Vulnerability of Stream Biological Communities in Los Angeles and Ventura Counties to Climate Change Induced Alterations of Flow and Temperature

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EXECUTIVE SUMMARY

Climate change induced shifts in precipitation and temperature patterns have the potential to alter habitat suitability and distribution of aquatic species throughout the Los Angeles and Ventura regions (Figure ES-1). In this study, we predict alterations to the distribution of six aquatic species that represent a range of habitat preferences and use these predictions to infer where aquatic life beneficial uses may be supported in the future.

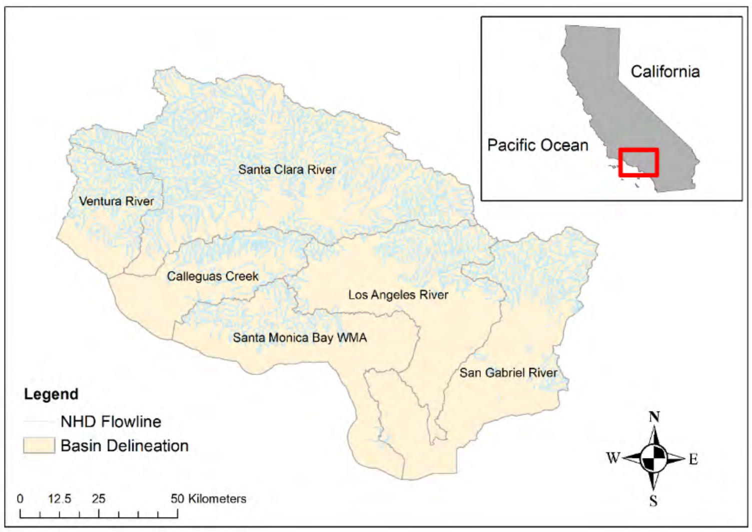


Figure ES-1: Study Region with the six major watersheds outlined and identified.

General Approach

We used a series of models to relate streamflow and stream temperature to the probability of species occurrences. With these relationships, combined with predicted future changes in flow and temperature, we map future species distributions.

Downscaled precipitation data for baseline years was used to hydrologically model 68 sub-watersheds within the region using a U.S. Army Corps rainfall-runoff model (HEC-HMS). The daily flow time series were converted into hydrologic metrics, like hydroperiod and storm flow recession, which have been shown to be ecologically relevant. Random forest models were used to predict these metrics at the remaining sub-watersheds within the region so that each stream reach had a series of hydrologic metrics associated with it for a subset of baseline years.

Similarly, downscaled air temperature data was used in modeling stream temperatures, with multiple linear regression modeling, at every sub-watershed within the region for the baseline years. The stream temperature data was converted into ecologically relevant metrics, like maximum 7-day maximum temperature, for use in the biological modeling.

Species occurrence data, from baseline years, was paired with the hydrologic metrics and the stream temperature metrics, from the month and stream reach of species occurrence, to develop a biological model of habitat preference. We selected six representative species - southern California steelhead/resident rainbow trout (*O. mykiss*), arroyo chub (*Gila orcuttii*), Santa Ana sucker (*Catostomus santaanae*), arroyo toad (*Anaxyrus californicus*), least Bell's vireo (*Vireo* *bellii pusillus*), and western pond turtle (*Actinemys marmorata*) to represent the range of species and habitats that occur in the region.

We use the relationships between species occurrence and stream characteristics to investigate species distribution in future years based on climate change scenarios. We used three downscaled future climate projections using models from the Coupled Model Intercomparison Project phase 5 (CMIP5) that capture much of the variation of all the climate models in CMIP5, and that have been found to be the best for planning in southern CA. The random forest for the hydrologic metrics, and the regression for stream temperature, were applied to future climatic conditions of precipitation and air temperature to project future stream conditions and used to model species distribution.

Expected Changes in Streamflow and Temperature

Our models predict consistent increases in stream temperature, across the major watersheds, for both minimum (~2°C increases) and maximum temperatures (~4°C increases; Figure ES-2), although a majority of the warming occurs in the high elevation sub-watersheds. Additionally, some watersheds that never had maximum stream temperatures greater than 30°C, an important biological threshold, in the baseline years do have these extreme temperatures in the future. Hydrologic changes include, among others, more frequent storms, more rapid recessions, higher maximum flows, and more central hydroperiods (Figure ES-2). While some hydrologic metrics changed consistently across watersheds, there were inconsistent changes for others. Most noticeable was the way lower elevation watersheds and the higher elevation watershed changed in response to climate change. For example, higher elevation watersheds will experience more storm events in the future years compared to their baseline, than the low elevation sub-watersheds.

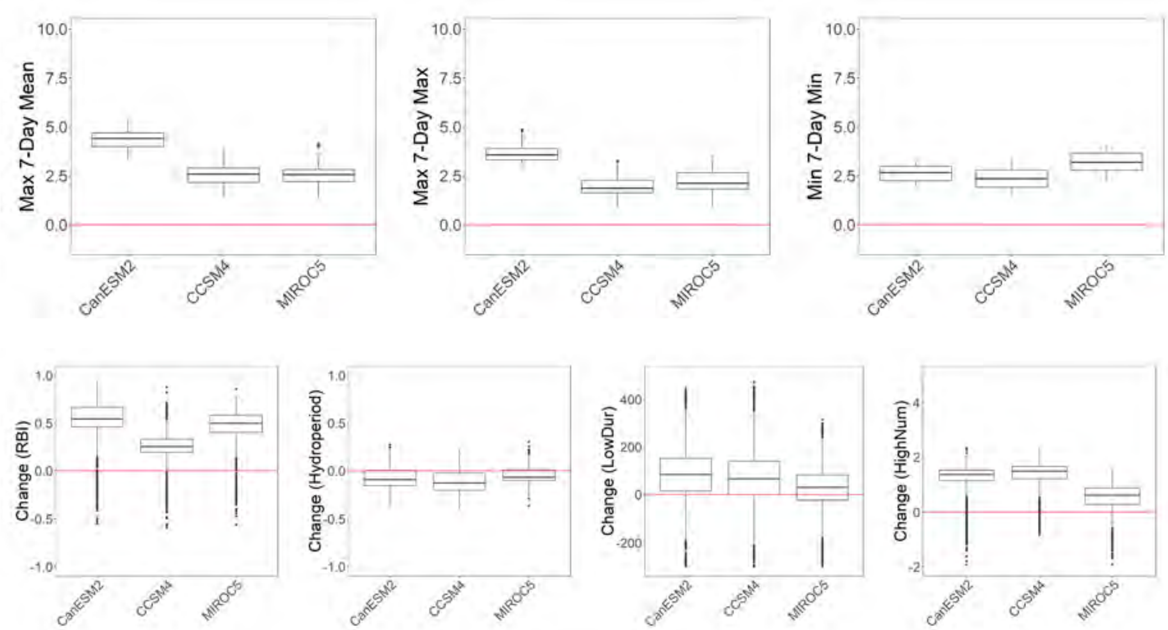
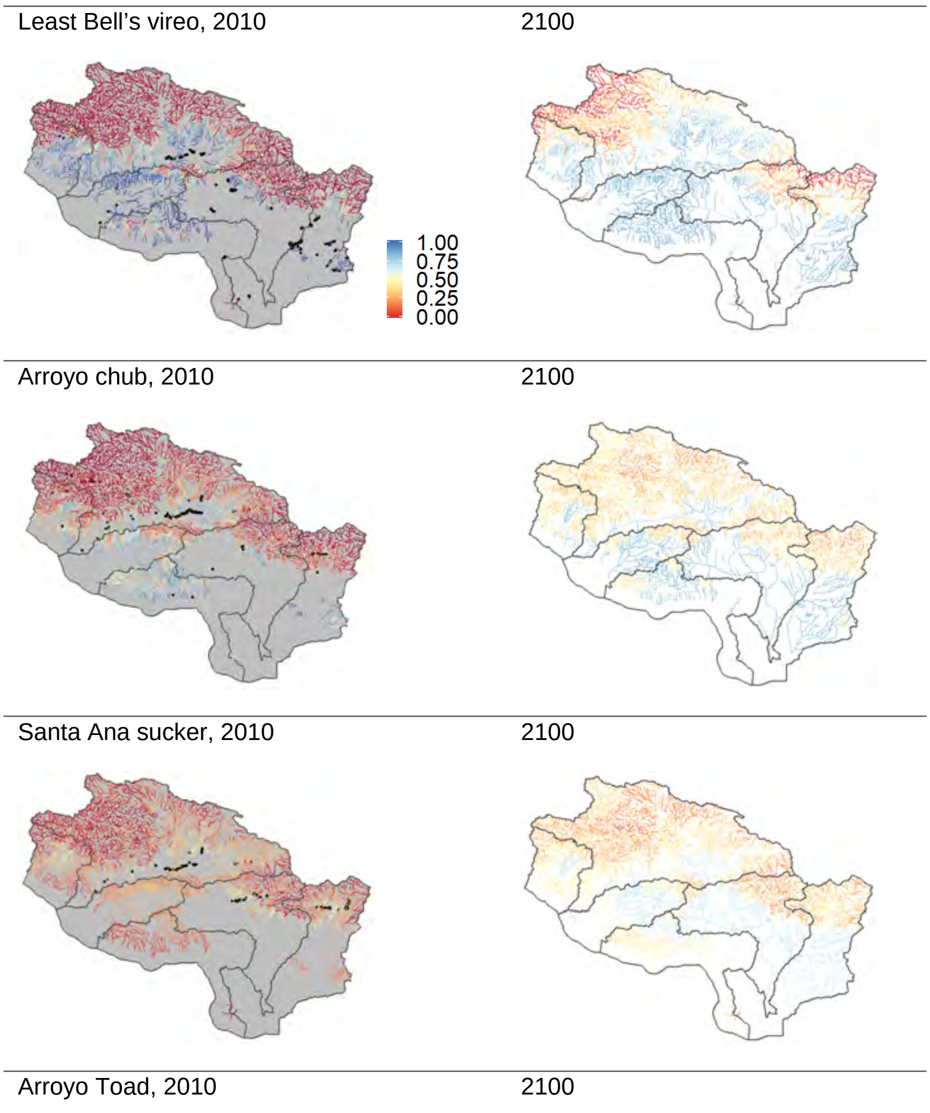


