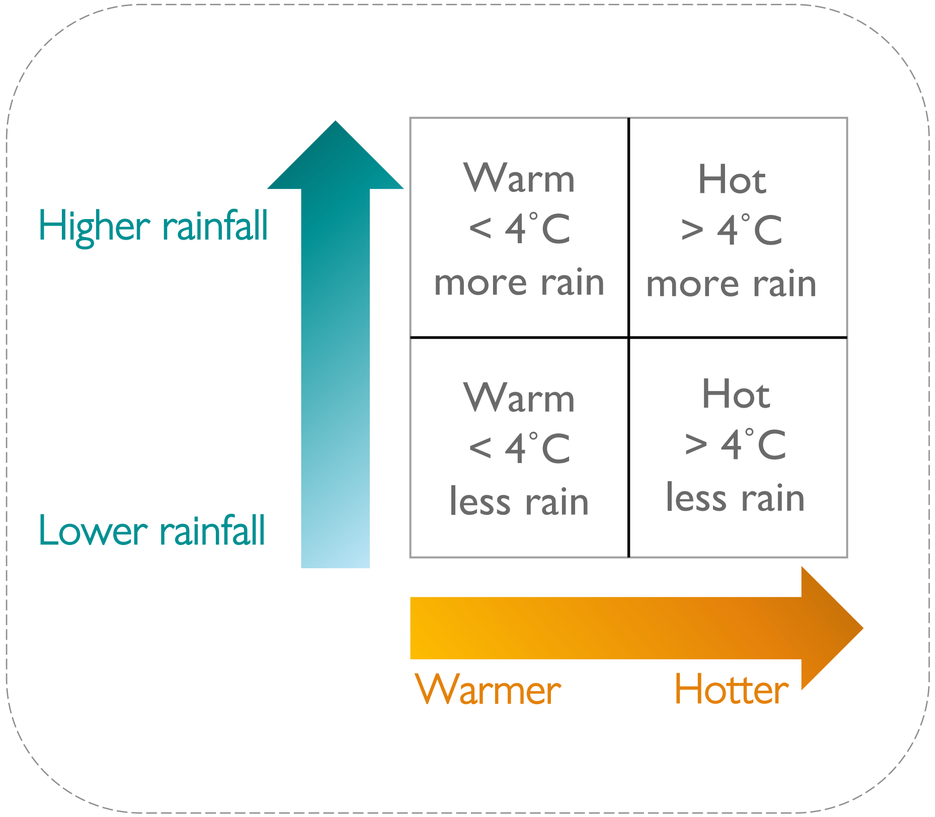
Late-*century values* were calculated for **climate projections** that span a range of temperature and precipitation conditions for **California**





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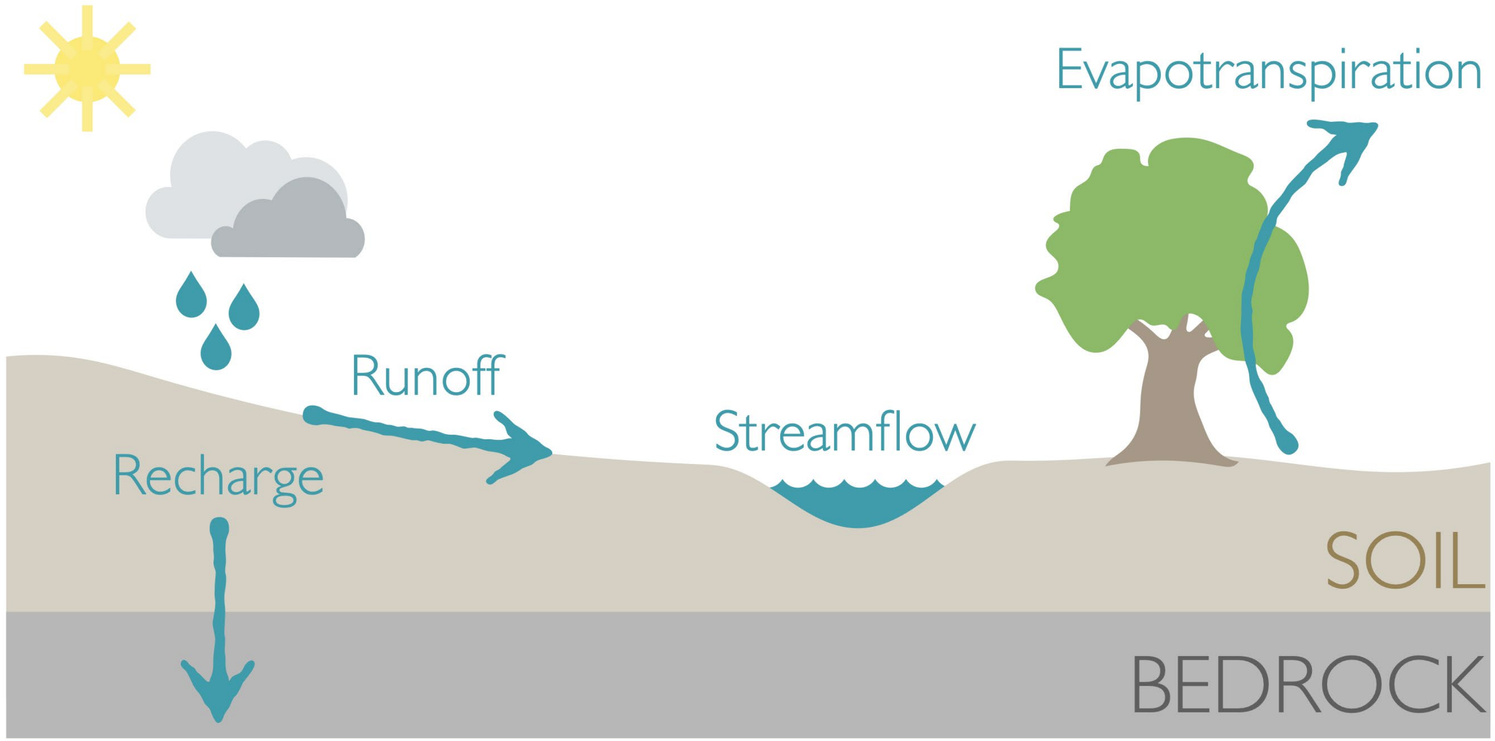
Basin Characterization Model (BCM)

Translating climate to watershed response

BCM INPUT

- Temperature
- Solar Radiation
- Precipitation
- Topography
- Soils
- Geology



UNIQUE BCM OUTPUT

Potential Evapotranspiration

–

Actual Evapotranspiration

=

Climatic Water Deficit

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Downscaled Temperature Inputs Derived from Global Climate Models

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Temperature | SUMMARY OF SCENARIOS COMPARED TO HISTORIC BASELINE

	Average (AVG) ºC			Winter Minimum (DJF) ºC			Summer Maximum (JJA) ºC		
Recent Historic (1981-2010)	14.3			4.9			25.9		
Scenario	Warm/High Rainfall	Warm/ Moderate Rainfall	Hot/Low Rainfall	Warm/High Rainfall	Warm/ Moderate Rainfall	Hot/Low Rainfall	Warm/High Rainfall	Warm/ Moderate Rainfall	Hot/Low Rainfall
Late-Century (2070-2099)	16.6	16.6	19.4	5.5	5.9	9.0	29.0	29.3	32.9
Change	2.2	2.2	5.1	0.6	1.0	4.1	3.1	3.4	7.0

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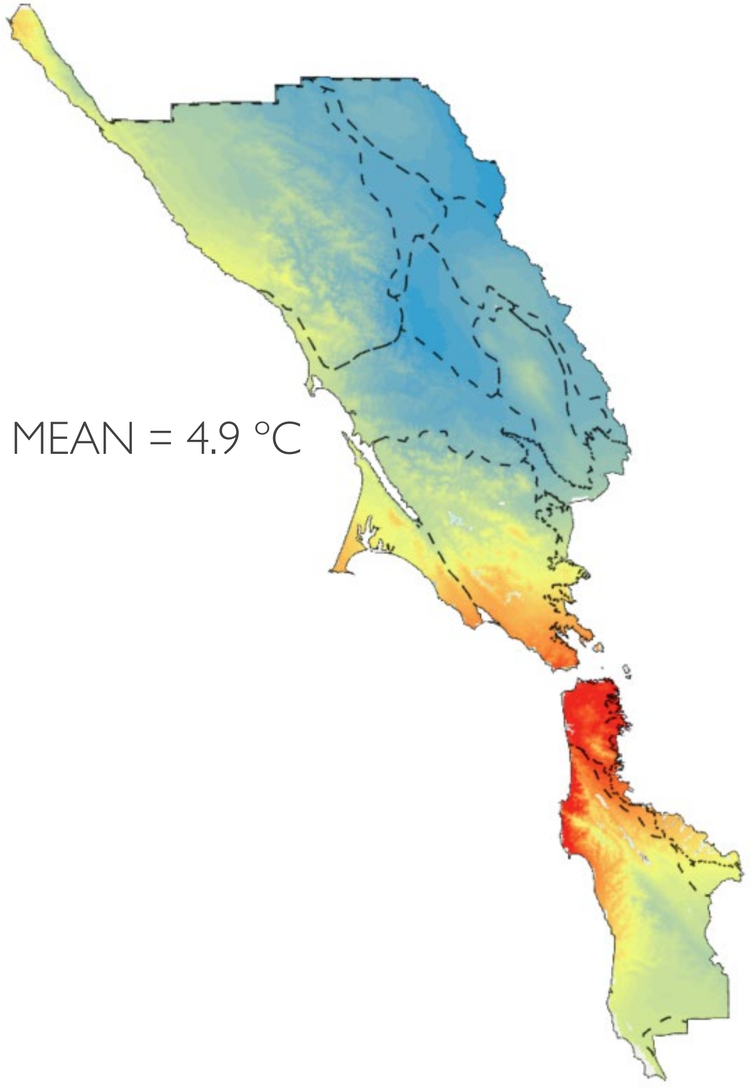
Data Source: Flint & Flint v8 (2021) & v6 (2014)

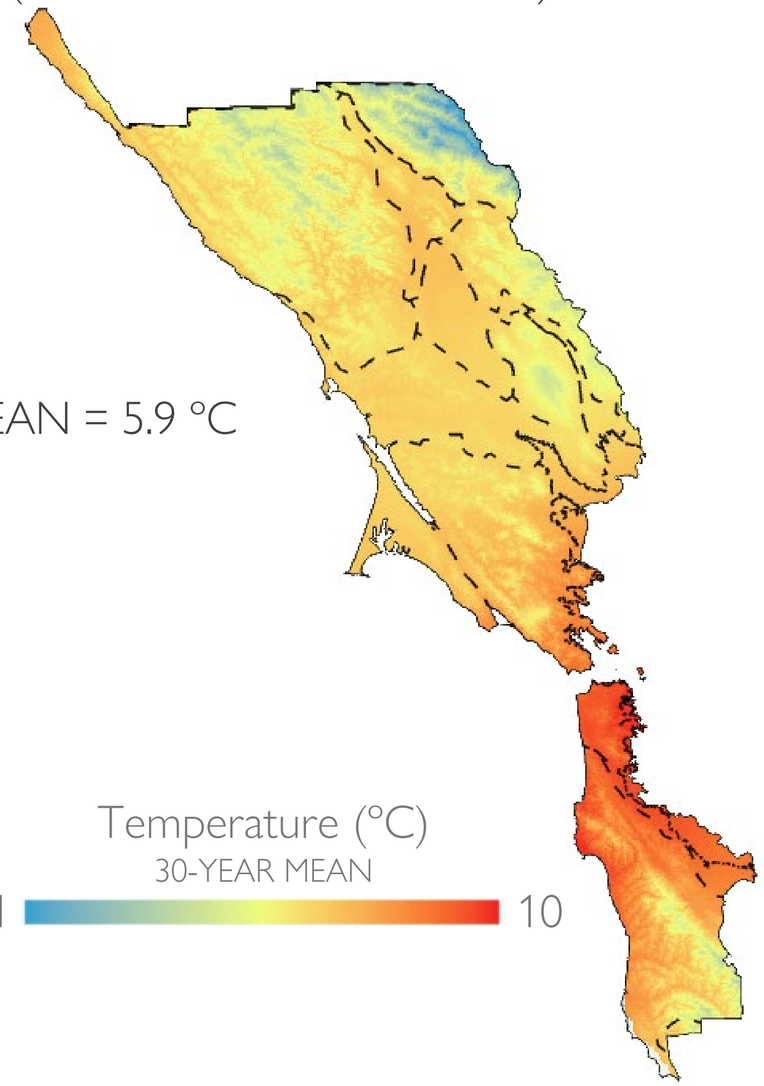
Temperature | WINTER MINIMUM (DEC, JAN, FEB), RECENT HISTORIC VS PROJECTED

Recent Historic (1981-2010)



MEAN = 4.9 °C

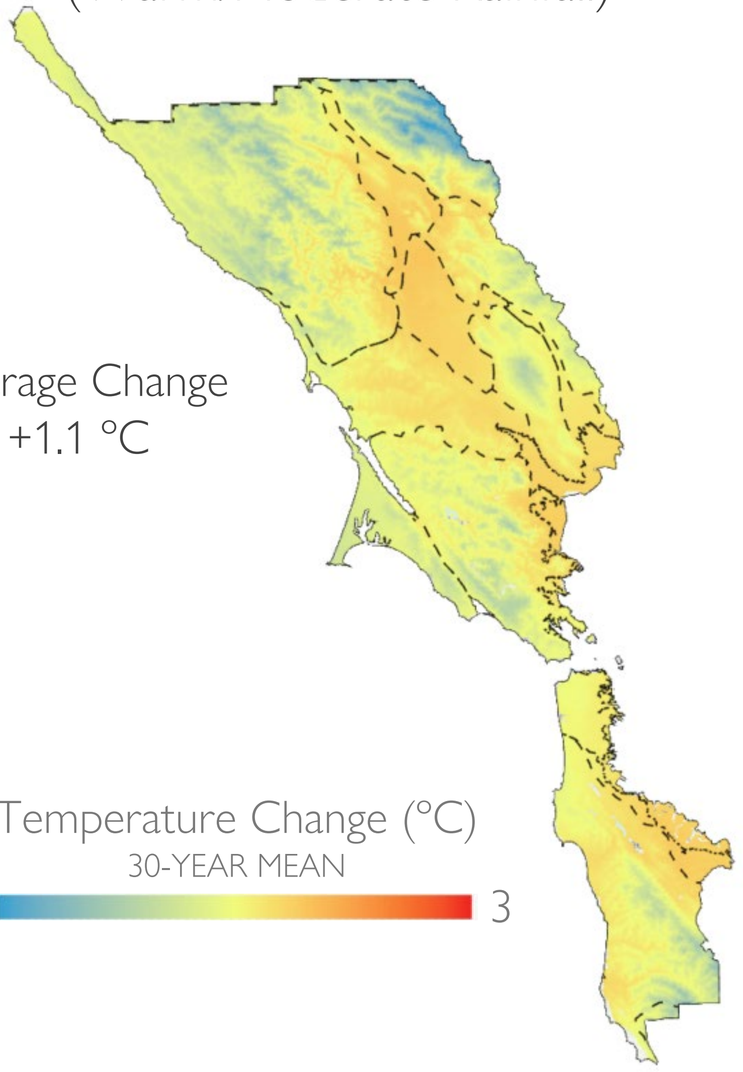
Late-Century (Warm/Moderate Rainfall)



MEAN = 5.9 °C

Temperature (°C)
30-YEAR MEAN
1 — 10

Change from Recent Historic (Warm/Moderate Rainfall)



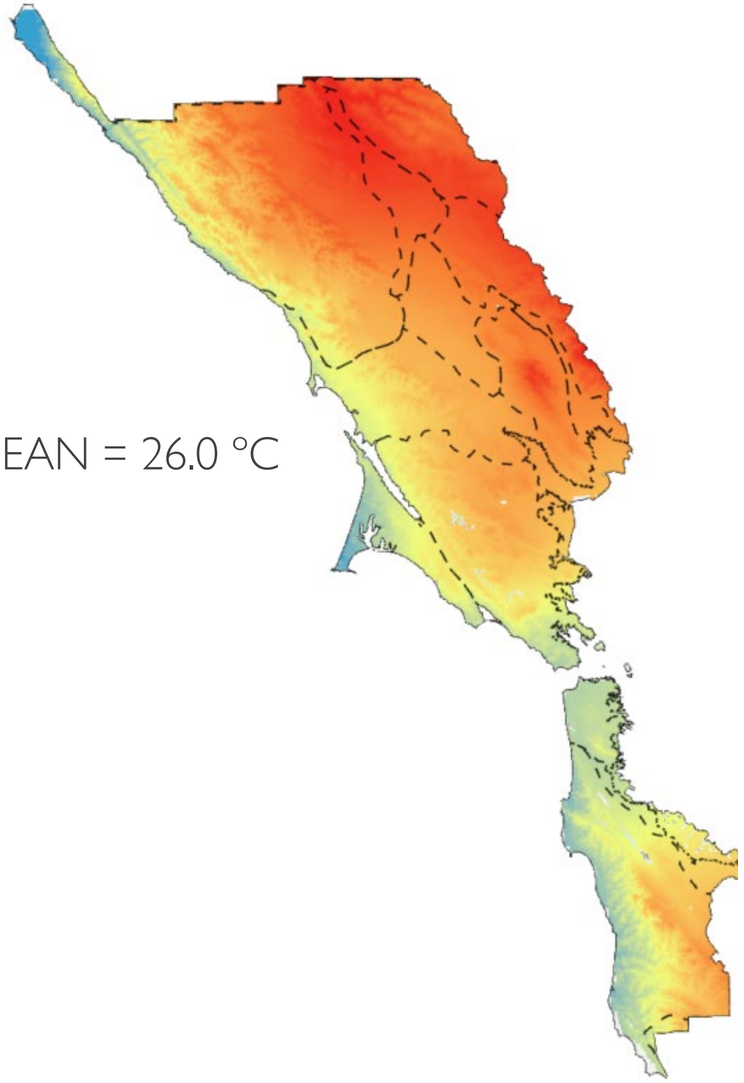
Average Change
+1.1 °C

Temperature Change (°C)
30-YEAR MEAN
-4 — 3

Data Source: Flint & Flint v8 (2021) & v6 (2014)

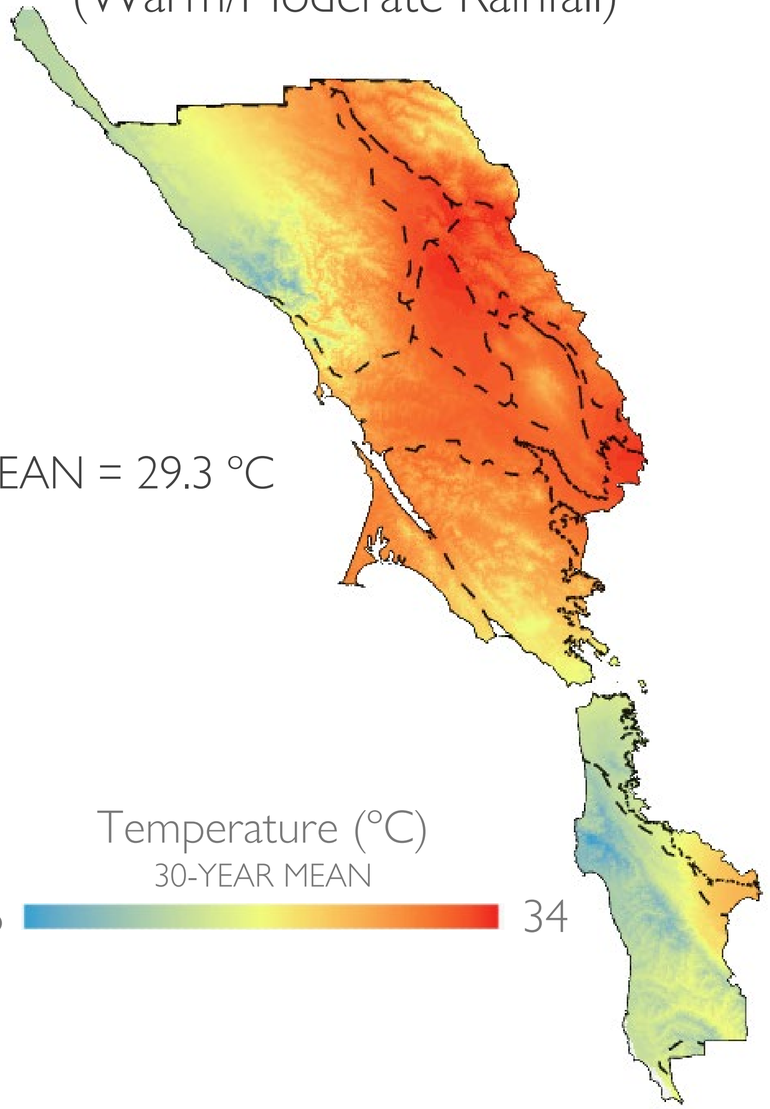
Temperature | SUMMER MAXIMUM (JUN, JUL, AUG), RECENT HISTORIC VS PROJECTED

Recent Historic (1981-2010)



MEAN = 26.0 °C

Late-Century
(Warm/Moderate Rainfall)

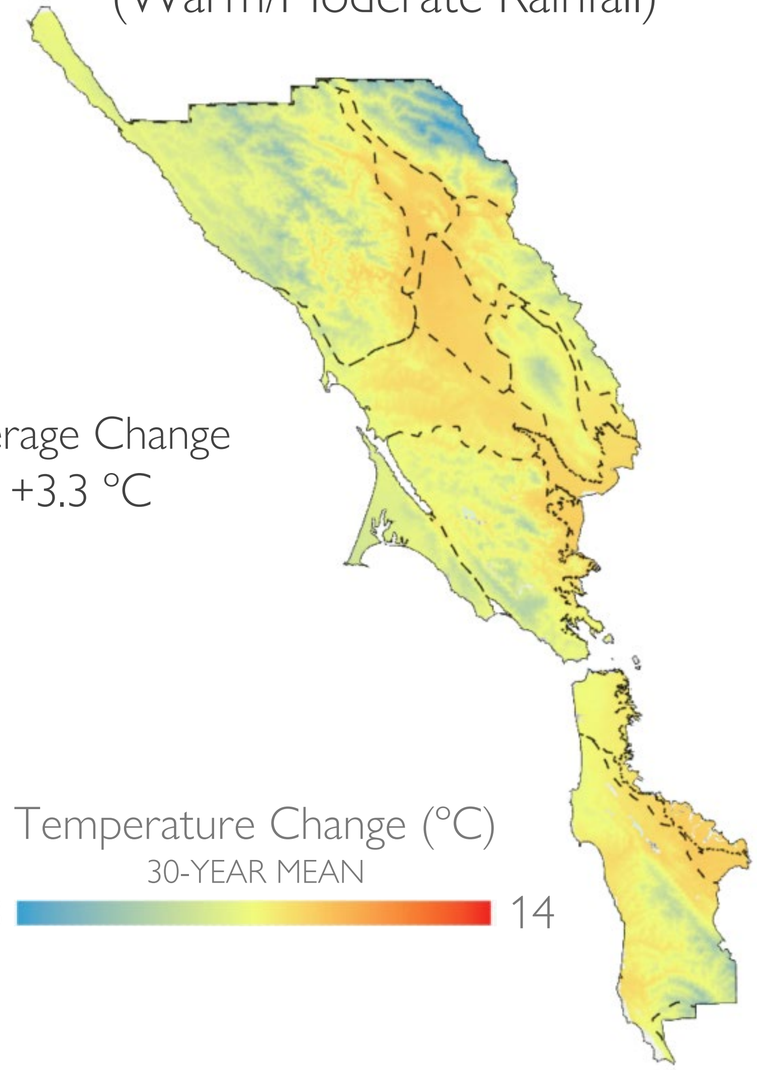


MEAN = 29.3 °C

Temperature (°C)
30-YEAR MEAN

16 — 34

Change from Recent Historic
(Warm/Moderate Rainfall)



Average Change
+3.3 °C

Temperature Change (°C)
30-YEAR MEAN

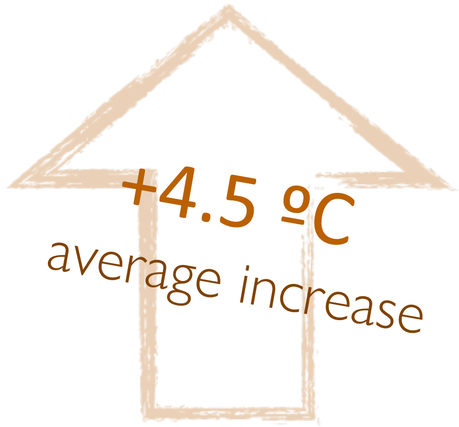
-3 — 14

Data Source: Flint & Flint v8 (2021) & v6 (2014)

Hotter Summers

Temperatures are projected to be between

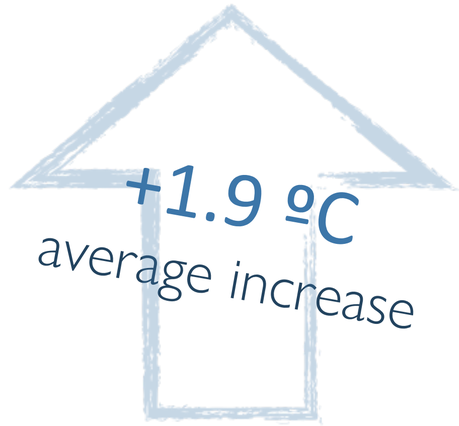
+3.1 to 7 ºC hotter



Milder Winter Weather

Temperatures are projected to be between

+0.6 to 4.1 ºC hotter



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Data Source: Flint & Flint v8 (2021) & v6 (2014)

Watershed Hydrology

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Precipitation | QUANTITATIVE SUMMARY

	Average Annual Precipitation (mm/year)		
Recent Historic (1981-2010)	1027mm		
Scenarios	Warm/High Rainfall	Warm/ Moderate Rainfall	Hot/Low Rainfall
Late-Century (2070-2099)	1423mm	1084mm	818mm
Percent Change	+38%	+5%	-20%

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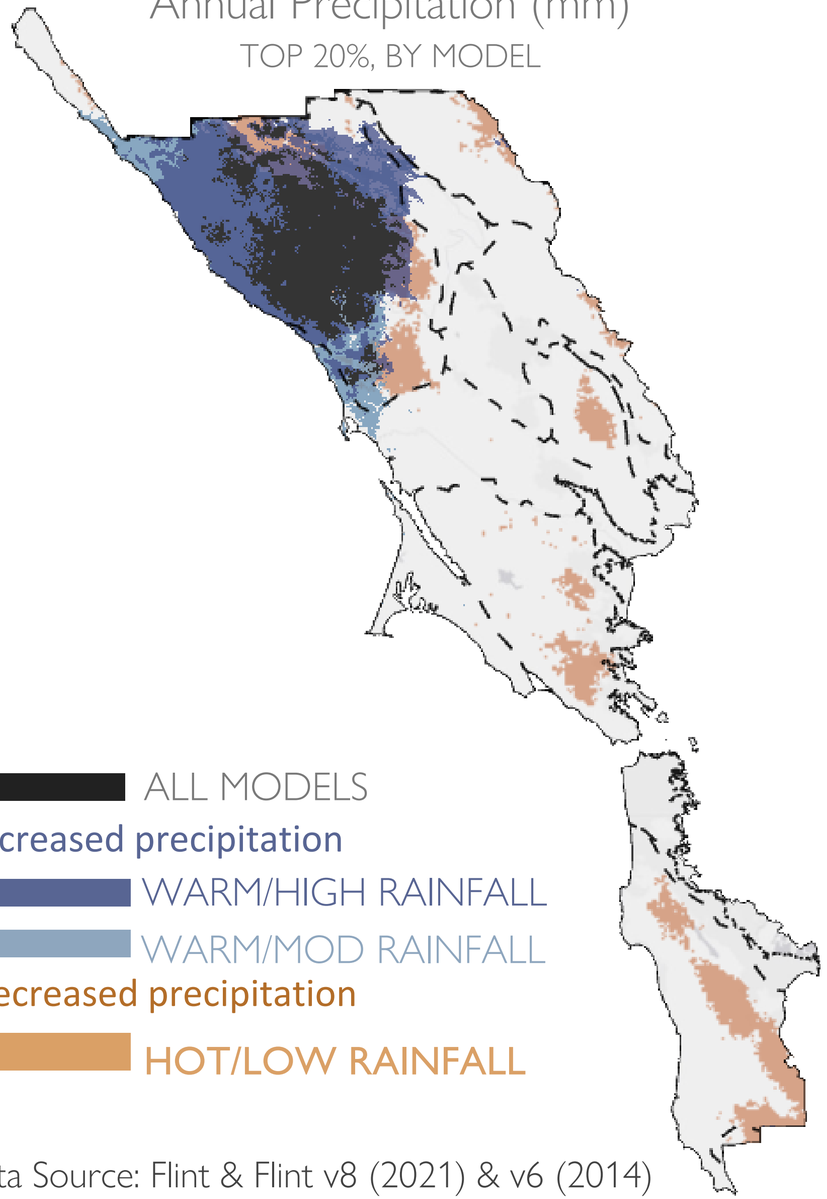
Data Source: Flint & Flint v8 (2021) & v6 (2014)

Hydrology | TRENDS IN ANNUAL AND SEASONAL PRECIPITATION

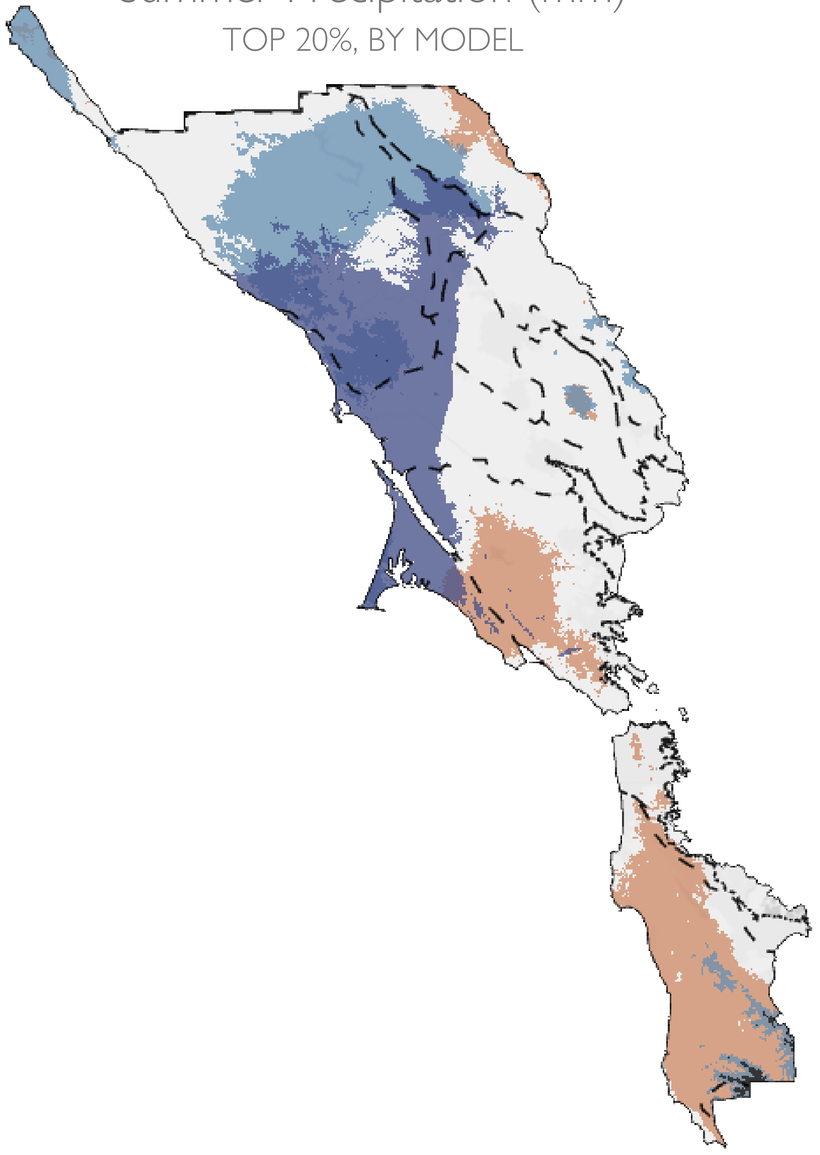
Greatest % Change in Annual Precipitation (mm)

TOP 20%, BY MODEL



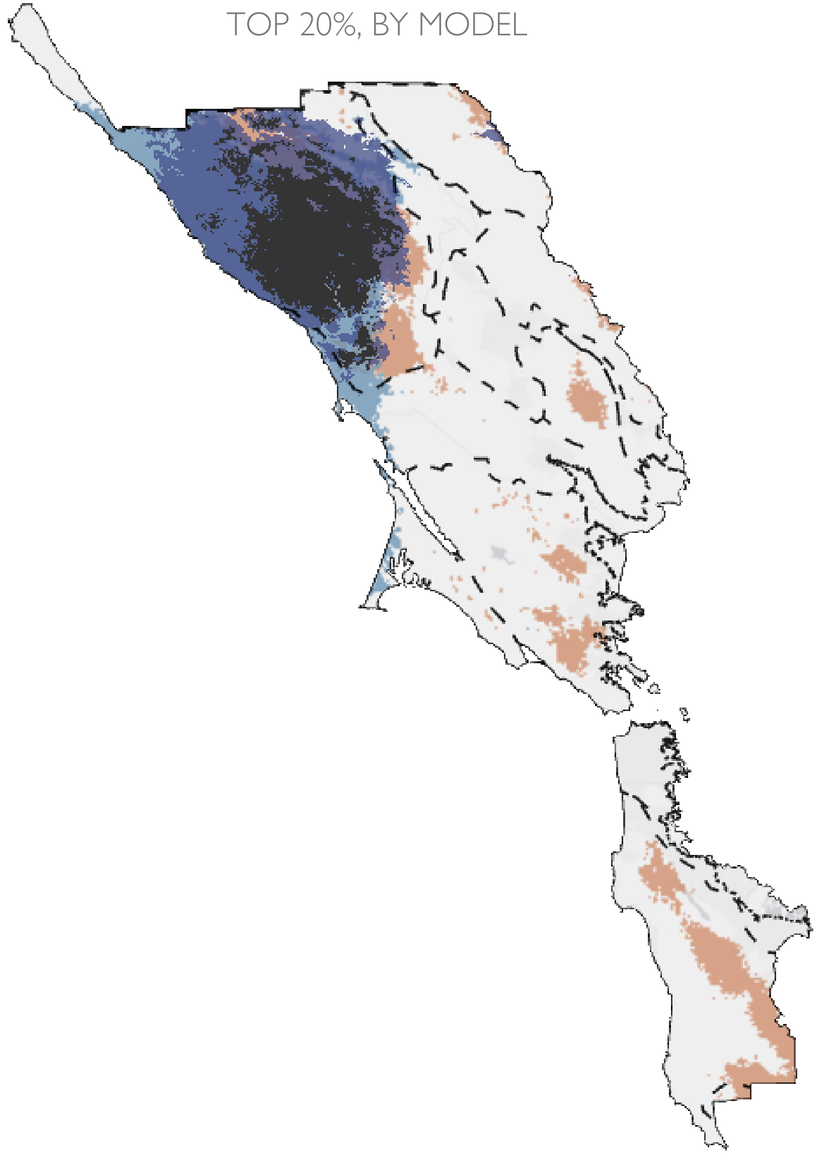
Greatest % Change in Summer Precipitation (mm)