Figure ES-2: Boxplots, showing the change from baseline to future year, for a series of temperature metrics (top row) and hydrologic metrics (bottom row) based on three global climate models.

Changes in Species Distributions

We expect that *O. mykiss*, arroyo toad and western pond turtle will have reduced range and probability of occurrence in future years due to climate change, and that arroyo chub, Santa Ana sucker, and least Bell's vireo have increased range and probabilities of occurrence due to climate change (Figure ES-3). In general, the three species that do not respond well to climate change occur in higher elevation watersheds, within this region, whereas the species that responded more favorably to climate change occur in lower elevation watersheds. The major driver behind these distributional shifts, flow or temperature changes varied between species and between high and low elevational areas.



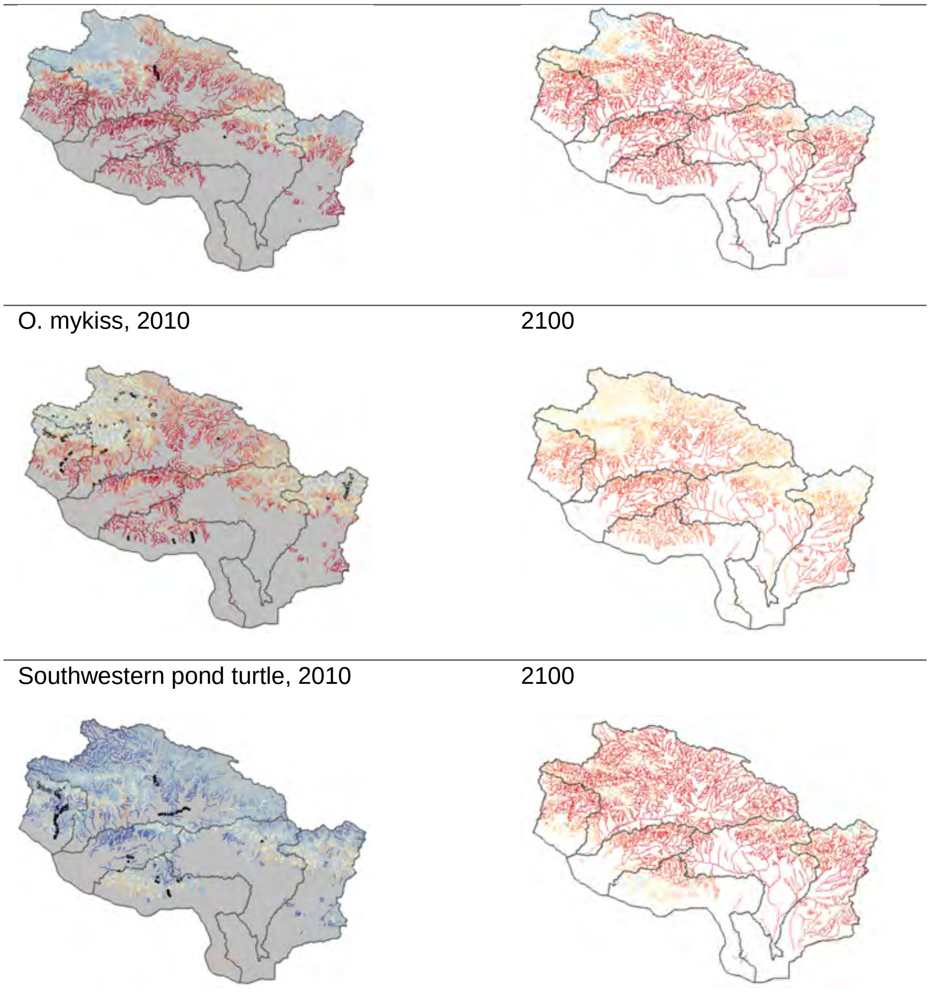


Figure ES-3: Example results for the focal species showing the change in distribution, and probability of occurrence, from a baseline to a future year, both moderate precipitation type years.

Future Planning

This study should be considered a first investigation of species vulnerability associated with climate change, and how distributions may change based on future streamflow and temperature. Results of this analysis can be used to support a variety of future management and monitoring decisions:

- Prioritizing areas for beneficial use protection through conservation and management actions.
- Informing future monitoring around areas with the highest probability of future changes.
- Identifying sentinel sites that are expected to have high vs. low changes to better track climate change effects.
- Identifying areas where managing other stressors (e.g., fish passage barriers) may be a priority based on expected future species distributions.

The relationships developed here, which describe favorable habitat conditions in natural watersheds for various species, can be used in other watersheds to inform water and land use decisions. Future efforts should include additional analysis of other stressors (e.g., habitat alteration, invasive species) and how their management could proportionately reduce potential climate change effects.

ACKNOWLEDGEMENTS

We thank our UCLA partners in this project for providing the downscaled climate projections which we used in this study for modeling stream flow and stream temperature. We are grateful to the following individuals for providing data for the species occurrence database: Rosi Dagit, Mary Larson, Chris Medak, Chris Dellith, Johnathan Baskin, and Jeff Weaver. We would also like to thank the members of our Technical Advisory Committee, who provided valuable feedback and suggestions throughout this project and helped make a better product:

Technical Advisory Committee (in alphabetical order)

1. Jessica Bean, State Water Resources Control Board
2. Gonzalo Castillo, United States Fish and Wildlife Service
3. Rosi Dagit, Research Conservation District of the Santa Monica Mountains
4. Katy Delany, National Park Service
5. Sabrina Drill, University of California Extension
6. Kyle Evans, California Department of Fish and Wildlife
7. Robert Holmes, California Department of Fish and Wildlife
8. Nathan Holste, United States Bureau of Reclamation
9. Jason Hwan, California Department of Fish and Wildlife
10. Mary Larson, California Department of Fish and Wildlife
11. Robert Lusardi, University of California, Davis
12. Doug McPherson, United States Bureau of Reclamation
13. Chris Medak, United States Fish and Wildlife Service
14. Jennifer Mongolo, County of Los Angeles Department of Regional Planning
15. Stacey Osterman, National Park Service
16. Jennifer Pareti, California Department of Fish and Wildlife
17. Kelly Schmoker, California Department of Fish and Wildlife
18. Nathan Sill, United States Forest Services
19. Andrew Valand, California Department of Fish and Wildlife
20. Erinn Wilson, California Department of Fish and Wildlife
21. Sarah Yarnell, University of California, Davis

PREFACE

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Project Motivation, Background, and Goals

Species that inhabit riparian and riverine environments adapt to the habitat formed by physical drivers of the stream. These physical drivers include precipitation, which produces stream flow, and air temperature, which impacts stream temperature. In many cases, not only are species acclimated to the local stream habitat, but they rely on the habitat characteristics to carry out some, or all, of their life history stages. For example, the tadpole development of the federally endangered arroyo toad (*Anaxyrus californicus*) occurs in river adjacent shallow pools which rely on high winter flows to scour emergent vegetation and deposit coarse sediment (U.S. Fish and Wildlife Service 2014). With no winter flooding, vegetation encroaches in streamside pools, which happened in middle Piru Creek from approximately 2011-2015, until the heavy 2017 water year rains allowed breeding to be reestablished (ESA Associates 2017). Similarly, Southern California steelhead (*Oncorhynchus mykiss*) rely on maximum pool temperatures to remain below approximately 30°C (Matthews & Berg 1997; Sloat & Osterback 2013). When these types of flow-ecology or temperature-ecology dependences are involved, a change to the physical drivers of that stream could be detrimental to the species.