TOP 20%, BY MODEL



Greatest % Change in Winter Precipitation (mm)

TOP 20%, BY MODEL



Data Source: Flint & Flint v8 (2021) & v6 (2014)

Hydrology | QUANTITATIVE SUMMARY

	Average Annual Runoff (mm/year)			Average Annual Recharge (mm/year)		
Recent Historic (1981-2010)	366mm			147mm		
Scenarios	Warm/High Rainfall	Warm/ Moderate Rainfall	Hot/Low Rainfall	Warm/High Rainfall	Warm/ Moderate Rainfall	Hot/Low Rainfall
Late-Century (2070-2099)	717mm	419mm	235mm	181mm	145mm	170mm
Percent Change	+96%	+14%	-36%	+23%	0%	-16%

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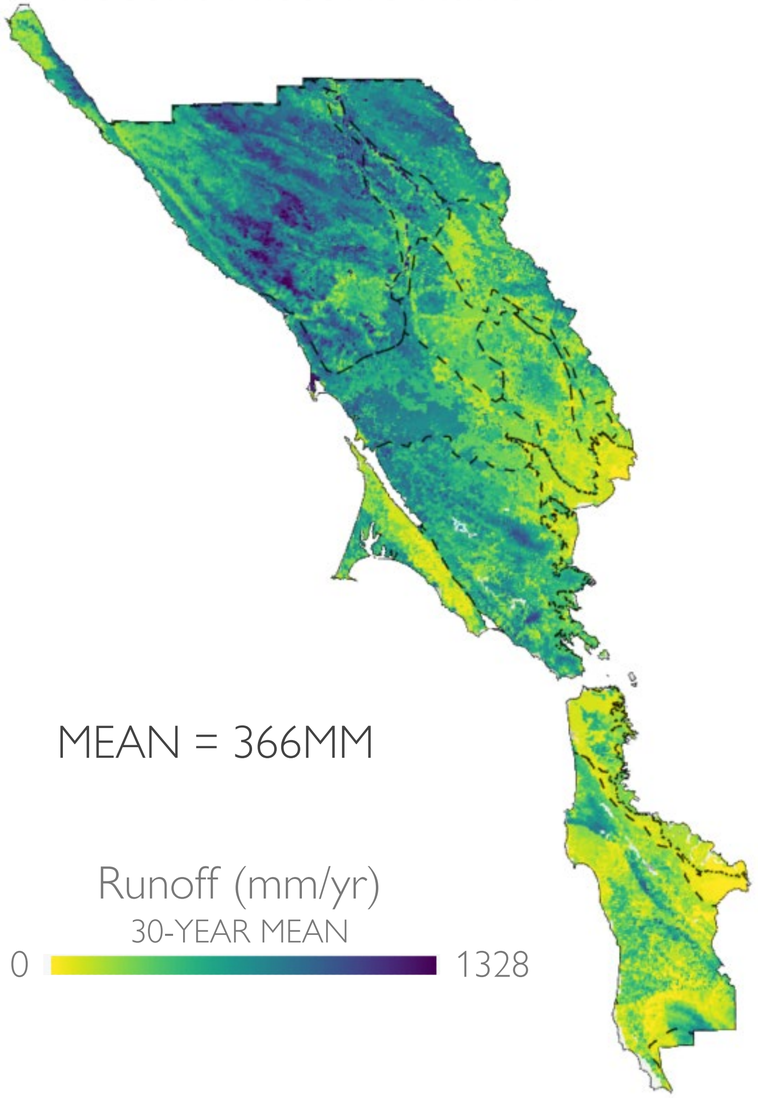
Data Source: Flint & Flint v8 (2021) & v6 (2014)

Hydrology | RECENT HISTORIC (1981-2077) WATER SUPPLY

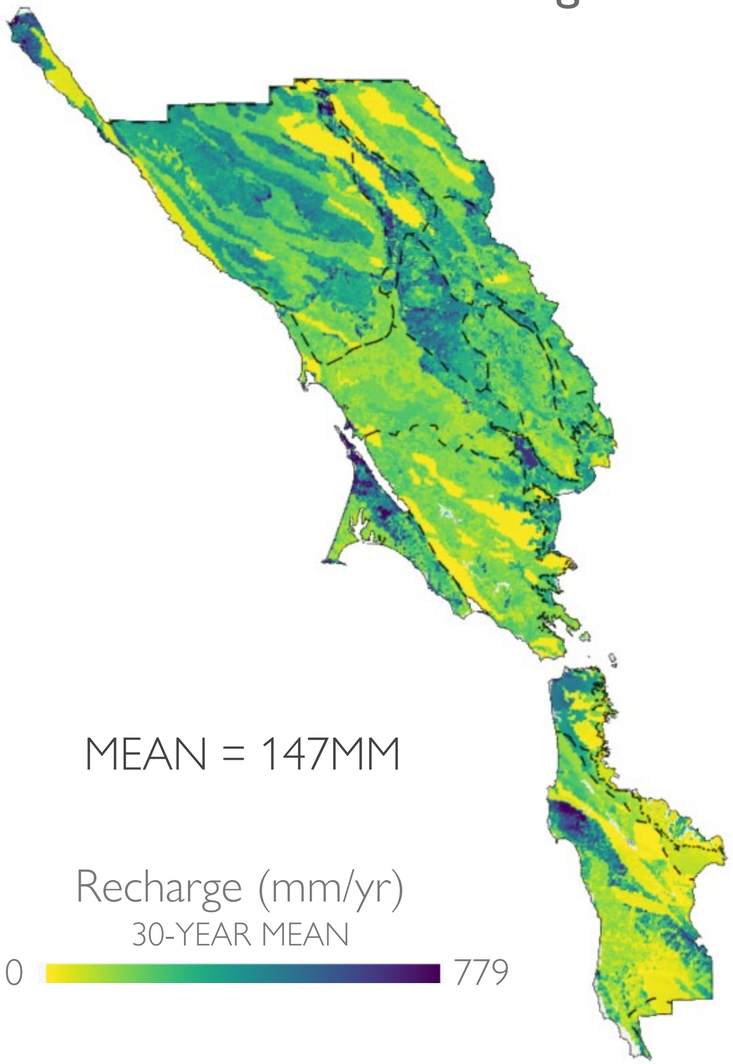
Recent Historic Runoff



MEAN = 366MM

Runoff (mm/yr)
30-YEAR MEAN
0 — 1328

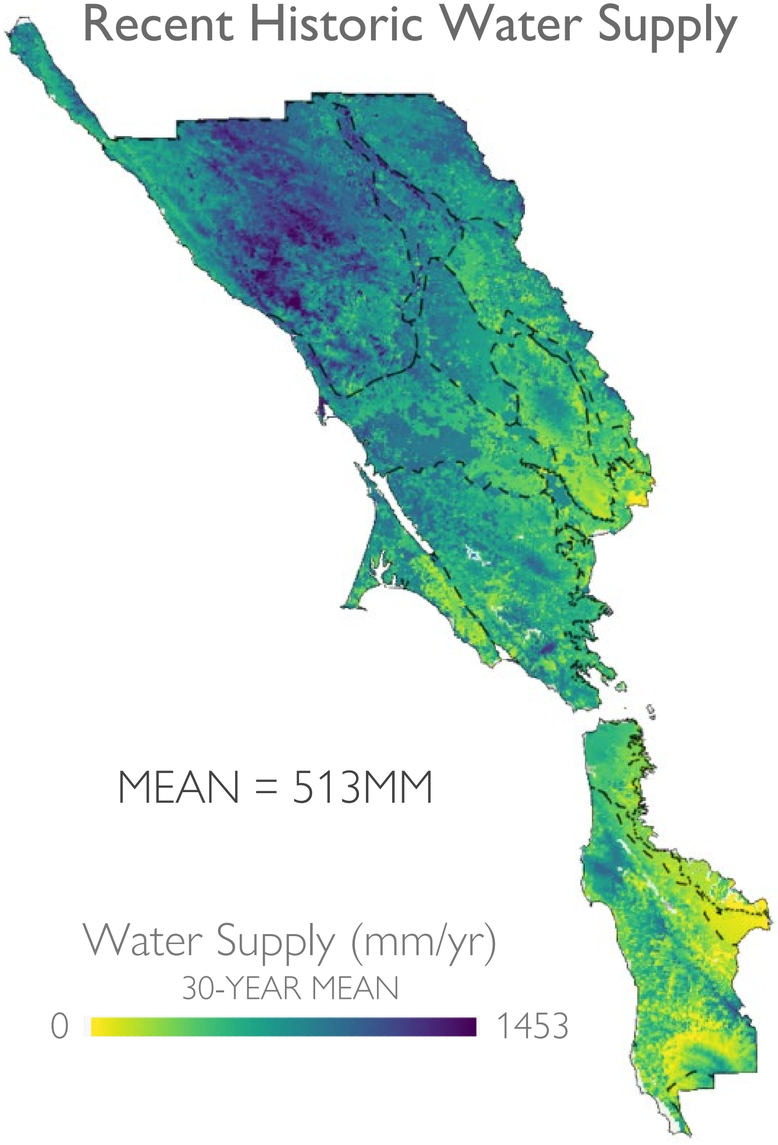
Recent Historic Recharge



MEAN = 147MM

Recharge (mm/yr)
30-YEAR MEAN
0 — 779

Recent Historic Water Supply



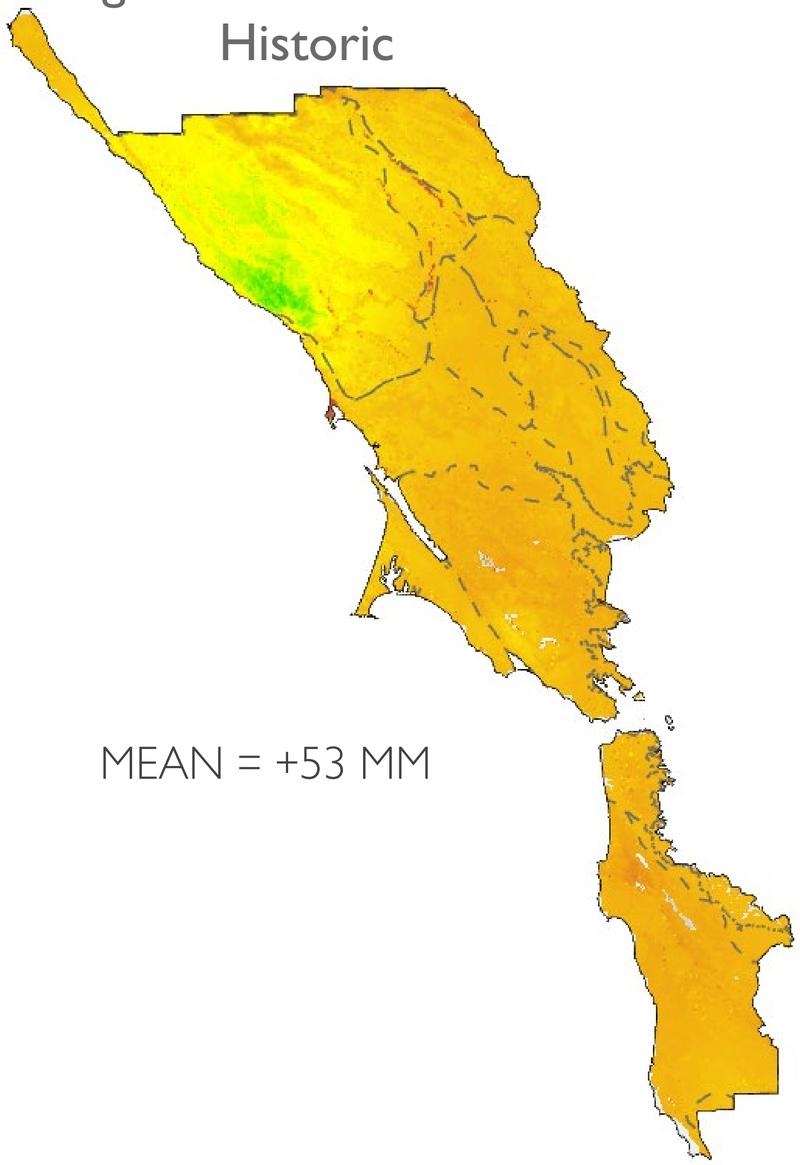
MEAN = 513MM

Water Supply (mm/yr)
30-YEAR MEAN
0 — 1453

Data Source: Flint & Flint v8 (2021) & v6 (2014)

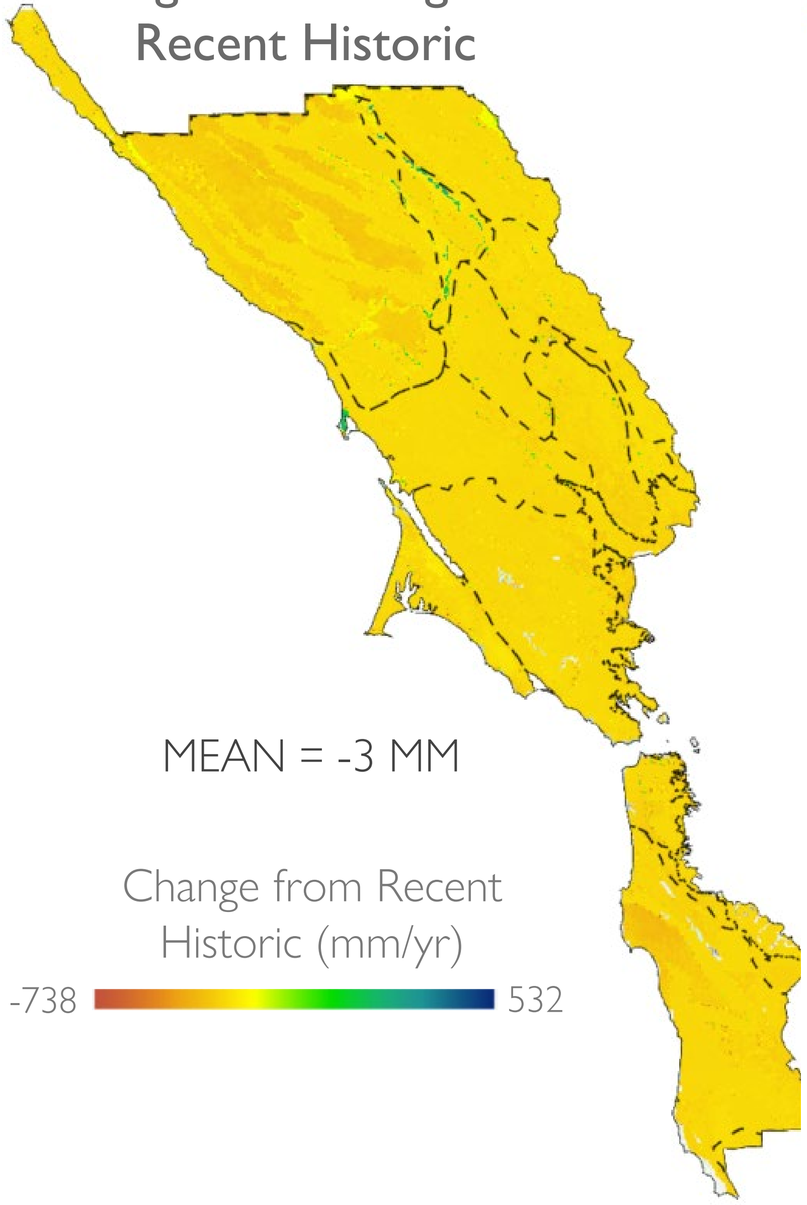
Hydrology | CHANGE IN WATER SUPPLY WARM/MODERATE RAINFALL (2070-2099)