Climate change will impact the physical drivers that support riparian and riverine species in southern California and around the world. For managers to effectively prioritize conservation or restoration projects, they need to know the environmental requirements of native species. To effectively manage over the long term, they need an understanding of the extent and the magnitude of potential changes to these environmental drivers in future years. The goal of this study was to quantify the likely impact of the changing climate on two physical drivers that are crucial to stream habitat, and then to determine the resulting potential effects on species that live in these habitats. We considered the flow regime and the stream temperature as two master variables that drive stream habitat and habitat suitability for various species. Streamflow can be quantified in ecologically meaningful ways, including the duration, timing, magnitude, frequency of events, and rate of change (Bunn & Arthington 2002; Poff et al. 1997). Stream temperature can also be quantified in ecologically meaningful way such as the maximum seven-day maximum temperature (Welsh et al. 2001). By quantifying the species requirements of these ecologically relevant flow and temperature variables in the current day, we can determine the likely impact to species occurrence by analyzing the extent to which the metrics change under scenarios of climate change.

The focus of this study is on natural and semi-natural streams in the Los Angeles Regional Water Quality Control Board's jurisdictional areas (i.e., Los Angeles and Ventura counties) (Figure 1). Urbanization dominates lower watersheds in the study area; consequently, factors other than climate change, such as waste water discharge, dam operation, and dry/wet weather runoff, exert much greater influence on species occurrences and distribution than climate change effects. Therefore, we limited our focus to the mainly unaltered watersheds, where changes in natural climate conditions will drive the changes in the stream, and ultimately impact the riparian and riverine fauna. We use temporally and spatially dynamic species distribution modeling to quantify the biologically relevant environmental metrics that meet the needs of species and predict how those metrics will change under different climate change scenarios. This research addresses the following questions:

1. What are the key stream flow and stream temperature patterns that drive the distribution of selected species?
2. What is the recent (30 years) and current day distribution of selected species as predicted from stream flow and stream temperature characteristics?
3. How does climate change impact the distributions of selected species in years 2040 and 2100?

METHODOLOGY

Watershed conditions including stream hydrology and stream temperatures were modeled for the years 1981 through 2014. Species occurrence data from that same timeframe was then related to the hydrologic and thermal regimes throughout the region to better understand the habitat preferences of each species. The relationships that were developed were then applied to future hydrologic and thermal conditions, based on climate change scenarios, to predict future habitat suitability. The major tasks within this study include the following:

1. Species selection and species data compilation
2. Watershed modeling
3. Flow metric calculation and extrapolation
4. Water temperature modeling
5. Develop flow/temperature-ecology relationships
6. Biological modeling based on current climate
7. Biological modeling based on climate change scenarios

Methods are summarized in this report, but for additional details on the first task, see (Stein, Taylor, Sengupta, & Yarnell 2018). Figure 2 shows the conceptual approach taken for this project.

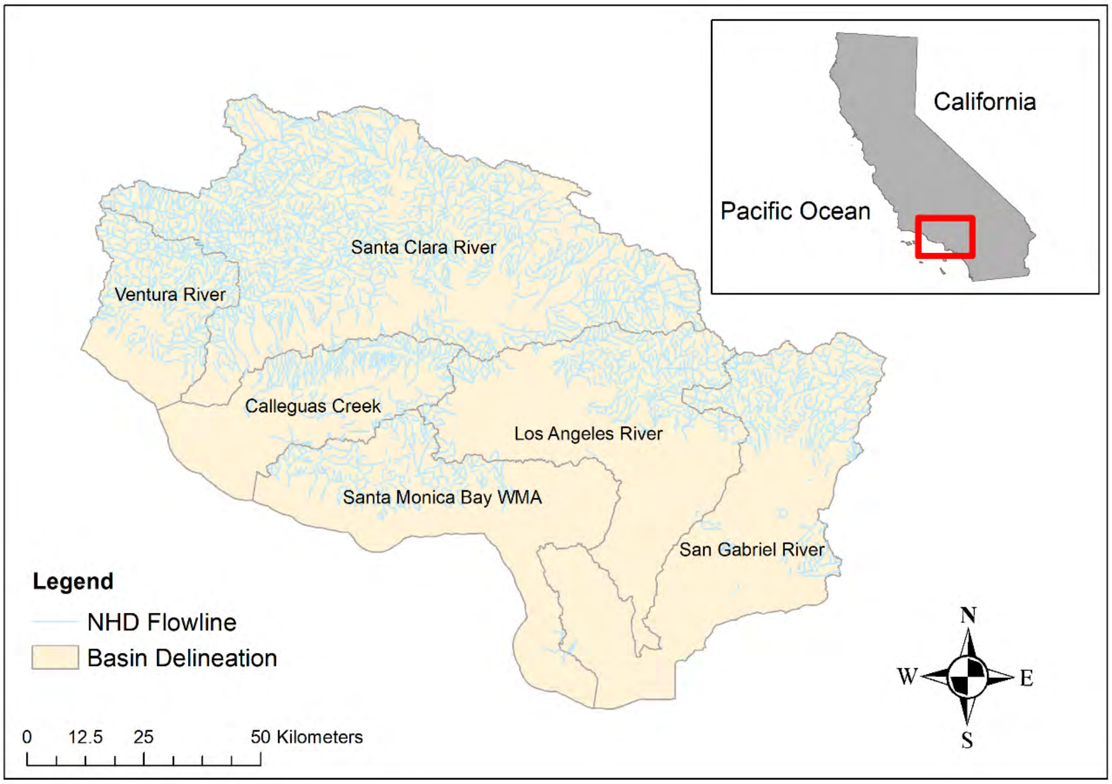


Figure 1: Study Region with the six major watersheds outlined and identified.

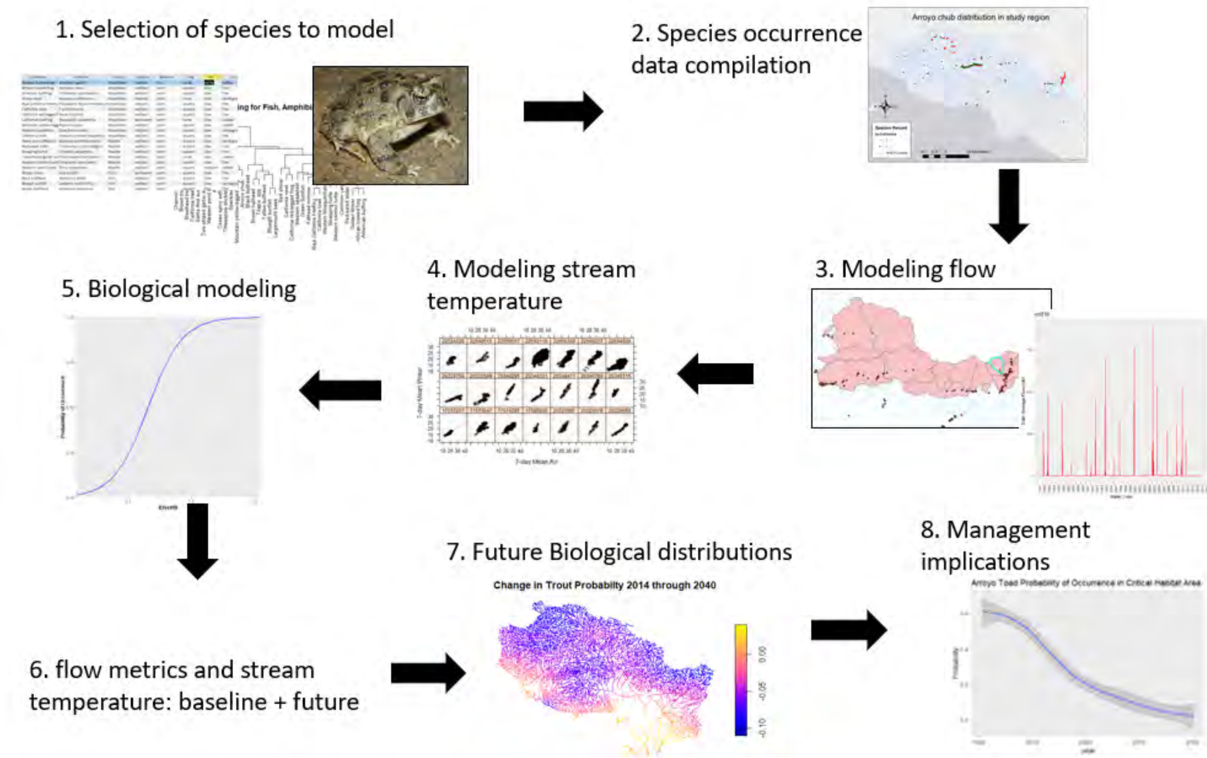


Figure 2: Conceptual model of study approach.