Change in Runoff from Recent Historic



MEAN = +53 MM

Change in Recharge from Recent Historic

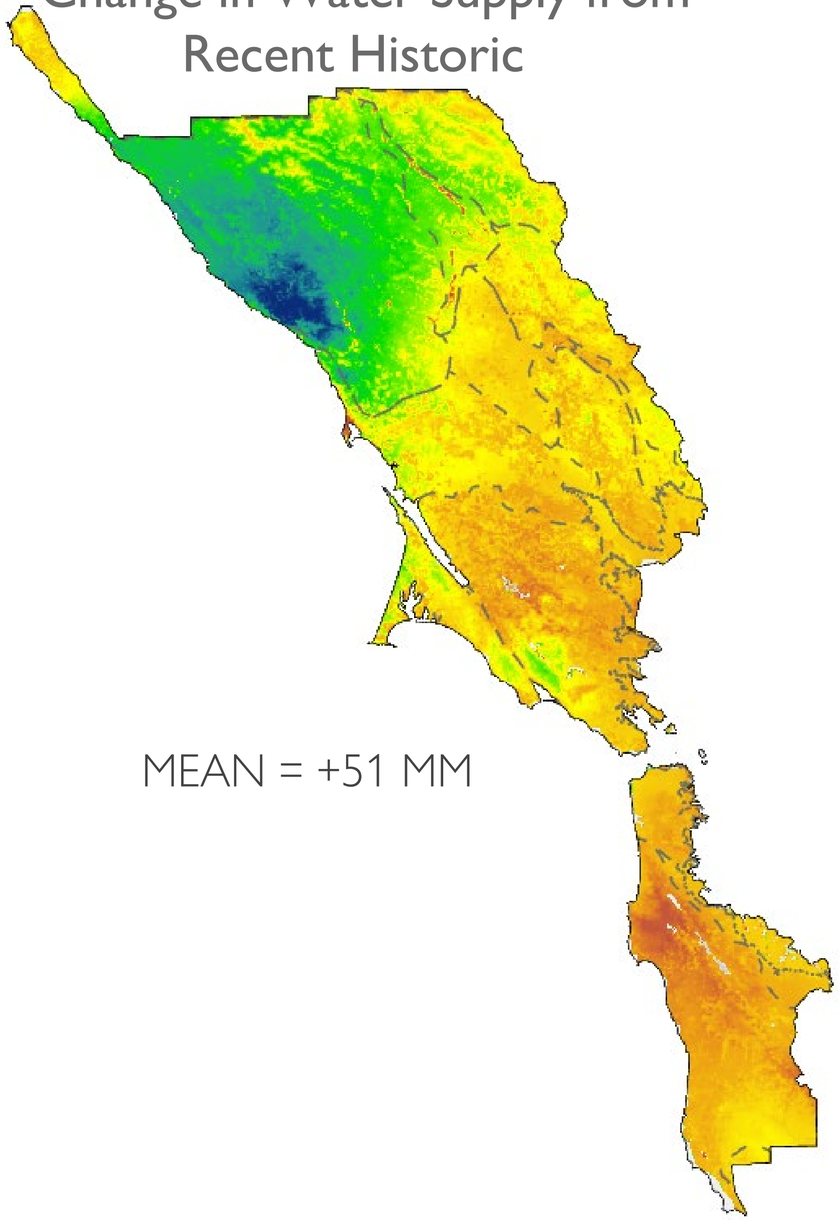


MEAN = -3 MM

Change from Recent Historic (mm/yr)

-738 532

Change in Water Supply from Recent Historic

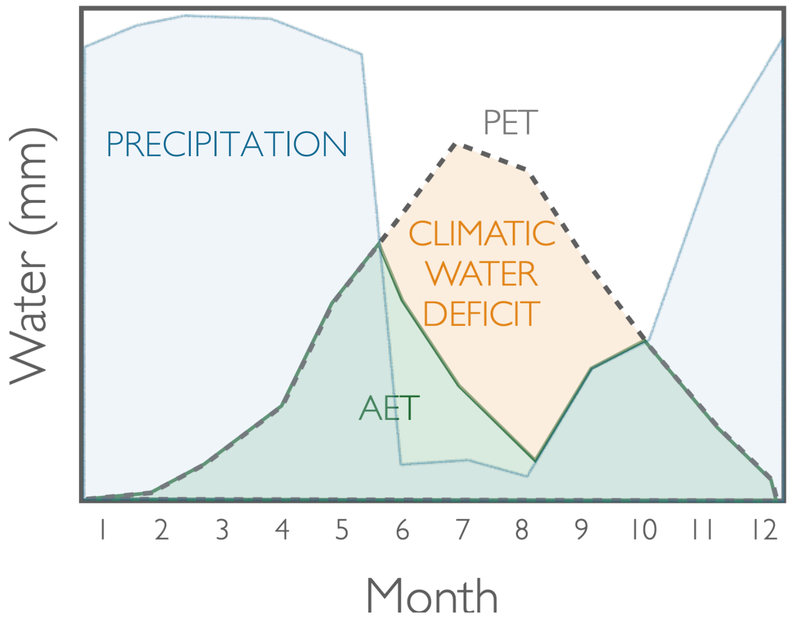


MEAN = +51 MM

Data Source: Flint & Flint v8 (2021) & v6 (2014)

Climatic Water Deficit (CWD)
A METRIC OF DROUGHT STRESS

Climatic Water Deficit = Potential Evapotranspiration − Actual Evapotranspiration



This metric integrates the effects of temperature and rainfall

- CWD increases with most projected climate scenarios
- CWD correlates with vegetation and fire risk, as well as drought

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Hydrology | CLIMATIC WATER DEFICIT QUANTITATIVE SUMMARY

	Average Annual Climatic Water Deficit (mm/year)		
Recent Historical (1981-2010)	660mm		
Scenarios	Warm/High Rainfall	Warm/Moderate Rainfall	Hot/Low Rainfall
Late-Century (2070-2099)	724mm	658mm	882mm
Percent Change	+10%	0%	+34%

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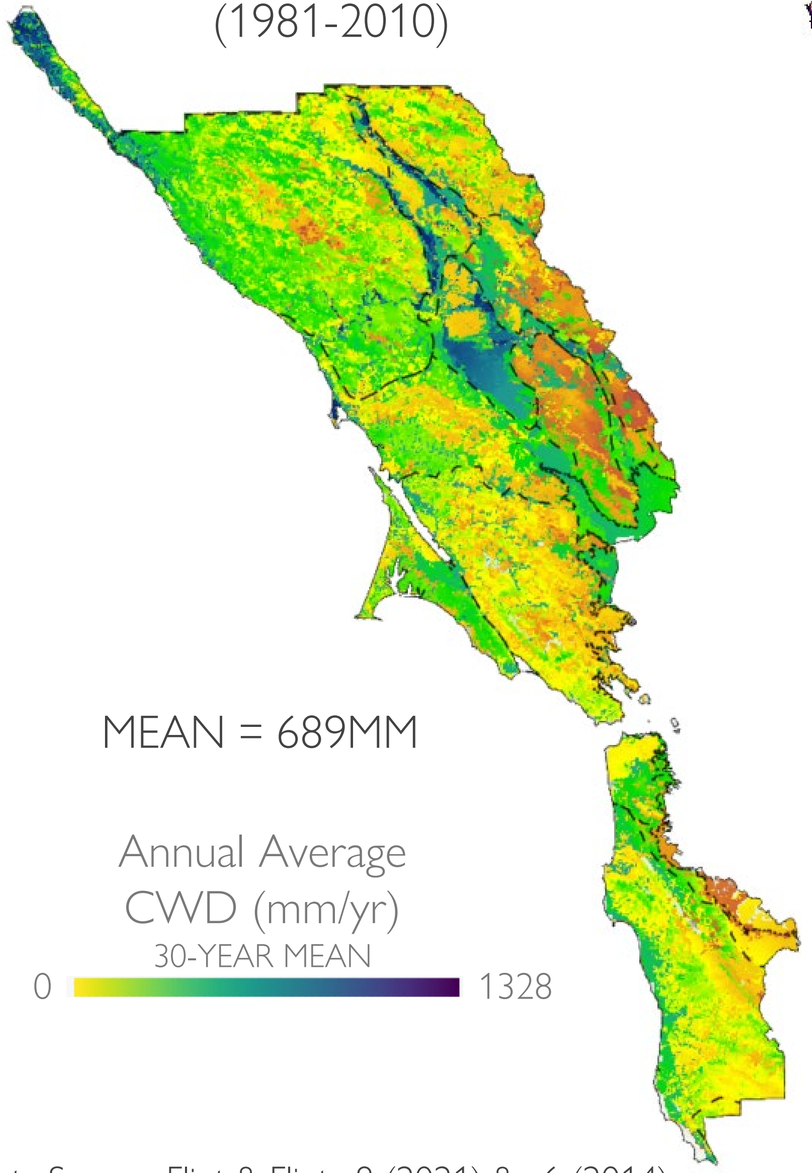
Data Source: Flint & Flint v8 (2021) & v6 (2014)

Hydrology | RECENT HISTORIC CLIMATIC WATER DEFICIT VARIABILITY

Recent Historic CWD
(1981-2010)

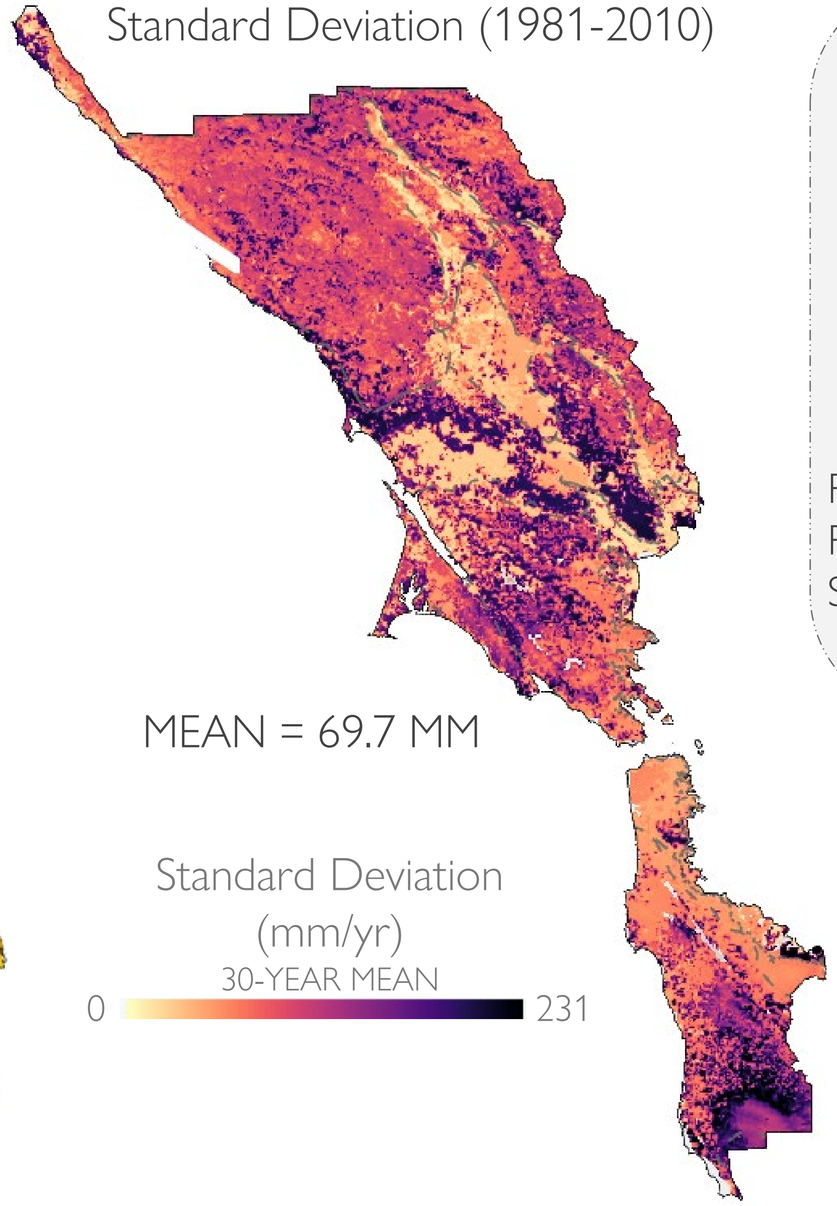


MEAN = 689MM

Annual Average
CWD (mm/yr)
30-YEAR MEAN

0 — 1328

Recent Historic CWD
Standard Deviation (1981-2010)



MEAN = 69.7 MM

Standard Deviation
(mm/yr)
30-YEAR MEAN

0 — 231

CALCULATING CHANGE IN CWD VARIABILITY

$$\text{Change (in Standard Deviation Units)} = \frac{\text{Projected 30yr mean} - \text{RH 30yr mean}}{\text{RH 30yr Standard Deviation}}$$

RH (Recent Historic 1981-2010)
Projected (Late Century 2070-20999)
Source: Thorne et al. 2015

Data Source: Flint & Flint v8 (2021) & v6 (2014)

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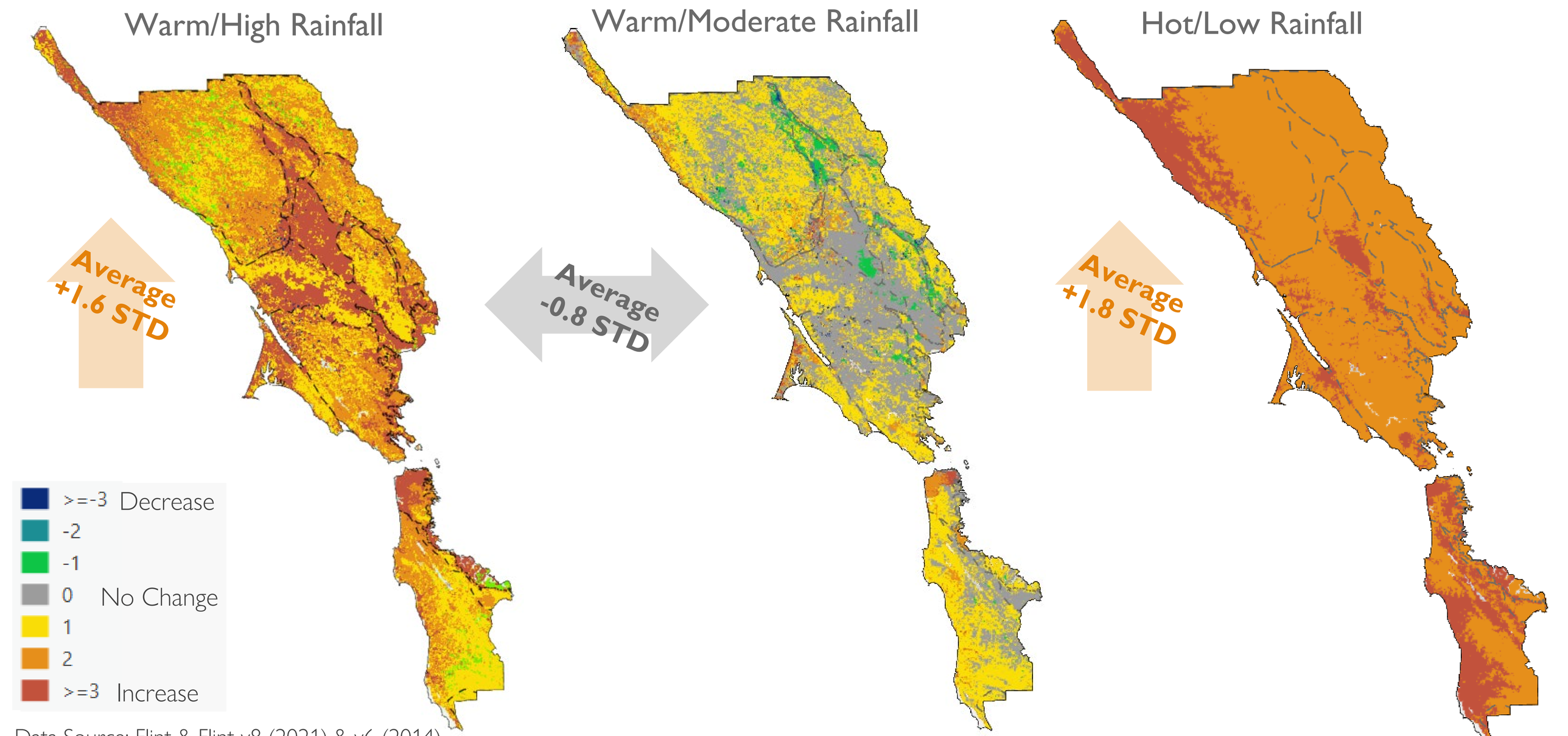
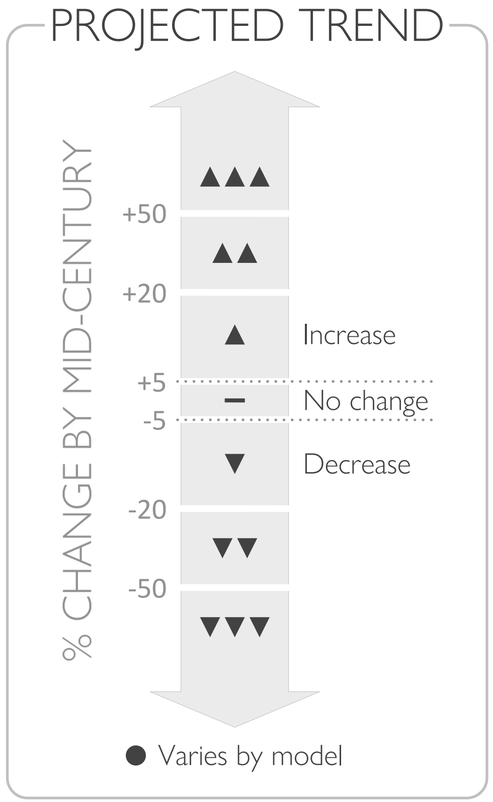
Hydrology | CHANGE IN CLIMATIC WATER DEFICIT FROM HISTORICAL (1981-2010)



Data Source: Flint & Flint v8 (2021) & v6 (2014)

Temperature and CWD increased for all scenarios
Precipitation, recharge, and runoff projections differed by scenario

VARIABLE	TREND	Warm/High Rainfall	Warm/ Moderate Rainfall	Hot/Low Rainfall
Annual Average Temperature	▲	△	△	△△
Winter minimum (Dec, Jan, Feb)	▲▲	△△	△△	△△
Summer maximum (Jun, Jul, Aug)	▲	△	△	△△
Annual Precipitation	▲	△△	△	▽▽
Seasonal Precipitation (Jun, Jul, Aug)	▲	△△	△△	—
Seasonal Precipitation (Dec, Jan, Feb)	●	△△	—	▽▽
Recharge	●	△△	—	▽
Runoff	●	△△	△	▽▽
Climatic water deficit	▲	△	—	△△



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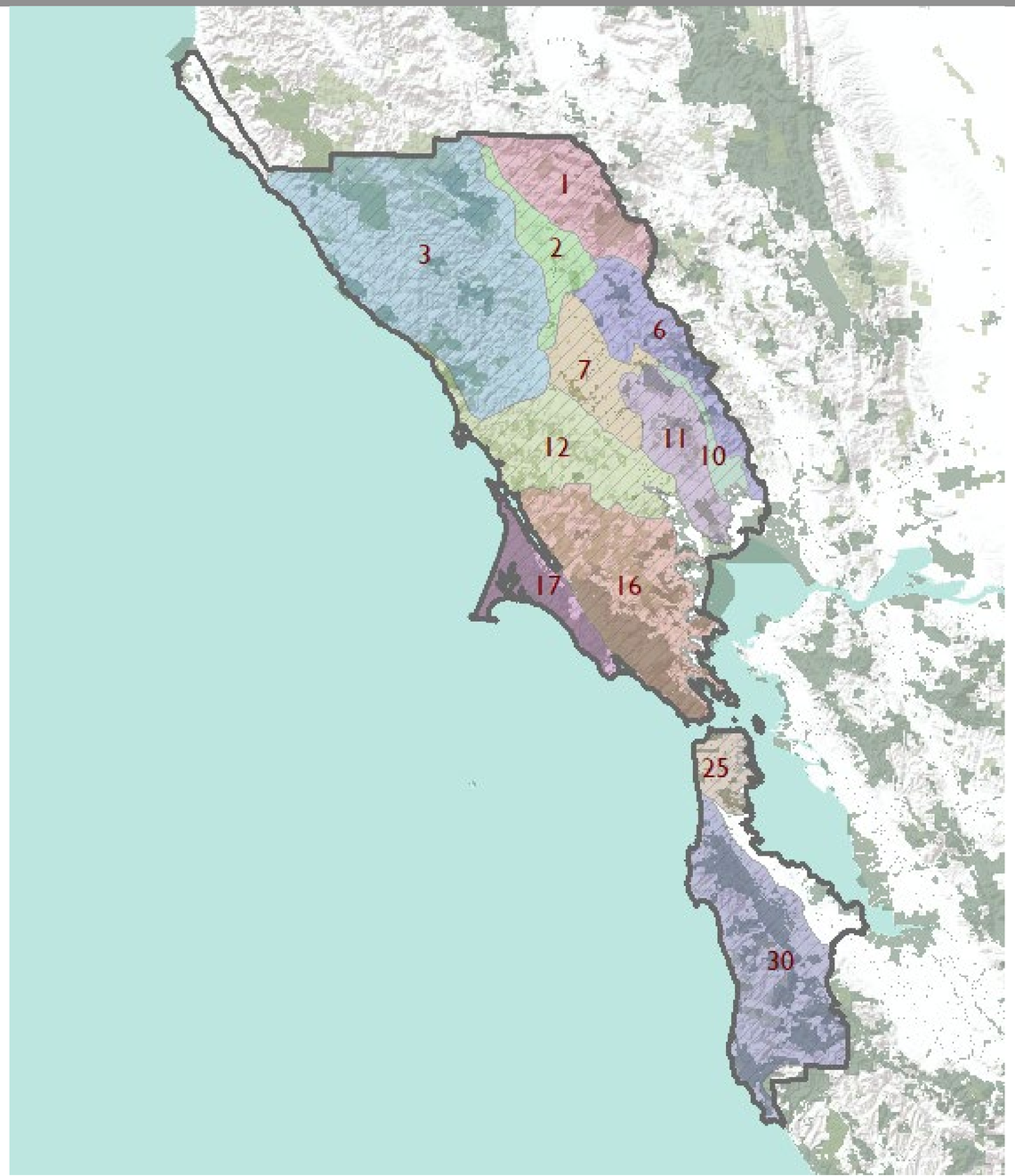
Conservation Landscape Network (CLN) Landscape Units | 12 GEOGRAPHIC EXTENTS



Landscape Units are geographic divisions based on physiographic features and inform the vegetation vulnerability model.

*Factors, excluding climatic-biotic, and edaphic conditions, affecting prevailing habitat conditions and biotic distributions (e.g. topography, drainage, erosion)

1 - Northern Mayacamas Mountains
2 -Russian River Valley
3 - Sonoma Coast Range
6 - Southern Mayacamas Mountains
7 - Santa Rosa Plain
10 - Sonoma Valley
11 - Sonoma Mountain
12 - Coastal Grasslands
16 - Marin Coast Range
17 - Point Reyes
25 - San Francisco
30 - Santa Cruz Mountains North

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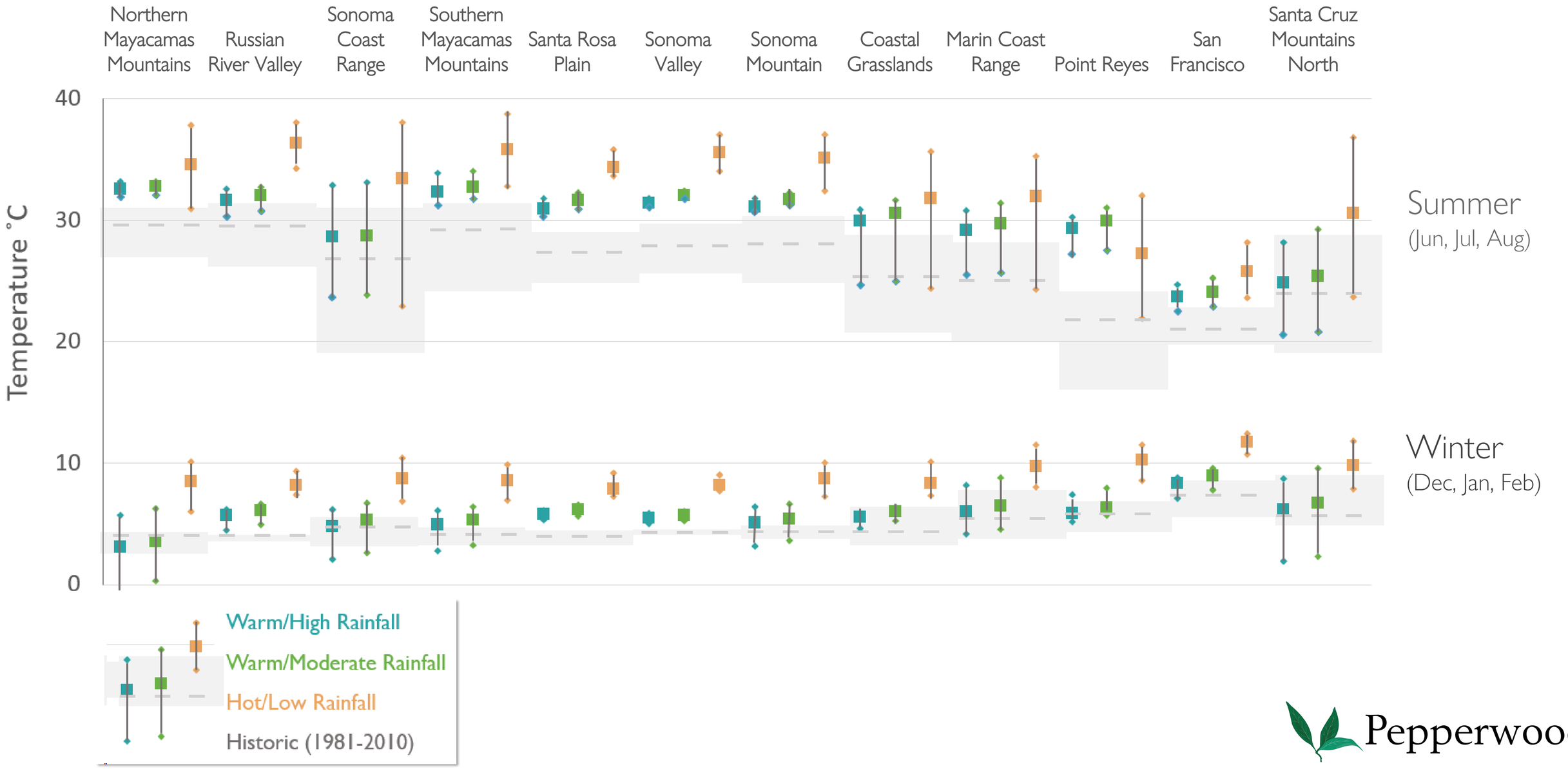
Temperature | SEASONAL (WINTER & SUMMER) AVERAGE TEMPERATURE BY LANDSCAPE UNIT



Data Source: Flint & Flint v8 (2021) & v6 (2014)

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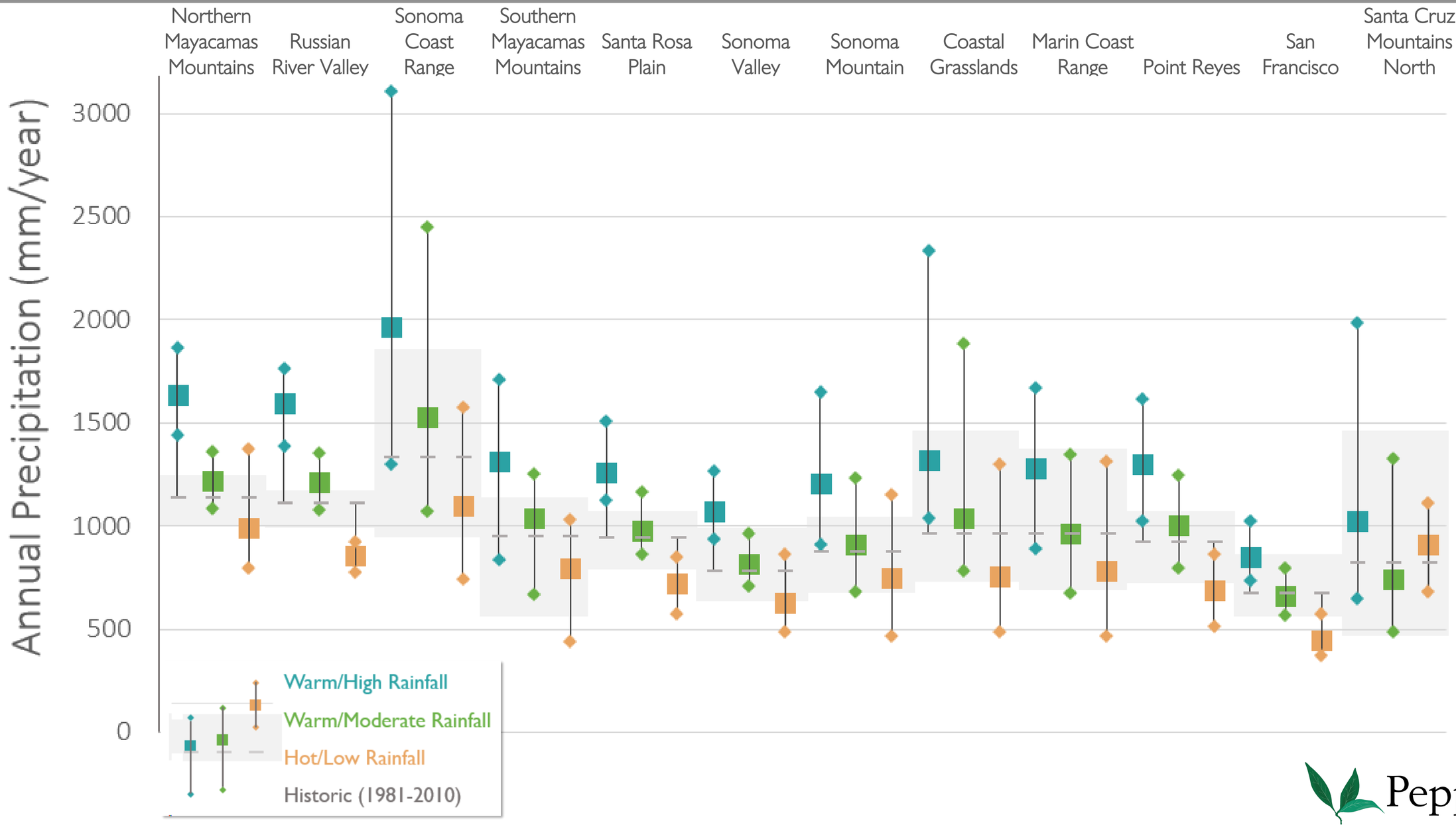
Precipitation | ANNUAL AVERAGE PRECIPITATION BY LANDSCAPE UNIT



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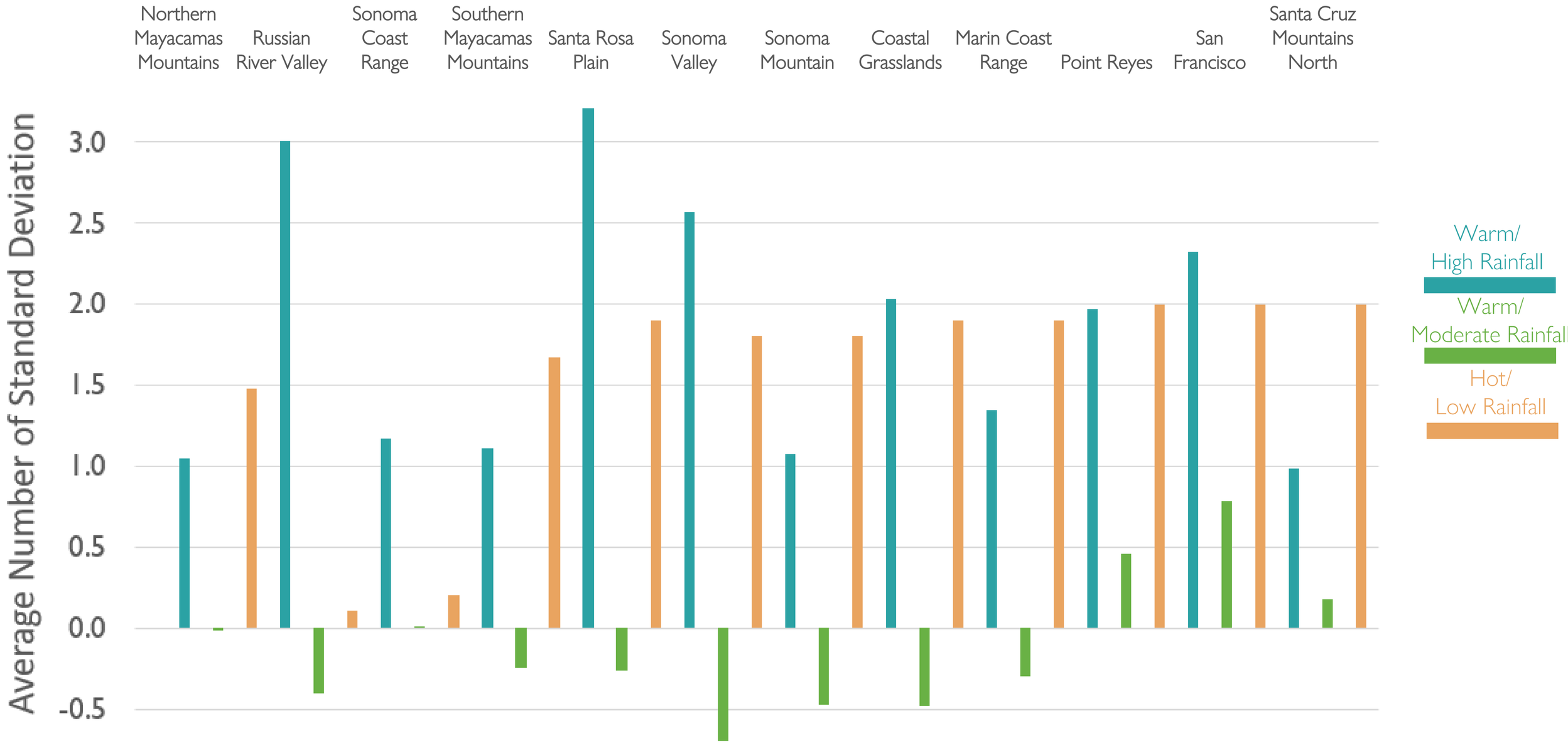
Data Source: Flint & Flint v8 (2021) & v6 (2014)