Species Selection

We identified approximately 65 riparian or riverine species in the study area from existing databases and reports (see Appendix A). We included all species which use the stream or adjacent riparian habitat for at least one of their life history stages but excluded species entirely dependent on other aquatic habitats like lake or marsh. Because it was not practical to assess each species individually, we grouped species, based on life-history traits and habitat preferences, and then analyzed a representative from selected groups. This allowed us to get a general understanding of how major groups of riparian-dependent species may respond to changing conditions, without needing to collect detailed occurrence data for all the species in the study area. To accomplish this, we first compiled a list of species in the region that rely on stream habitat for at least one of their life history stages. Through a rigorous literature review and comments from the Technical Advisory Committee, we compiled a life-history database that listed habitat and life-history characteristics of each species. Habitat requirements included variables that species are adapted to that will be impacted by climate change, such as channel velocity, vegetation preference, and substrate type. For a complete list of variables, see Appendix B.

We used clustering analysis to group the 65 species based on similar life-history requirements. The habitat and life-history variables were compiled as categorical data and transformed to a numeric dissimilarity matrix for use in clustering, using Gower distance (Gower 1971). Based on the habitat dissimilarity matrix, similar taxa were grouped using a hierarchical clustering method. The result was six clusters of birds and six clusters combining fish, amphibians, and reptiles. All clustering tasks were completed in RStudio (RStudio Team 2016) with the package "cluster" (Maechler, Rousseeuw, Struyf, Hubert, & Hornik 2017). Final clusters are shown in Appendix C. Cluster representatives (Table 1) were selected based on management importance, data availability, and input from the Technical Advisory Committee.

Table 1: Cluster representatives selected for this project. Species selected for habitat modeling. Conservation status codes as follows: CESA (California Endangered Species Act); FESA (Federal Endangered Species Act); FT (federally threatened); FE (federally endangered); ST (state threatened); SE (state endangered); G1 (globally critically imperiled); S1 (state critically imperiled); G2 (globally imperiled); S2 (state imperiled); G3 (globally vulnerable); S3 (state vulnerable); G4 (globally apparently secure); G5 (globally secure); T1Q (subspecies critically imperiled); T2 (subspecies imperiled). For more information on the conservation statue refer to (https://www.wildlife.ca.gov/Data/CNDDB/Plants-and-Animals) and for more information on NatureServe listing status see Faber-Langendoen et al. (2012).

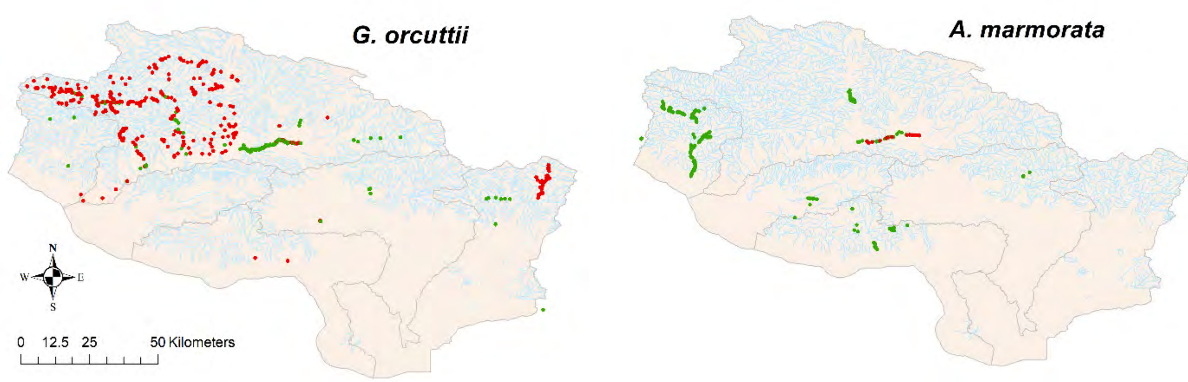
Common name	Scientific name	Life history stage	Habitat description	Conservation status	
				CESA/FESA	NatureServe
Arroyo chub	*Gila orcuttii*	All	Warm, sluggish, shallow, backwater or main channel of low gradient streams	none	G2 S2
Santa Ana sucker	*Catostomus santaanae*	All	Warm to cool flowing water with coarse substrate of low to mid gradient stream	FT	G1 S1
Steelhead (Southern California DPS)/ rainbow trout	*Oncorhynchus mykiss*	All	Cool, swift, high gradient streams with coarse substrate and deep pools	FE (Steelhead)	G5T1Q S1
Western pond turtle	*Actinemys marmorata*	Juvenile / adult	Warm, low to mid gradient stream with deep pools	none	G3/G4 S3
Arroyo toad	*Anaxyrus californicus*	Clutch	Temporary shallow backwater pools in sandy substrate	FE	G2 G3 S2 S3
Least Bell's vireo	*Vireo bellii pusillus*	Breeding pair	Dense, 5-10 year successional stage, riparian vegetation	FE SE	G5T2 S2

Species Occurrence Data

We compiled presence and absence observations for the selected species; a list of sources is shown in Appendix A. In this report, we refer to species by their common name, except for southern California steelhead/rainbow trout, which we refer to as *O. mykiss* because both life history forms were included in the analysis. We reviewed multiple sources of occurrence data from manuscripts, agency reports and standardized surveys, consulting firm memos, and unpublished raw data sets. The key species occurrence metadata that were required for this study was location data at the National Hydrography Dataset (NHD) reach scale (https://www.usgs.gov/core-science-systems/ngp/national-hydrography), and temporal data at the month scale. The spatial and temporal resolution used ensured that the analysis was not biased toward data rich streams. The data was minimally altered to get consistency across datasets. For example, sources reported record locations in different ways including GPS coordinates, a stretch of stream such as between two stream crossings, or visually with a map. To make the record location consistent, we used the following procedures:

1. A precise coordinate was always used when available.
2. Stream segment locations were digitized at the beginning and end of the reach, or throughout the reach if multiple NHD stream reaches are within the segment.
3. Locations shown on a map were digitized by finding the location visually in Google Maps and recording the coordinates.

Species occurrence is recorded as presence or absence. If multiple species observations were reported in the same NHD reach, or if a total count was provided, a single occurrence point was used. Absence was assumed when a survey failed to find the species, or when a survey did not record the presence of a species in certain locations but did in others. In some cases, the surveyor was contacted to ensure a lack of species record could be considered an absence. We acknowledge that survey techniques are limited in their ability to detect species 100% of the time and thus there is greater uncertainty in the absence data relative to the presence data. Final species occurrence data are shown in (Figure 3).



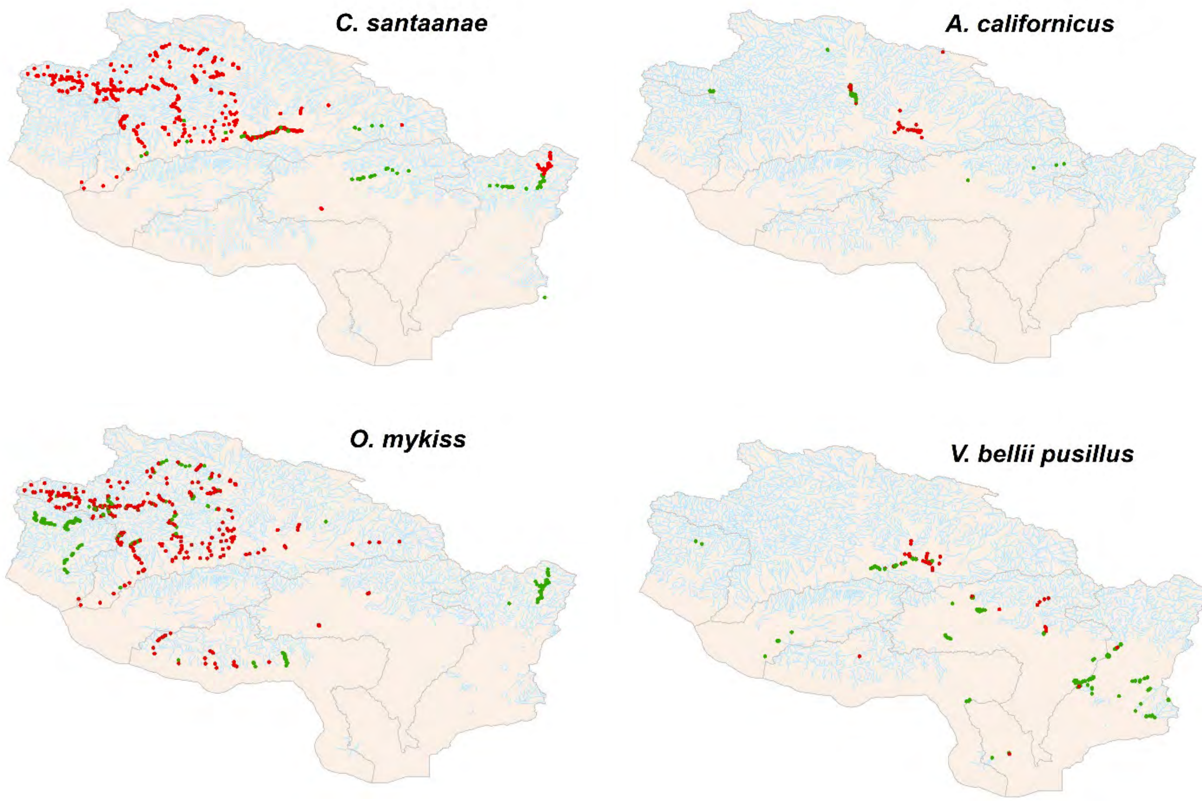


Figure 3: Final species occurrence data across the study region. Each point represents a survey location. Red points are species absence and green points are species presence.