Climatic Water Deficit | AVERAGE NUMBER OF STANDARD DEVIATIONS FROM RECENT HISTORIC (1981-2010)



Data Source: Flint & Flint v8 (2021) & v6 (2014)

WILDFIRE PROBABILITY

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FIRE | ASSESSING PRESENT DAY WILDFIRE HAZARD (REGION ET AL. 2015 & DILLON ET AL. 2015, 2018)

VARIABLE	METRIC	INPUTS
Wildfire Hazard ***Potential for causing damage to vulnerable resources***	**Burn Probability of a fire in one year period (frequency)**	**U.S. Forest Service FSim 120m** **Single Year Conditions** **(Existing fuels + historic weather)**
	Fire Intensity **(severity)** - **Flame length** - **Fireline intensity**	**Pyrologix WildEST utility** **Multiple Simulations** **(dynamic fuels + weather)**

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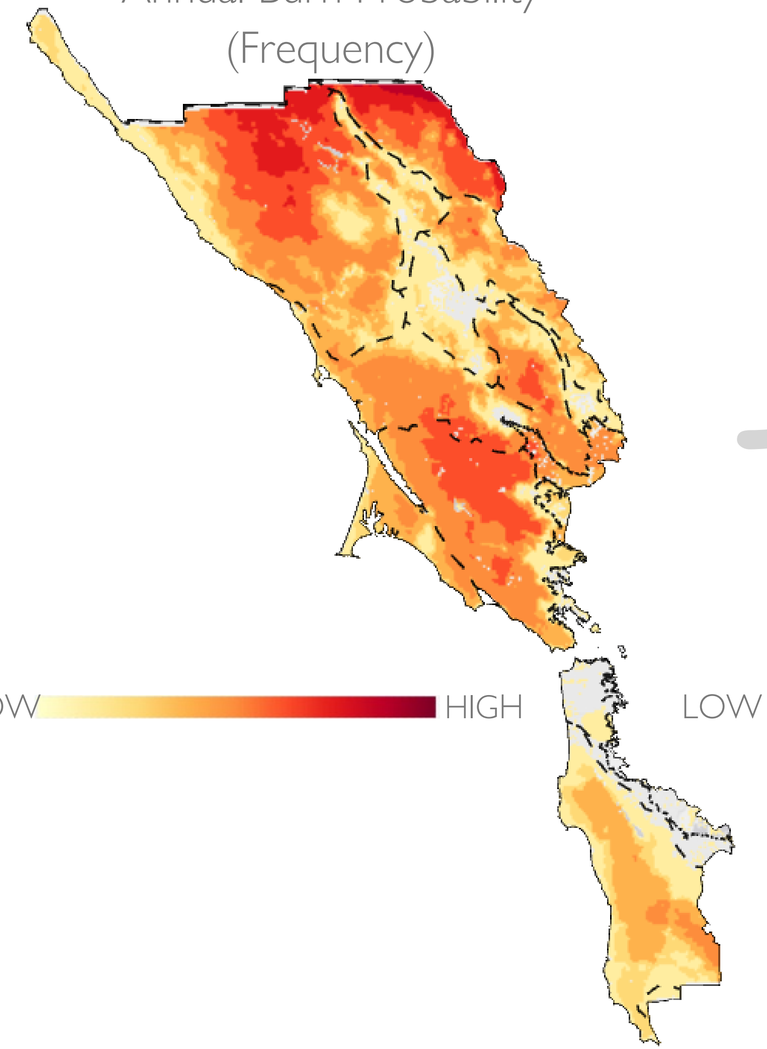
Fire | BURN PROBABILITY + FIRE INTENSITY (REGION ET AL. 2015 & DILLON ET AL. 2015, 2018)

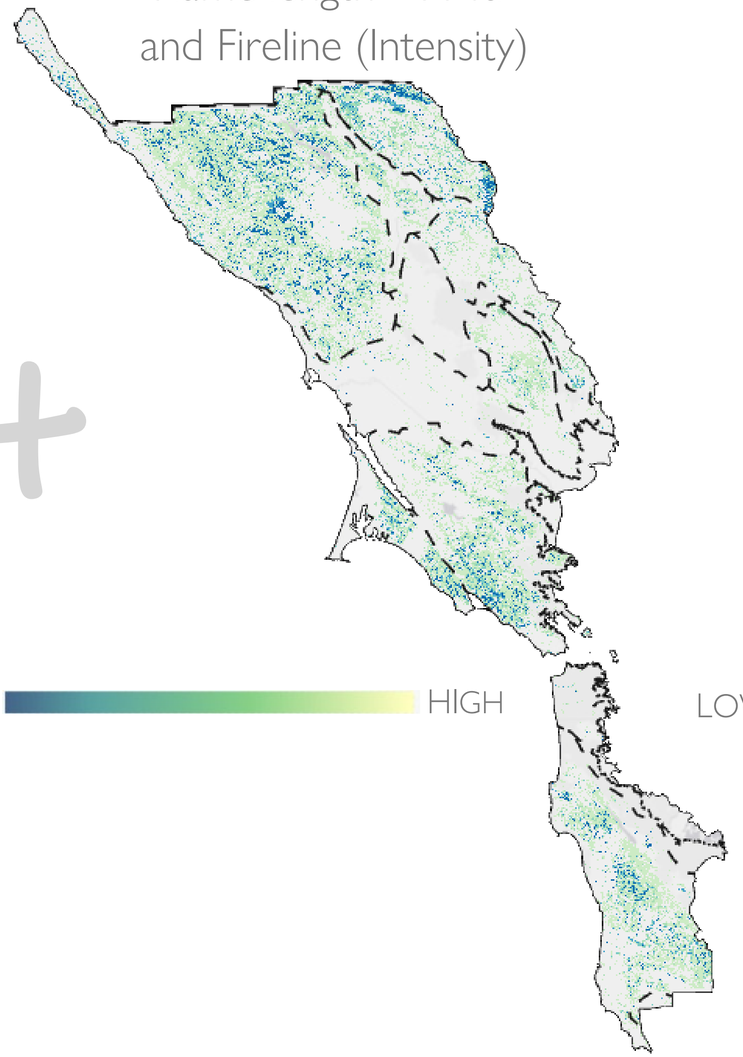
Annual Burn Probability
(Frequency)



LOW HIGH

+

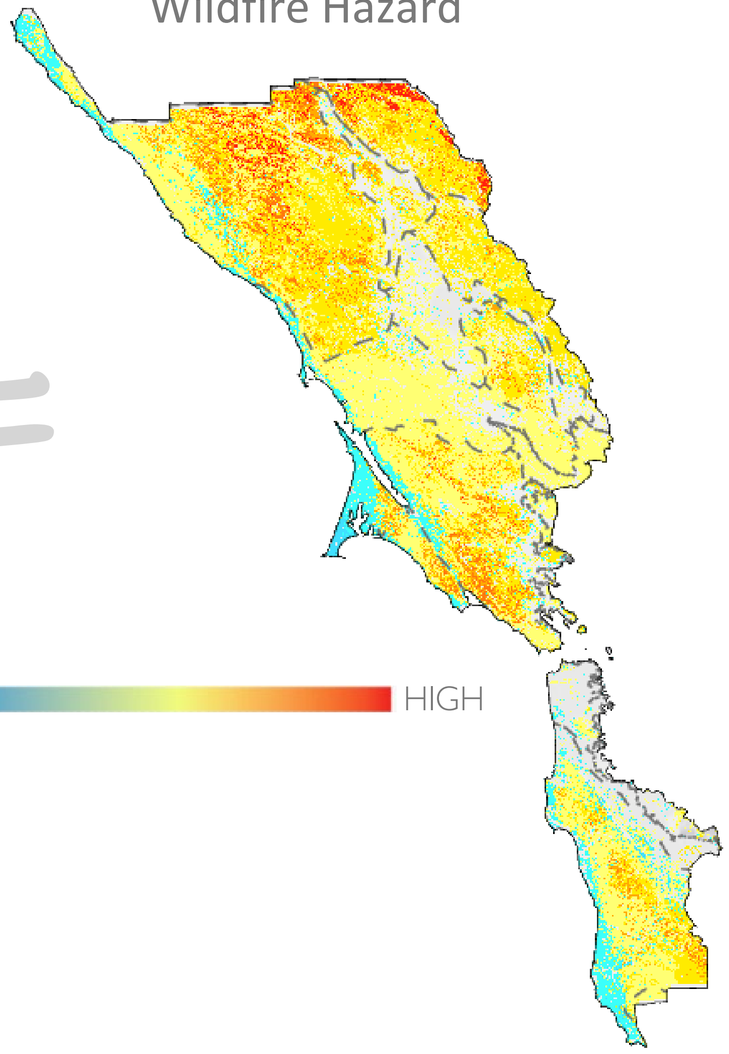
Flame length >11 ft.
and Fireline (Intensity)



LOW HIGH

=

Wildfire Hazard



LOW HIGH

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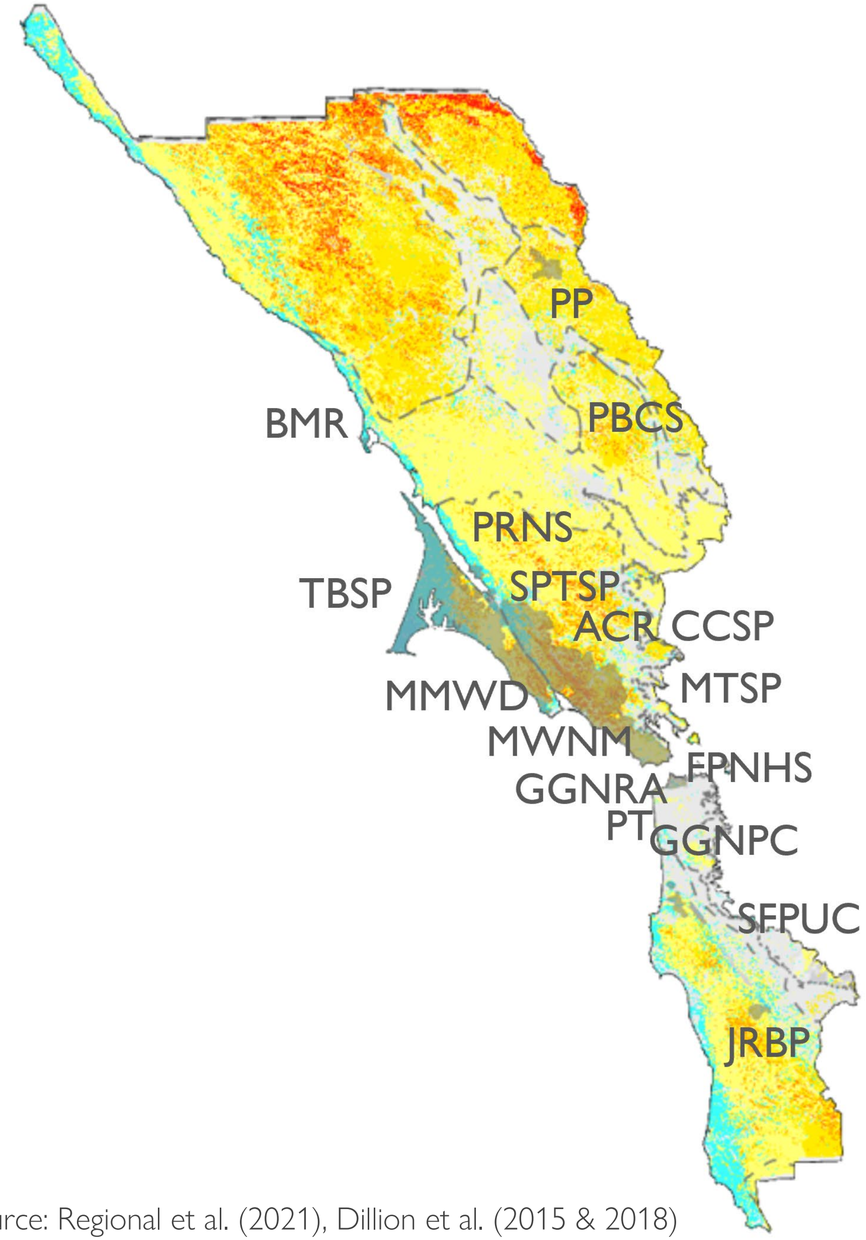
Data Source: Region et al. (2021), Dillon et a. (2015, 2018)

Fire | WILDFIRE HAZARD PROBABILITY AND GOLDEN GATE BIOSPHERE NETWORK LANDS



ACR	Audubon Canyon Ranch
BMR	Bodega Marine Reserve
CCSP	China Camp Sate Park
FPNHS	Fort Point National Historic Site
GGNRA	Golden Gate National Recreation Area
GGNPC	Golden Gate National Parks Conservancy
JRBP	Jasper Ridge Biological Preserve
MWNM	Muir Wood National Monument
PBCS	Point Blue Conservation Science
PRNS	Point Reyes National Seashore
PP	Pepperwood Preserve
PT	Presidio Trust
SPTSP	Samuel P. Taylor State Park
SFPUC	San Francisco Public Utilities Commission
TBSP	Tomales Bay State Park

LOW HIGH

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Data Source: Regional et al. (2021), Dillion et al. (2015 & 2018)

FIRE | WILDFIRE HAZARD BY ECOSYSTEM

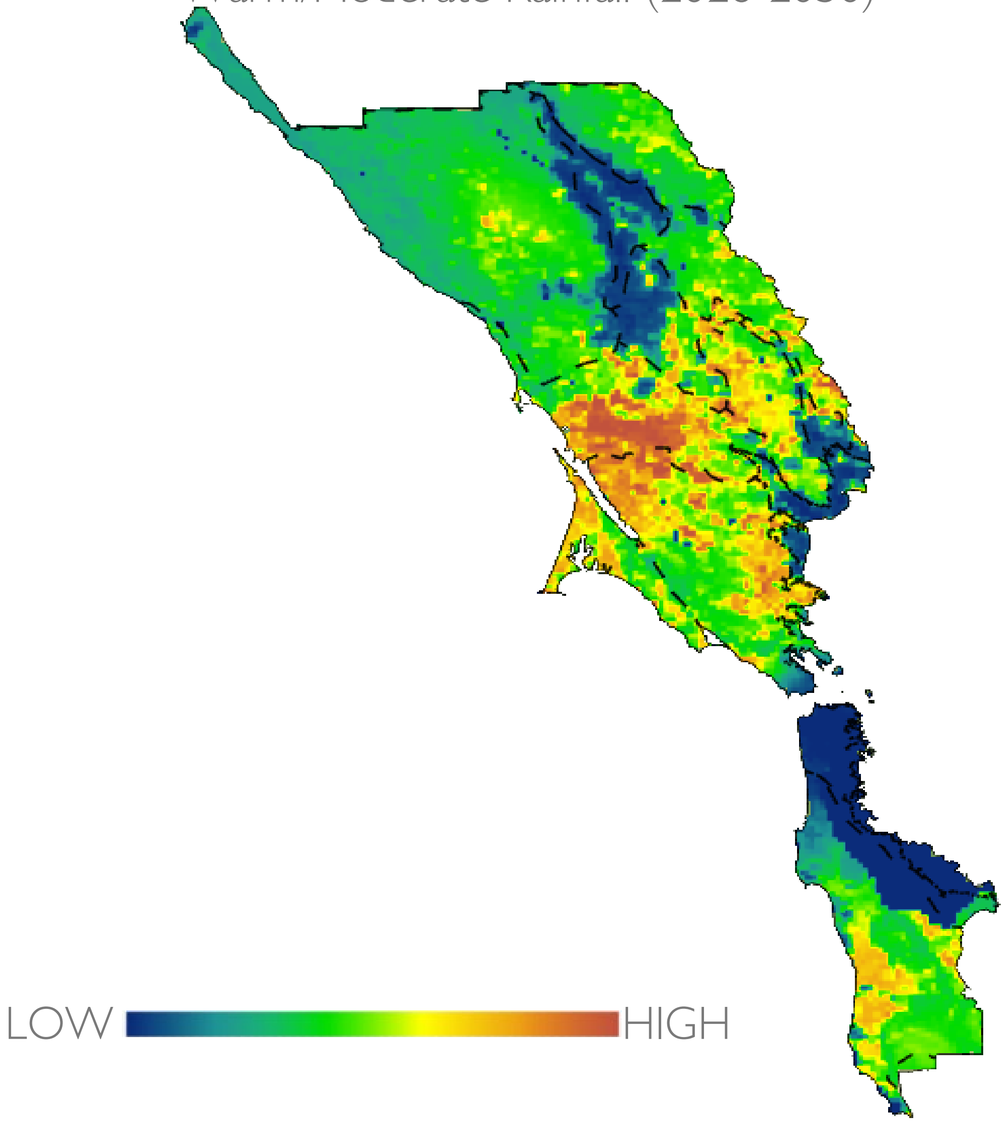
Ecosystems	Total Acres	Acres Ranked for Wildfire Hazard	Urban & Non-burnable fuel	Percent Area by Wildfire Hazard Rank			
				Low	Moderate	High	Very High
Coastal Dunes	5,780	4,922	15.5%	85%	0.5%	-	-
Coastal Prairie	395,485	341,278	14%	75%	10%	0.8%	0.2%
Coastal Redwood Forest	162,675	154,309	4.4%	42%	49%	4%	0.6%
Coastal Scrub	111,650	105,502	6.6%	82%	11%	0.4%	-
Freshwater Marshes	20,375	12,162	39.9%	57%	3%	0.1%	-
Maritime Chaparral	13,377	11,860	11%	24%	53%	9%	3%
Mixed Evergreen Forests	61,122	57,922	5%	15%	65%	11%	4%
Open Oak Woodlands/Savanna	206,996	180,438	13%	31%	49%	5%	2%
Riparian Forests/Woodlands	130,116	119,981	15%	32%	53%	-	-