Watershed Modeling

A major goal of this study is quantifying relationships between stream flow and species occurrence. However, the study region has a paucity of flow gages, particularly in the upper watersheds which are unaltered and the focus of this study. Therefore, while flow gages were used when present, hydrologic modeling using HEC-HMS (http://www.hec.usace.army.mil/software/hec-hms/), was conducted in ungauged watersheds to provide a flow time series at locations with species presence and absence data (Figure 4). Deciding which watersheds were modeled was driven by the species occurrence data, the characteristics of the watershed, and the location of the watershed. We selected watersheds that had a high density of species observations, and the watershed had to be free of dammed areas and have low urbanization.

To determine which watersheds were considered urbanized (for *exclusion* in our study), we hierarchically clustered stream reaches, using the NHD stream reach designation as our spatial unit. Clustering was based on four U.S. EPA StreamCat data sets (Hill, Weber, Leibowitz, Olsen, & Thornbrugh 2016) (Table 2). We cut the tree at five clusters based on the major divisions between NHD stream reaches. With this method, there was one cluster that represented the minimally altered stream reaches (low or no dams, low impervious surface area, low urban space of any kind, and low road density) in the region which we included in our study. To further ensure that all watersheds with major dams were also excluded, we created a new binary category for dam density within the watershed and removed any remaining streams in the unaltered category that had a dam density greater than zero. The dams removed are those that change the hydrology massively by damming water in reservoirs, for this reason, we did not attempt to remove all other types of dams, of which there are likely many, like silt dams or recreational dams because they likely do not change the hydrology much. Naturally, most of the stream reaches which are included in this study are mountainous, whereas the streams in the valleys have been impacted by the sprawling urbanization in the region.

Table 2: Data used for clustering from EPA StreamCat. 'W's refers to watershed and means that variable refers to the entire region that ultimately runs through that pour point. 'Cat' refers to catchments and means the variable only refers to the region upstream until the next confluence. For more information on these variables refer to https://www.epa.gov/national-aquatic-resource-surveys/streamcat.

Data Set name	Variable	Description
Dams_Region18	DamDensWs	Density of georeferenced dams within watershed (dams/ square km)
Dams_Region18	DamNrmStorWs	Volume all reservoirs (NORM_STORA in NID) per unit area of watershed (cubic meters/square km)
ImperviousSurfaces2011_CA	PctImp2011Cat	Mean imperviousness of anthropogenic surfaces (NLCD 2011) within catchment
NLCD2011_Region18	PctUrbOp2011Cat	% of catchment area classified as developed, open space
NLCD2011_Region18	PctUrbLo2011Cat	% of catchment area classified as developed, low-intensity land use
NLCD2011_Region18	PctUrbMd2011Cat	% of catchment area classified as developed, medium-intensity land use
NLCD2011_Region18	PctUrbHi2011Cat	% of catchment area classified as developed, high-intensity land use
RoadDensity_Region18	RdDensCat	Density of roads (2010 Census Tiger Lines) within catchment (km/square km)

HEC-HMS is driven by precipitation and watershed parameters, such as soil, land cover, and drainage area. We used a regional ensemble approach of HEC-HMS models that has been calibrated and validated with local gages (Sengupta et al. 2018). Precipitation data (Berg et al. 2015; downscaled by Huang & Hall 2018) was 3-hourly at a 90 m resolution and included water-years 1981- 2014. We condensed the 3-hourly modeled flow series into daily average flow (cfs). In total, sixty-eight watershed models were developed, and seven flow gages were used. Any gage data was applied to the species data within the same reach as the gage, and generally for the reach immediately up and downstream. For a detailed description of the HEC-HMS modeling, see Appendix D.

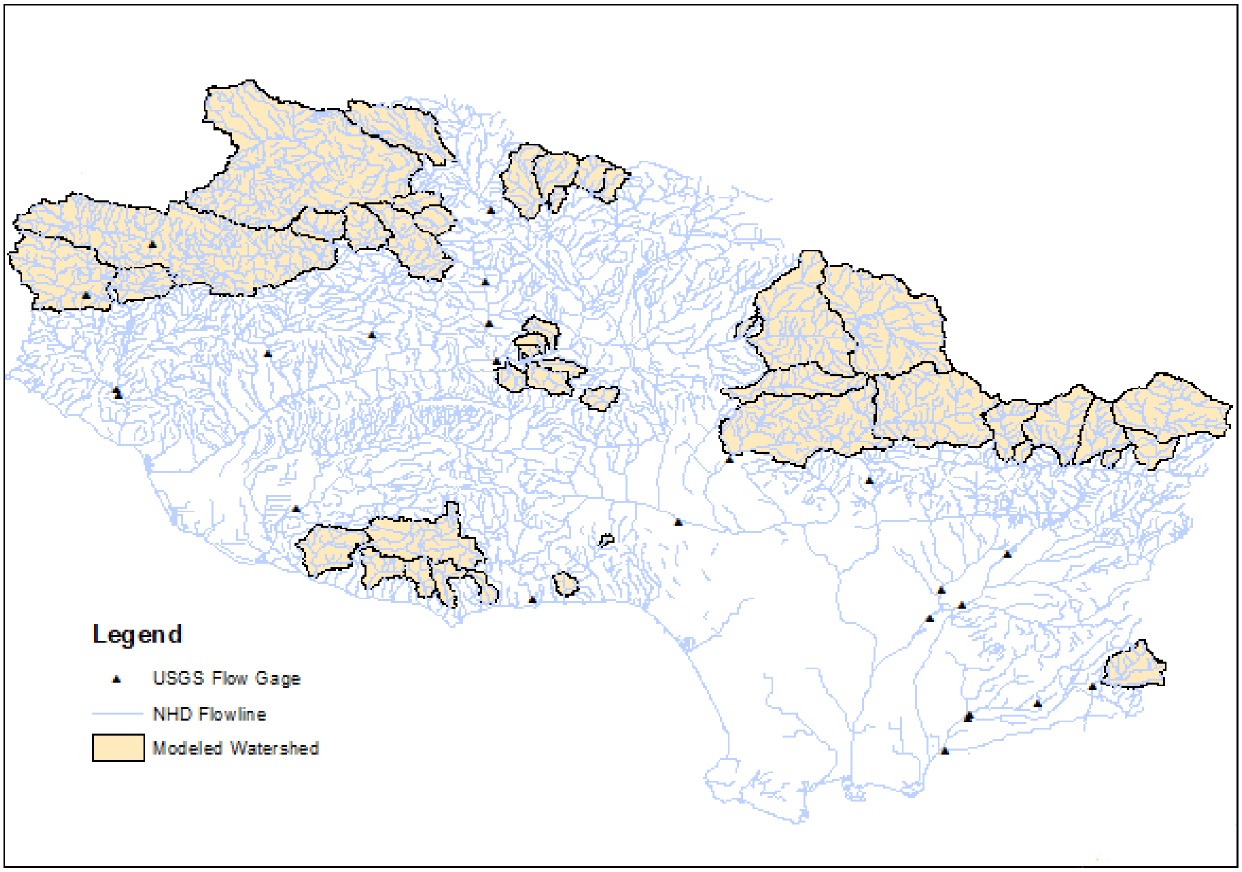


Figure 4: Map showing the sub-watersheds that were modeled with HEC-HMS and the flow gages in the region. Flow gages were only used if they were in the same or adjacent reach as species occurrence data, therefore not all the flow gages shown were used.

Flow Metric Calculation

Flow-ecology studies have shown that it is patterns of flow that are important to wildlife (Yarnell et al. 2015), not necessarily the daily flow for a given point in time. Therefore, we calculated biologically meaningful variables that impact the habitat suitability for species from the stream flow time series derived from the gages or models (Table 3). These metrics were selected based on their ability to describe the hydrological pattern and based on what we know from the literature to be important to the life-history stages of the focal species. All metrics were calculated from the date of species observations to accommodate dynamic stream conditions. All processing for the flow metrics was completed in Rstudio (RStudio Team 2016).

Table 3: Stream flow metric. *Script used for metric calculation and definition came from Konrad, Brasher, & May (2008). The range shows the 3-year timeframe for the baseline flow data used in this project with the units given in the definition column – these values are meant to give someone an idea of what is reasonable. Values outside of these ranges are likely in other regions or time periods for most metrics (except, for example, the probability-based metrics like hydroperiod). Timeframe refers to the numbers of years of flow data used in the calculation, measured back in time, from date of species occurrence.

Variable	Pattern	Definition [units]	Range	Timeframe

Qmean*	Magnitude	[ft^3/s] mean streamflow for the period of analysis	0-97	3,5 10, all
QmeanMedian*	Magnitude	[ft^3/s] median annual mean streamflow	0-91	3,5 10, all
Qmax*	Magnitude	[ft^3/s] median annual maximum daily streamflow	0-1681	3,5 10, all
Qmin*	Magnitude	[ft^3/s] median annual minimum daily streamflow	0-34	3,5 10, all
QmeanIDR*	Variability	[ft^3/s] 90th percentile of annual mean streamflow - 10th percentile of annual mean streamflow	0-97	3,5 10, all
QmaxIDR*	Variability	[ft^3/s] 90th percentile of annual maximum streamflow - 10th percentile of annual maximum streamflow	0-4655	3,5 10, all
QminIDR*	Variability	[ft^3/s] 90th percentile of annual minimum streamflow - 10th percentile of annual minimum streamflow	0-41	3,5 10, all
Qmed*	Magnitude	[ft^3/s] median daily streamflow	0-49	3,5 10, all
HighNum*	Frequency	[events/year] number of events > high flow threshold (90^{th} percentile streamflow).	0-12	3,5 10, all
LowNum*	Frequency	[events/year] number of events <= low flow threshold (10^{th} percentile streamflow).	0-23	3,5 10, all
HighDur*	Duration	[days/event] - longest consecutive days > the high flow threshold	0-780	3,5 10, all
LowDur*	Duration	[days/event]- longest consecutive days <= the low flow threshold	0-1004	3,5 10, all
NoDisturb *	Duration	[days] - longest number of consecutive days between the low and high flow threshold	0-799	3,5 10, all
Hydroperiod*	Duration	[%, e.g., 0.01 = 1%] - fraction of period of analysis with streamflow	0-1	3,5 10, all
FracYearsNoFlow*	Frequency	[%] - fraction of years with at least one no-flow day	0-1	3,5 10, all
Mednoflowdays*	Frequency	[days/year]- median annual number of no-flow days	0-365	3,5 10, all
RecessMaxLength*	Duration	[days] Maximum length of streamflow recession	0-900	3,5 10, all
R10D.5*	Variability	[cfs/day] - Median 10-day recession rate for low flow year	-0.7 – 0	3,5 10, all

R10D.9*	Variability	[cfs/day] - 90% percentile 10-day recession rate for low flow year	-0.6-0	3,5 10, all
R10D4D*	Variability	[cfs/day] - 10-day recession rate starting after 4 days of recession	-0.8 - 0	3,5 10, all
BFR*	Variability	[cfs/day] - Base flow recession.	-0.8 - 0	3,5 10, all
SFR*	Variability	[cfs/day] - Storm flow recession.	-0.9 - 0	3,5 10, all
MaxMonth*	Timing	[1= Jan] - month of maximum mean monthly streamflow	1-12	3,5 10, all
MinMonth*	Timing	[1= Jan] - month of minimum mean monthly streamflow	1-11	3,5 10, all
Max Month Q*	Magnitude	[ft^3/s] - maximum mean monthly streamflow	0-380	3,5 10, all
Min Month Q *	Magnitude	[ft^3/s] - minimum mean monthly streamflow	0-33	3,5 10, all
Q01-Q99*	Magnitude	[ft^3/s] - streamflow quantiles	0-1229 (Q99)	3,5 10, all
Qmean12month	Magnitude	[ft^3/s] - Mean streamflow in the 12 months preceding a specific date	0-590	1
RBI	Variability	[unitless] Richards-Baker flashiness Index.	0-2	3,5 and 10
Twoyr, fivyr, tenyr	Timing	[days] - Number of days from a specific date to a storm.	0-3159 (twoyr)	all

Regional Streamflow Extrapolation

The stream flow metrics from the gauged or HEC-HMS modeled watersheds were extrapolated to all NHD reaches in the study using a random forest approach. Two types of variables were included in the random forest: static predictors (Table 4), which included watershed characteristics like watershed area, slope, geology, land cover, and soils, and variable predictors, which included precipitation metrics. The static predictors were from USEPA StreamCat. The variable predictors were from the baseline precipitation data set. We used the same script (Konrad et al. 2008) used to calculate the flow metrics, to calculate precipitation metrics, which became the variable predictors.

Table 4: Static predictor variables used in the flow metric extrapolation. All variables have been joined to the NHD stream reach data and are available from the EPA StreamCat. A brief definition is given, but refer to the source column for more information about each source.

Variable	Source	Definition
Ws/CatPctFull	EPA StreamCat	% of the watershed/catchment that is covered by the landscape layer.

Ws/CatAreaSqKm	EPA StreamCat	Watershed area (square km) at NHDPlus stream segment outlet or area of local NHDPlus catchment (square km)
PctImp2011Cat	ImperviousSurfaces2011_CA	
ElevWa/Cat	Elevation_Region18	Mean watershed/catchment elevation (m)
HydrlCondWs/Cat	GeoChemPhys3_Region18	Mean lithological hydraulic conductivity (micrometers per second) content in surface or near surface geology within watershed/catchment
PctNonCarbResidWs	Lithology_Region18	% of watershed area classified as lithology type: non-carbonate residual material
PctAlluvCoastWs	Lithology_Region18	% of watershed area classified as lithology type: alluvium and fine-textured coastal zone sediment
Precip8110Ws/Cat	PRISM_1981_2010	30-year normal mean precipitation (mm): Annual period: 1981-2010 within the watershed/catchment
Tmax8110Ws/Cat	PRISM_1981_2010	30-year normal maximum temperature (C°): Annual period: 1981-2010 within the watershed/catchment
Tmean8110Ws	PRISM_1981_2010	30-year normal mean temperature (C°): Annual period: 1981-2010 within the watershed
Tmin8110Ws	PRISM_1981_2010	30-year normal minimum temperature (C°): Annual period: 1981-2010 within the watershed
RckDepWs/Cat	STATSGO_Set2_Region18	Mean depth (cm) to bedrock of soils within watershed/catchment
WtDepWs/Cat	STATSGO_Set2_Region18	Mean seasonal water table depth (cm) of soils within watershed/catchment
OmWs	STATSGO_Set2_Region18	Mean organic matter content (% by weight) of soils within watershed
PermWs	STATSGO_Set2_Region18	Mean permeability (cm/hour) of soils within watershed
PctUrbOp2011Ws/Cat	NLCD2011_Region18	% of watershed/catchment area classified as developed, open space land use
PctUrbMd2011Ws/Cat	NLCD2011_Region18	% of watershed/catchment area classified as developed, medium-intensity land use
PctBl2011Ws/Cat	NLCD2011_Region18	% of watershed/catchment area classified as barren
PctDecid2011Cat	NLCD2011_Region18	% of catchment area classified as deciduous forest
PctConif2011Ws/Cat	NLCD2011_Region18	% of watershed/catchment area classified as evergreen forest
PctShrb2011Ws/Cat	NLCD2011_Region18	% of watershed/catchment area classified as shrub/scrub

PctGrs2011Ws/Cat	NLCD2011_Region18	% of watershed/catchment area classified as grassland/herbaceous
PctHay2011Ws/Cat	NLCD2011_Region18	% of watershed/catchment area classified as hay
PctOw2011Ws	NLCD2011_Region18	% of watershed area classified as open water
PctIce2011Ws	NLCD2011_Region18	% of watershed area classified as ice/snow
PctMxFst2011Ws	NLCD2011_Region18	% of watershed area classified as mixed deciduous/evergreen forest
PctCrop2011Ws	NLCD2011_Region18	% of watershed area classified as crop
PctWdWet2011Ws	NLCD2011_Region18	% of watershed area classified as woody wetland
PctHbWet2011Ws	NLCD2011_Region18	% of watershed area classified as herbaceous wetland

Four random forest models were created for each flow metric based on January, April, July, and October data from 1981 to 2014 to account for seasonal variation in flow. Two models, using 75% of the data for training, were also created for each flow metric, month combination, where the first was based on all static and variable predictors and the second was based on the top ten most important predictors from the first model. Variable importance was based on the increase in model error after excluding each predictor. The final model for each metric, month combination was based on overall performance on a validation dataset that was a random selection of 25% of the observations from the complete dataset.

Overall performance was assessed using root mean squared errors and R-squared values comparing the observed flow metrics and those predicted from each model for the validation dataset (Appendix F). Flow metrics were then extrapolated to all NHD stream reaches within the region using the best performing model for each metric, month combination. To predict the flow metrics for the climate change scenarios, the random forest extrapolation was repeated using the same static predictors, but with the future precipitation data from three global climate models, instead of the current precipitation. Some of the static variables may change in future years, like land cover, however, because our focus was on the unaltered watersheds predominantly in mountainous areas, we do not anticipate much change.