Pepperwood

Data Source: Regional et al. (2021) and Marin County Fine-scale vegetation, Golden Gate Parks Conservancy and Tukman Geospatial LCC (2021)

Fire | PROJECTING CHANGE IN WILDFIRE PROBABILITY DUE TO CLIMATE AND LAND-USE (PARK ET. AL 2021)

Mean Annual Fire Probability
Warm/Moderate Rainfall (2026-2050)



Inputs	Metric
Fuel Dryness	Climatic Water Deficit (Average and Deviation)
Fuel Availability	Actual Evapotranspiration (Average and Deviation)
	Vegetation Regeneration (Year Since Fire)
Human Influences	House density
	Roads
	Electrical Infrastructure
	Agriculture

Data Source: Park et al. (2021)

Pepperwood

Vegetation Vulnerability Assessment

Ackerly et al. Probabilistic Vegetation Model

Pepperwood

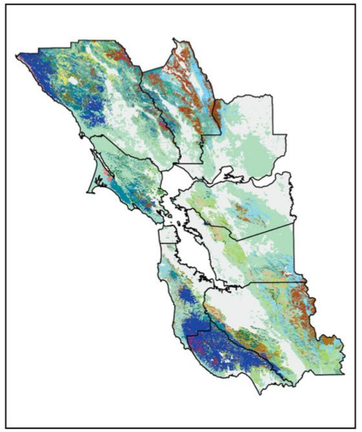
The Probabilistic Vegetation Model (PVM)

Ackerly et al. (2015) modeled the distribution of 22 major vegetation types, most defined by a single dominant woody species, across the San Francisco Bay Area.

Results can be used to facilitate landscape scale analyses

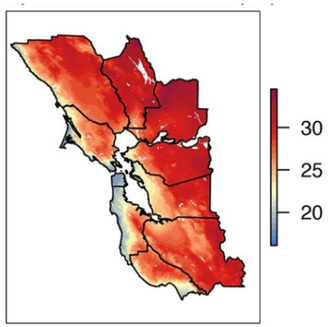
- Project biotic responses to future climate change
- Evaluate responses of individual species along with the overall responses of communities and ecosystems

22 Vegetation Types

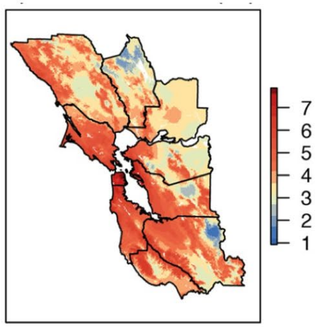


Climatic Variables (1951-1980 historic norms)

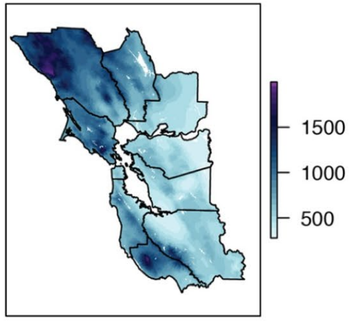
Summer maximum temperature (°C)



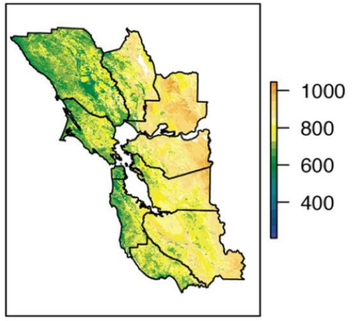
Winter minimum temperature (°C)



Annual precipitation (mm)



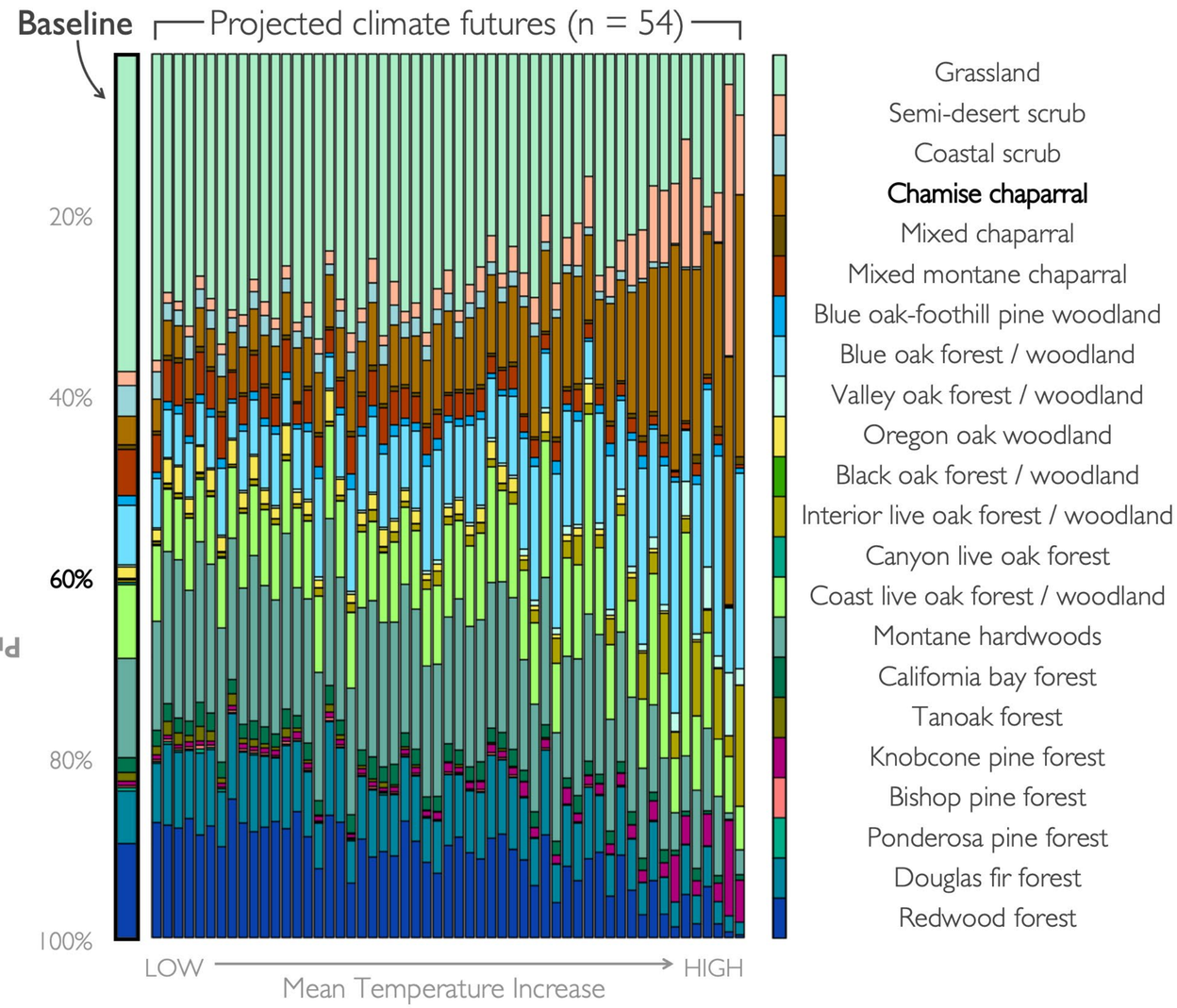
Climatic water deficit (mm)



Ackerly DD, Cromwell WK, Weiss SB, Flint LE, Flint AL. 2015.
A Geographic Mosaic of Climate Change Impacts on Terrestrial Vegetation: Which Areas Are Most at Risk? PLoS ONE 10(6)

Pepperwood

Modeled frequency of 22 vegetation types



The model was projected for 54 future climate scenarios, spanning a representative range of temperature and precipitation

18 climate projections x **3 time periods** = 54 scenarios

2010 – 2039 **2040 – 2069** **2070 – 2099**

This figure shows the relative frequency of 22 vegetation types, parameterized for the historical baseline period and then projected for 54 possible futures

Ackerly et al. 2015

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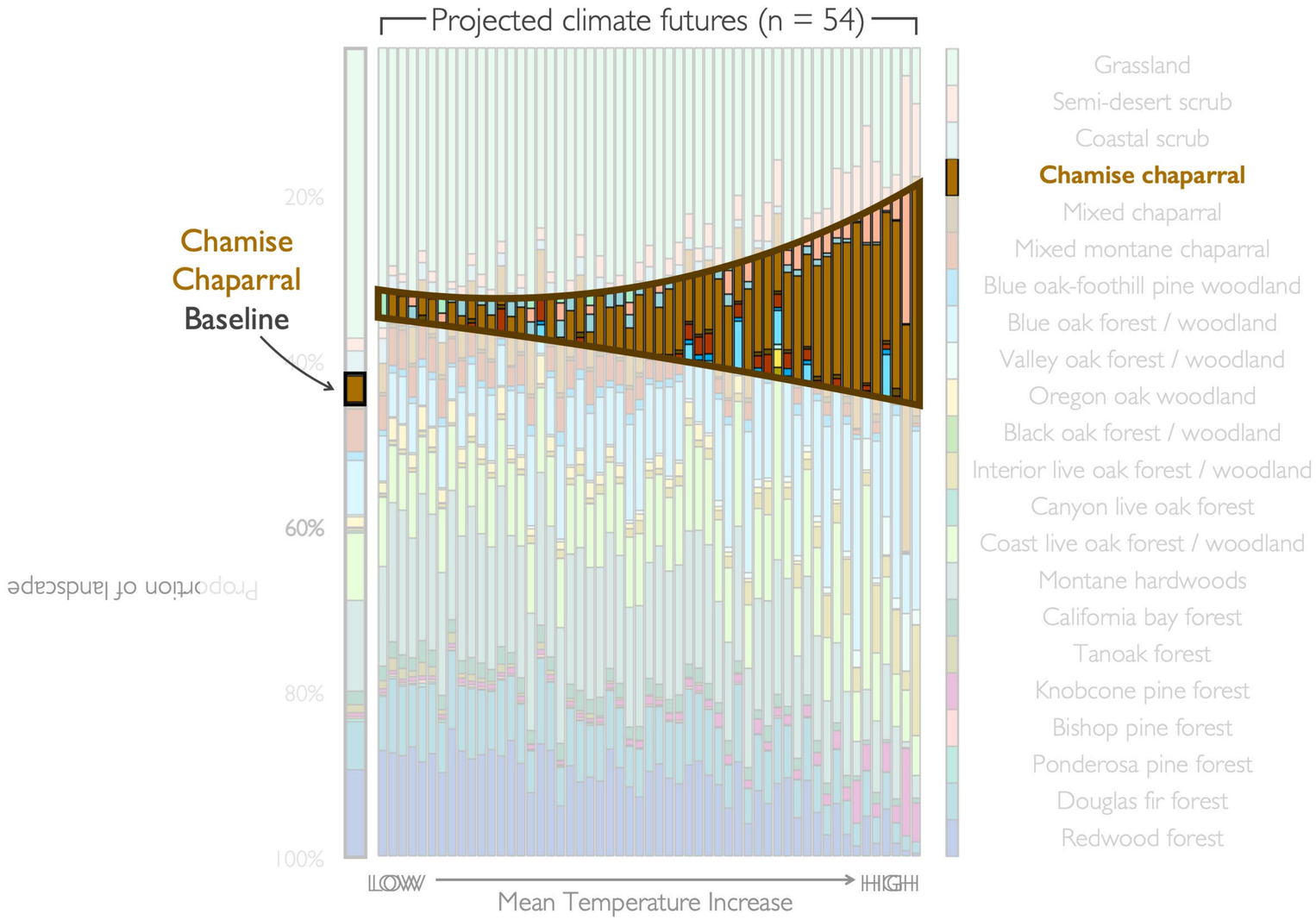
General trend: Increase in relative distribution of **chamise chaparral**



Ackerly et al. 2015

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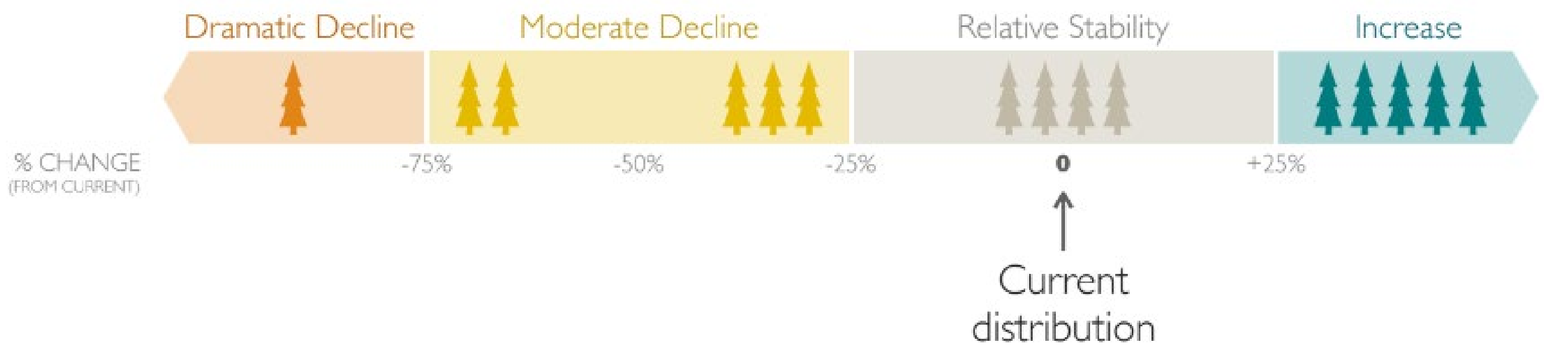
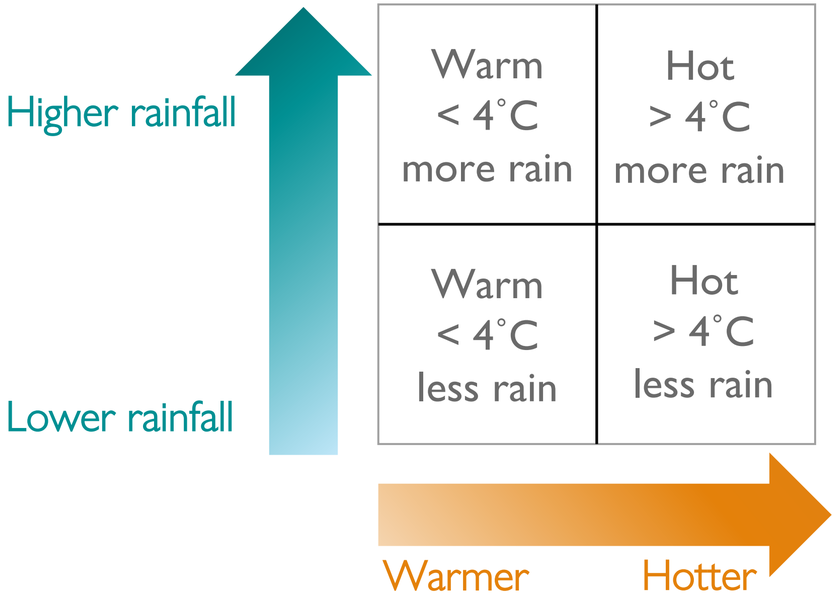
Species-specific potential responses to climate change





Tolerance (**stable** or **increase**) across all scenarios

Decline (**moderate** or **dramatic**) across all scenarios

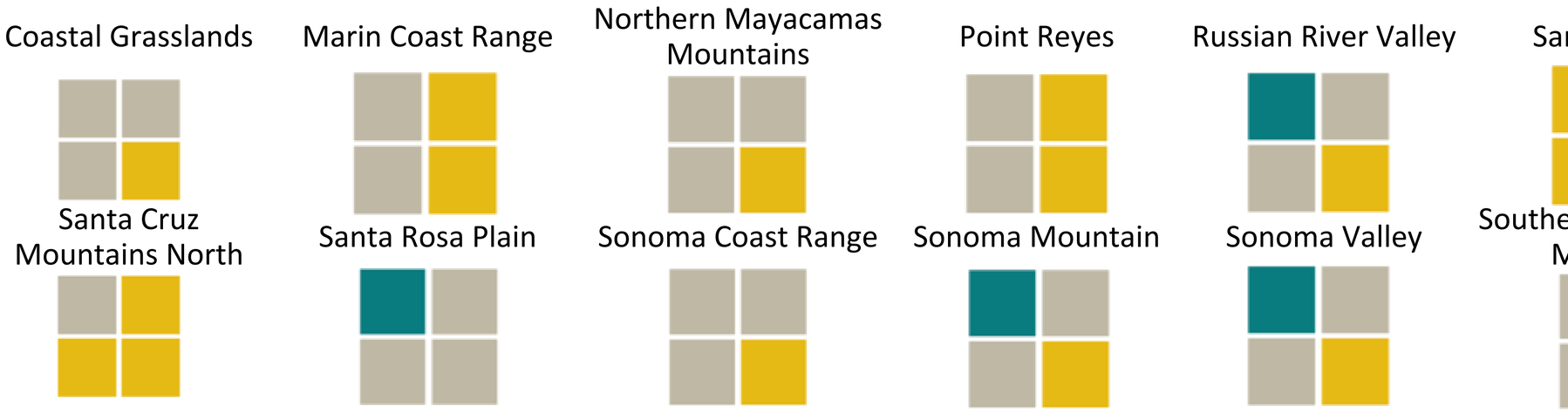
Pepperwood

The direction and magnitude of change was projects for each vegetation type across the four types of climate scenarios

…for each of the 12 Landscape Units

Projected habitat suitability was projected for each vegetation type was represented as a set of ***four squares, for example***:

Redwoods



Pepperwood

Vulnerable oaks

Decline (**moderate** or **dramatic**) across all scenarios

Dying blue oaks, especially on south-facing slopes

Photo: Todd Dawson

Miniature leaves during drought

2015-16 drought
San Luis Obispo county

Normal leaves

Photo: Todd Dawson

	Sonoma Coast Range	Russian River Valley	Northern Mayacamas Mountains	Southern Mayacamas Mountains	Sonoma Valley	Sonoma Mountains	Santa Rosa Plains	Coastal Grassland	Marin Coast	Point Reyes	San Francisco	Santa Cruz Mountains North
Black oak *(Quercus kelloggii)*	■■	-	■■	■■	-	■■	-	■■	-	-	-	-
Blue oak *(Quercus douglasii)*	■■	■■	■■	■■	-	■■	-	-	■■	-	■■	■■
Canyon live oak *(Quercus chrysolepis)*	■■	■■	■■	■■	-	-	-	-	-	-	-	-
Oregon oak *(Quercus garrana)*	■■	■■	■■	■■	■■	■■	■■	■■	■■	-	-	

Pepperwood

Resilient oak

Tolerance (**stable** or **increase**) across all scenarios

Photo: David Ackerly

Photo: National Parks

May expand under warmer climates. While sensitive to warmer summers, it may be favored by increasing winter temperatures.

	Sonoma Coast Range	Russian River Valley	Northern Mayacamas Mountains	Southern Mayacamas Mountains	Sonoma Valley	Sonoma Mountains	Santa Rosa Plains	Coastal Grassland	Marin Coast	Point Reyes	San Francisco	Santa Cruz Mountains North
Coast live oak (*Quercus agrifolia*)						-						

Pepperwood

Stable and Expanding Chaparral

Tolerance (**stable** or **increase**) across all scenarios

Chamise

Photo: Caliscpae

California Bay

Photo: National Wildlife Federation

Coyote bush

Photo: Wikimedia Commons, Franco Folini

	Sonoma Coast Range	Russian River Valley	Northern Mayacamas Mountains	Southern Mayacamas Mountains	Sonoma Valley	Sonoma Mountains	Santa Rosa Plains	Coastal Grassland	Marin Coast	Point Reyes	San Francisco	Santa Cruz Mountains North
Chamise (*Adenostoma fasciculatum*)	■	-	■	■	■	-	-	■	■	-	-	■
California Bay (*Umbellularia california*)	□	■	□	■	-	■	-	■	□	■	■	■
Coyote brush (*Baccharis pillars*)	□	□	-	□	□	-	-	□	□	□	-	□

Pepperwood

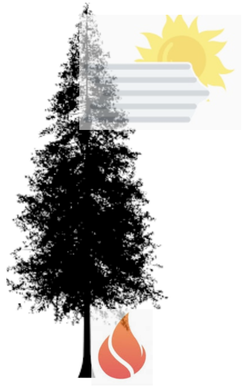
Sensitive Redwoods

Mixed (increase, stable or moderate) across all scenarios

Vulnerable redwoods should be prioritized for protection and stewardship

Photo: Gary Kazanjian

Sensitive to water deficit and high temperatures. Likely to persist best in cool north-facing slopes, riparian and moist valleys, and areas of persistent fog, where summer drought is reduced.



	Sonoma Coast Range	Russian River Valley	Northern Mayacamas Mountains	Southern Mayacamas Mountains	Sonoma Valley	Sonoma Mountains	Santa Rosa Plains	Coastal Grassland	Marin Coast	Point Reyes	San Francisco	Santa Cruz Mountains North
Redwood (*Sequoia sempervirens*)					-					-	-	

Pepperwood

TAKE AWAYS

1.) **Temperature increases across all scenarios**, does not indicate direction or rate of change

2.) **Precipitation is highly variable across all the scenarios**, trending toward extreme events

3.) **New models project more rainfall,** particularly in northwestern portion of Sonoma County

4.) **Water deficits are likely to increase across all scenarios**, which in turn increase fire hazard locally and may reduce suitable habitat for non-drought tolerant species

Pepperwood

Data Basin (databasin.org)

Golden Gate Biosphere Climate Adaptation Project

Created by Kai Henifin

Dec 5, 2022 (Last modified Nov 8, 2023)

Manage... Add to...

About

The goal of this project is to integrate existing, best available science with an expert elicitation process to improve understanding of whether and how important natural resources in the Golden Gate Biosphere Network (GGBN) region may be vulnerable to changing climate conditions and what management actions can be implemented to reduce vulnerabilities and/or increase resilience of those resources.

Tags

golden gate biosphere, adaptation planning, climate, bcm, north bay, basin characterization model

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- **Fire Datasets** (4 items)
- **Species Distribution Models (SDM)** (3 folder(s) and 18 item(s))

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Questions

Kai Henifin
khenifin@pepperwoodpreserve.org

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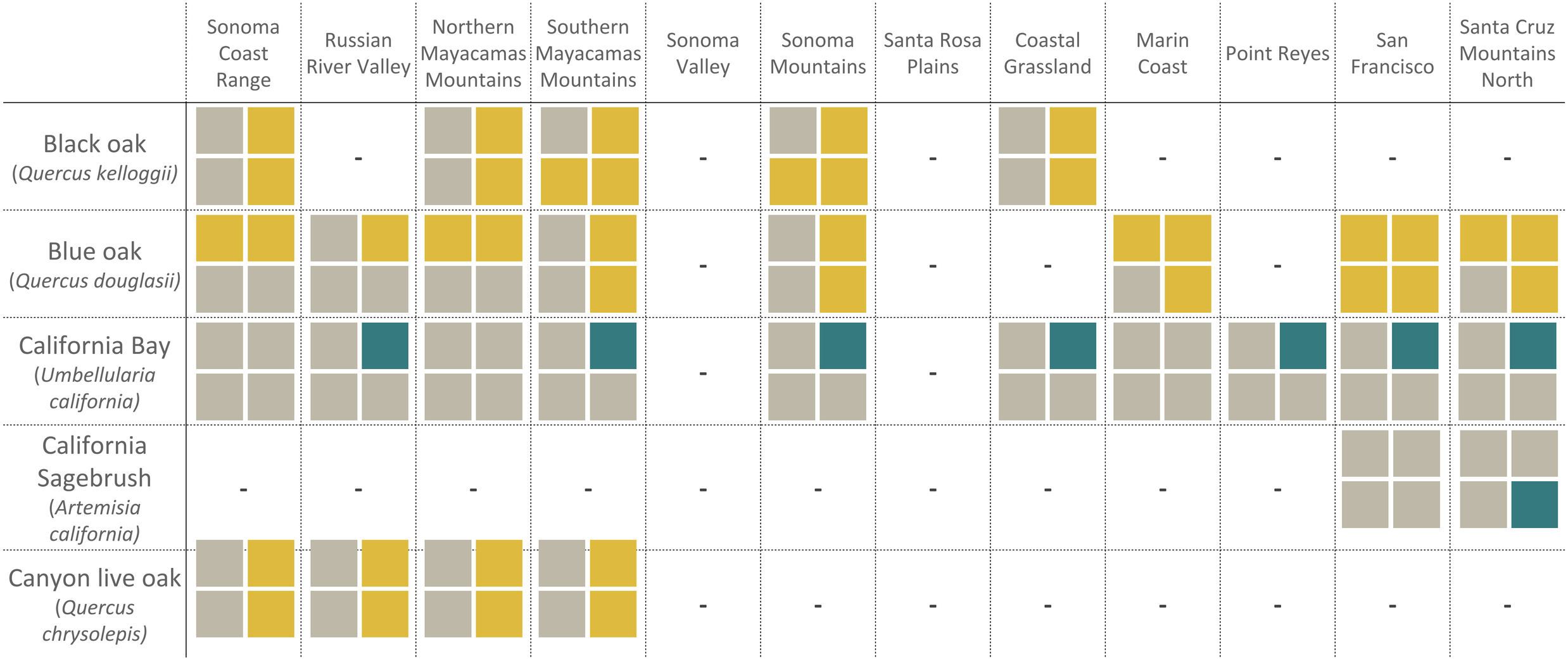
APPENDIX

Pepperwood

Probabilistic Vegetation Model (PVM) | Landscape Unit



Data Source : Ackerly et al. 2015

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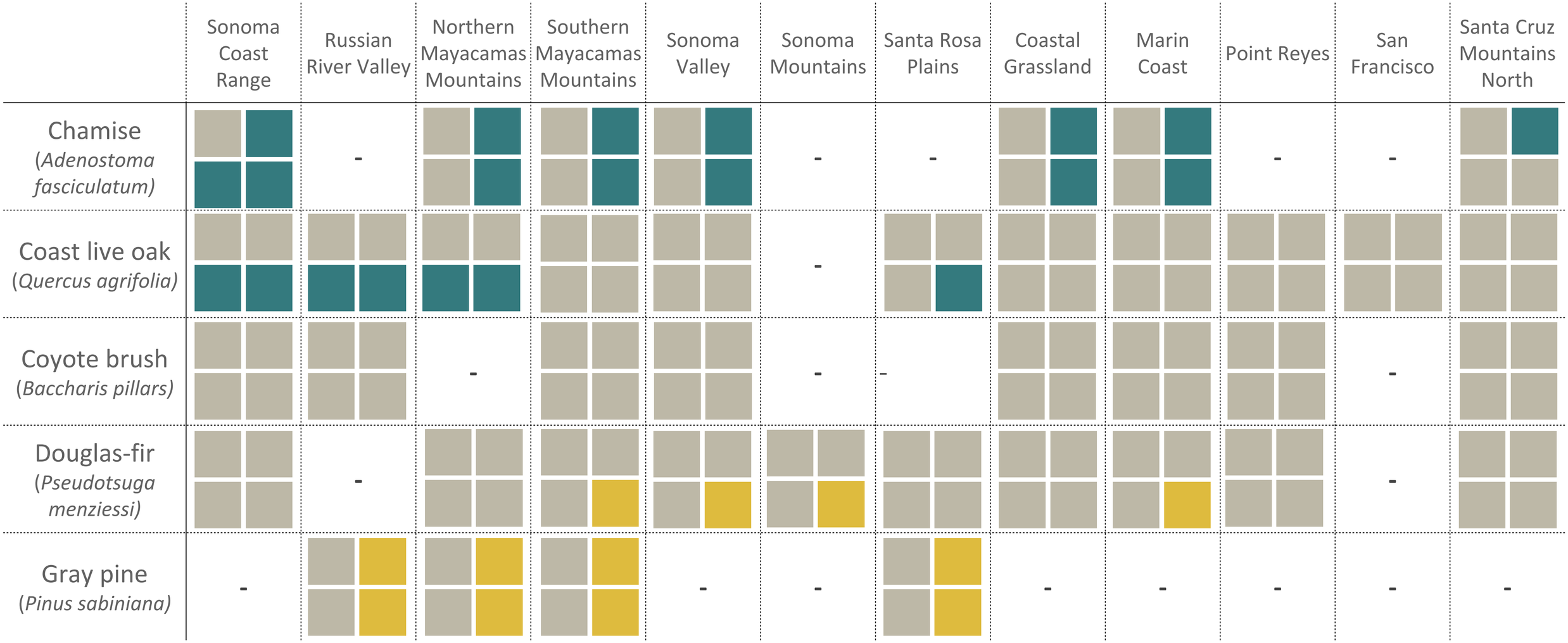
Probabilistic Vegetation Model (PVM) | Landscape Unit



Data Source : Ackerly et al. 2015

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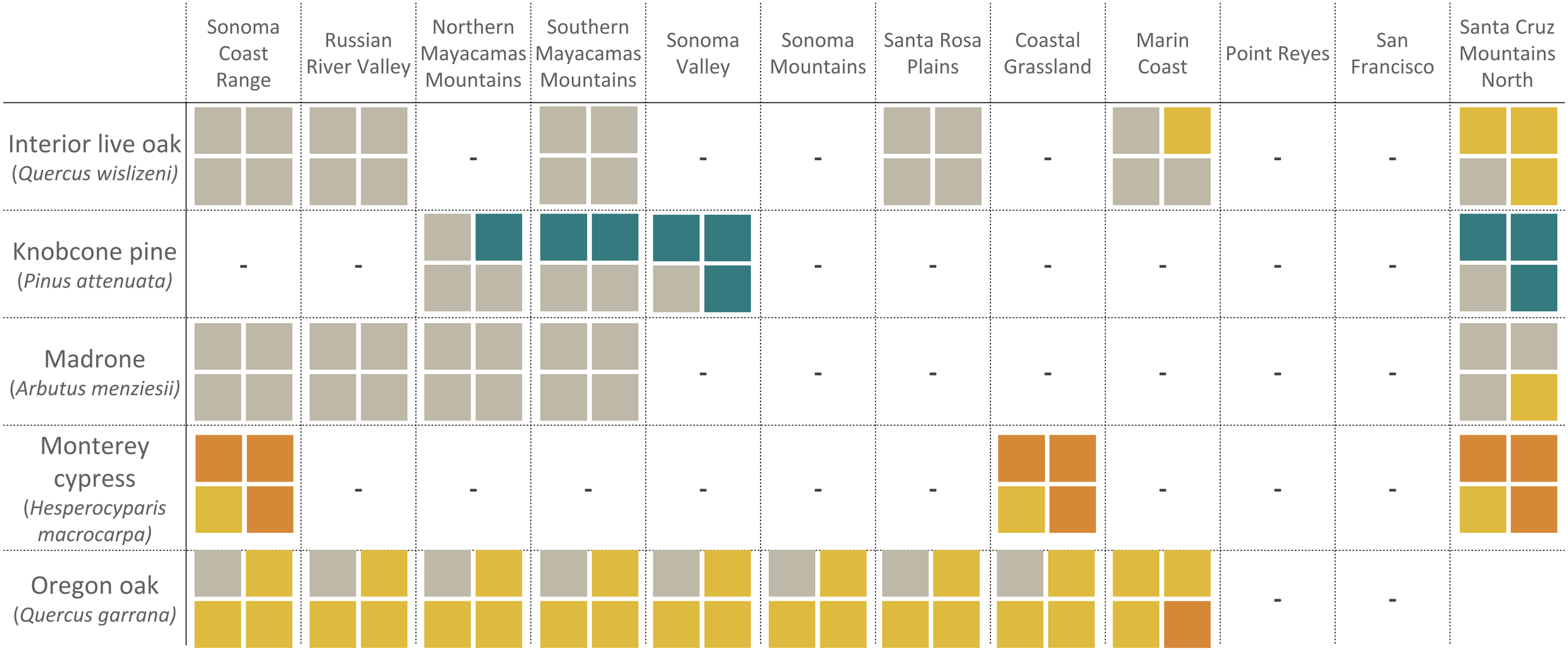
Probabilistic Vegetation Model (PVM) | Landscape Unit



Data Source : Ackerly et al. 2015

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Probabilistic Vegetation Model (PVM) | Landscape Unit

	Sonoma Coast Range	Russian River Valley	Northern Mayacamas Mountains	Southern Mayacamas Mountains	Sonoma Valley	Sonoma Mountains	Santa Rosa Plains	Coastal Grassland	Marin Coast	Point Reyes	San Francisco	Santa Cruz Mountains North
Redwood (*Sequoia sempervirens)*					-					-	-	
Valley oak (*Quercus lobata)*			-		-	-				-	-	

Data Source : Ackerly et al. 2015

Pepperwood