Water Temperature Modeling

We used six temperature metrics to predict species occurrence (Table 5) which include values reported in the literature to be ecologically relevant (Sloat & Osterback 2013; Welsh et al. 2001; TAC feedback) and include metrics that address patterns of the temperature regime aside from just magnitudes. We calculated water temperature based on regional air temperature data (Walton, Sun, Hall, & Capps 2015; downscaled by Huang & Hall 2018) or from a gridded observational dataset (Livneh et al. 2015), using a multiple linear model that also included watershed area (A), and watershed elevation (E) as the predictor variables. Raw stream temperature data and air temperature were summarized as running 7 day average, minimum, and maximum temperatures which have been found in the literature to have a more linear relationship than daily data (Stefan & Preud'homme 1993). Final models below:

$$eq.1: 7\ day\ mean\ water\ =\ 0.6078\ (7\ day\ mean\ air) + 0.0003\ (A)$$

$$eq.2: 7\ day\ max\ water\ =\ 0.5455\ (7\ day\ max\ air) - 0.0059\ (E)\ - 0.0006\ (A)$$

$$eq.3: 7\ day\ min\ water\ =\ 0.4815\ (7\ day\ min\ air) - 0.0003\ (E) + 0.0006\ (A)$$

Table 5: Stream temperature metric definitions. The months included in calculating these metrics are May through September, which are the warm months and thus the time when water temperatures can be a concern.

Temperature Pattern	Metric	Definition
Magnitude	Minimum 7-day minimum	[°C] The minimum value of a rolling 7-day minimum
	Maximum 7-day maximum	[°C] The maximum value of a rolling 7-day maximum
	Maximum 7-day average	[°C] The maximum value of a rolling 7-day average
Variability	Maximum 7-day range	[°C] The maximum difference between the rolling 7-day maximum and minimum. I.e. the largest temperature swing within a 7-day period.
	Mean 7-day range	[°C] The average difference between the rolling 7-day maximum and minimum. I.e. the average temperature swing within a 7-day period.
Frequency	Number of 7-day maximums > 30°C	[days] The number of 7-day rolling averages that are greater than 30°C

Two air temperature data sets were used; one from the regional model that provided the precipitation data (Walton et al. 2015; downscaled by Huang & Hall 2018) and one from a state-wide dataset of historical observations downloaded at https://cal-adapt.org/data/ (Livneh et al. 2015). The regional air temperature was modeled mean air temperature at daily increments of 90m resolution from water year 1981- 2014. The statewide air temperature data consists of daily maximum and minimum air temperature values from 1950 -2013 with approximately 6 km pixels. We averaged the maximum and minimum to get daily mean air temperature, so it would be comparable to the modeled dataset.

Unlike the flow modeling, we included stream reaches in the urbanized or dammed watersheds. While some altered characteristics will impact stream temperature, such as bottom releases from reservoirs or concrete lining, the coefficients were similar between the individual altered and unaltered reaches, so we expect they are similar. This contrasts with the physical flow modeling, where dams and urbanization completely change the streamflow and the flow modeling could not be applied in these altered regions.

Twenty-one stream sites throughout southern California (Figure 5) were used to develop the statistical relationships between air and stream temperature. Sites were included where continuous temperature data was available, i.e., no spot measurements (refer to Table 6 for the length of the stream record and a short description of the site). Criteria for the streams included a record of temperature monitoring in the summer months, May through September, and reported maximum and minimum temperature or sub daily reporting so that we could calculate the maximum, minimum, and average stream temperature. If maximum and minimum were reported, we calculated the mean as the daily average. If sub daily values were reported, the maximum was the maximum value reported, the minimum was the minimum value reported, and the mean was a daily average.

For every day of the stream temperature record, daily air temperature was extracted from either of the two air temperature datasets depending on which air temperature dataset covered that date and location. A seven-day running average, minimum, and maximum was calculated for the stream temperature and the air temperature. The three stream temperature metrics were regressed against the air temperature metrics to create a model for average, minimum, and maximum stream temperature. This model was used to calculate the average, minimum, and maximum stream temperature for every day throughout the entire timeframe of this study, 1981 through 2014, and for every reach within the region. Refer to Appendix E for the stream temperature model performance and model residuals.

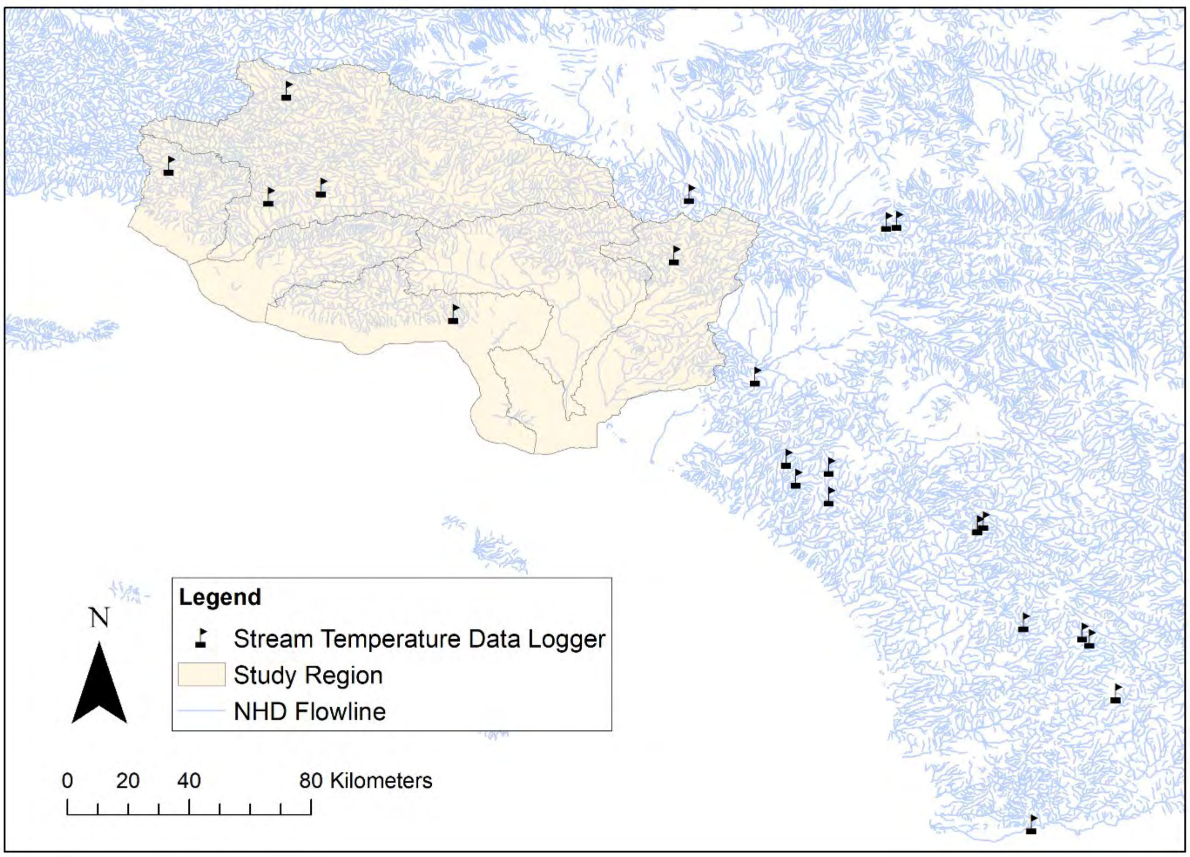


Figure 5: Locations with stream temperature loggers. Outlines of the six major watersheds are shown for reference.

Table 6: List of the NHD stream reaches that were included in the air temperature to water temperature model. All streams were in a relatively to completely unaltered state unless noted in the description. *After COMID means the air temperature data was Livneh et al. (2015), otherwise it was Walton et al. (2015).

NHD Reach	Start	End	Days	Stream Temperature Data	Stream name and short description
17573647*	4/30/1969	1/15/1971	625	USGS Current Water Data for USA	Santa Paula Creek ~ 6km from Santa Clara river.
17574397*	11/8/1966	9/6/1978	4320	USGS Current Water Data for USA	Tributary to Sespe creek ~6km to Santa Clara River.
20325695*	4/2/2013	12/31/2013	273	Southern CA Stormwater Monitoring Coalition (SMC)	Tributary to Tijuana River, San Diego county
20329578*	4/3/2013	12/31/2013	272	Southern CA Stormwater Monitoring Coalition (SMC)	Temescal creek, San Diego county
20329654*	4/10/2008	7/16/2008	97	Southern CA Stormwater Monitoring Coalition (SMC)	Santa Ysabel Creek, San Diego county
20329758*	4/11/2008	7/9/2008	89	Southern CA Stormwater Monitoring Coalition (SMC)	San Diego River in San Diego county
20332588*	4/25/2013	8/1/2013	98	Southern CA Stormwater Monitoring Coalition (SMC)	Cold Stream, San Diego county
20348295*	4/4/2013	12/31/2013	271	Southern CA Stormwater Monitoring Coalition (SMC)	Tributary to San Juan Creek, Orange county
20348331*	4/28/2008	7/3/2008	66	Southern CA Stormwater Monitoring Coalition (SMC)	Tributary to San Juan Creek, Riverside county
20348471*	4/23/2008	6/24/2008	62	Southern CA Stormwater Monitoring Coalition (SMC)	San Juan Creek, Orange County.
20348769*	4/4/2013	10/20/2013	199	Southern CA Stormwater Monitoring Coalition (SMC)	Tributary to San Mateo Creek, San Diego County.
22549515*	4/8/2008	6/14/2008	67	Southern CA Stormwater Monitoring Coalition (SMC)	Arroyo Seco Creek, Riverside County.
22550557*	4/3/2013	8/13/2013	132	Southern CA Stormwater Monitoring Coalition (SMC)	Tributary to Arroyo Seco creek, Riverside county.
22563116*	2/2/1968	12/31/2013	16769	USGS Current Water Data for USA	Santa Ana River below Prado Flood Control Basin. Dams, channelization, urbanization.
22658309*	12/1/2006	12/31/2013	2587	USGS Current Water Data for USA	Deep creek, San Bernardino county.
22660257*	2/28/2007	12/31/2013	2498	USGS Current Water Data for USA	West Fork Mojave River. Dams and urbanization.
22684930*	1/18/1962	3/9/1979	6259	USGS Current Water Data for USA	Big Rock Creek, Angeles National forest, LA county.

17567207	5/14/2014	9/30/2014	139	Surface Waters Ambient Monitoring Program (SWAMP)	Lockwood creek, tributary to Piru creek.
17585800	5/28/2014	7/29/2014	62	Southern CA Stormwater Monitoring Coalition (SMC)	Matilija creek, Ventura county.
20365115	5/20/2014	7/31/2014	72	Southern CA Stormwater Monitoring Coalition (SMC)	Coastal creek, Santa Monica mountains.
22524629	5/6/2014	9/30/2014	147	Surface Waters Ambient Monitoring Program (SWAMP)	Bear Creek, tributary to west fork San Gabriel.

Biological Modeling

We used biological models to predict probability of species occurrence based on streamflow and stream temperature. The results are temporally and spatially variable as stream flow and stream temperature vary over years and regionally. This means the probability distribution of species varies within the region and looks different depending on the year of interest. Probability of occurrence is related to specific flow and temperature metrics that represent ecologically meaningful measures of the overall flow regime. We modeled three baseline years, a representative wet (1993), dry (2014), and moderate (2010) year, and two future years, 2040 (dry) and 2100 (moderate). For the two future years, three global climate models were used to provide a range of possible future scenarios assuming Representative Concentration Pathway (RCP) 8.5: CanESM2, CCSM4, and MIROC5, from the same sources as the baseline data. According to IPCC (2014), RCP 8.5 represents the upper end of an emission scenario in which no efforts are taken to decrease greenhouse gas emissions.

These three climate models were part of the Coupled Model Intercomparison Project Phase 5 (CMIP5). When compared to observed historical conditions, they all performed well with mean annual temperature predictions (the bias was within the range of the observed), but for precipitation, only CanESM2 had bias within the range of the observed data; the other two had bias above the range (Rupp, Abatzoglou, Hegewisch, & Mote 2015). These were chosen was because they capture a large amount of the variation among climate models in terms of the projections for future climate and they scored well in model performance of atmospheric rivers hitting California. Additionally, these three models were among the 10 models selected as the best for planning in California based on global and southwestern USA historical performance, and based on their ability to capture California's climate variability (DWR 2015).

The one hundred and sixty flow metrics (Table 3) and six temperature metrics (Table 5), discussed in the previous sections, were calculated and were tested to see how they related to species occurrence with simple logistic regression. The metrics that were found to be insignificant ($P > 0.05$) were removed from the pool of metrics. Each species was analyzed separately, therefore priority metrics vary by species. The remaining flow and stream temperature metrics were used to predict the probability of species occurrence. For flow metrics, we used a random forest model to accommodate the higher number of important variables and this yielded a 'presence' or 'absence' outcome. To convert this outcome to probability, we looked at the percentage of time that a presence outcome occurred out of the 500 trees that were produced with the random forest and this became the probability. Validation of these biological random forest models are shown in Appendix G. With the temperature metrics, we used logistic regression modeling which yielded a probability of occurrence outcome. The two models, flow and temperature, resulted in two different predictive maps of species occurrence that needed to be combined. To synthesize the results of the flow and temperature modeling, we selected the minimum value of the two models in each stream reach (Figure 6). For example, if the outcome of the flow model was a ‘P=0.60’ and the outcome of the temperature model was a ‘P=0.78’ then the final species occurrence probability was a 0.60. A probability of 0, based on either the flow or temperature modeling, would result in an overall P=0. This way, flow and temperature are considered equally important and either can be the limiting environmental variable. As shown, in an example of this approach, Figure 6, streamflow is the limiting variable throughout most of the region.

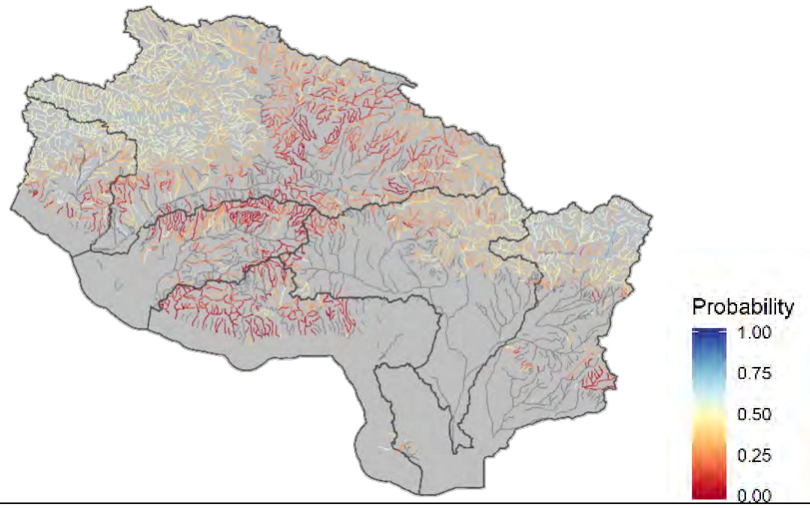
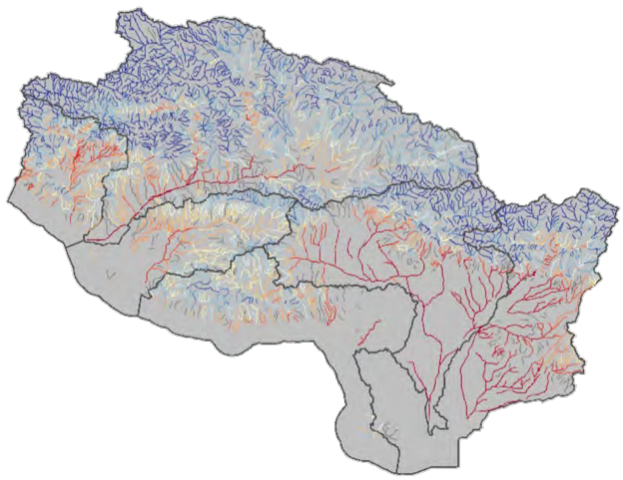
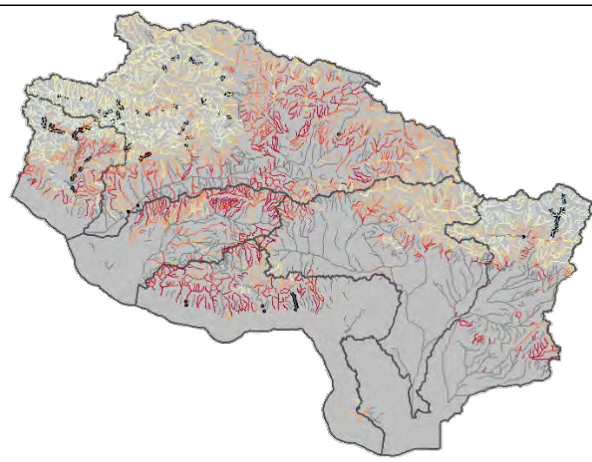
Metric	Prediction map
Streamflow	
Stream temperature	
Final Prediction	

Figure 6: Example showing how the stream flow and stream temperature maps were combined. The figure shows the prediction for *O. mykiss* based on streamflow (top panel), stream temperature (middle panel) and then the combined final map (lower panel). The colors represent probability of occurrence. Points in the lower panel show observation data of *O. mykiss*.

RESULTS AND DISCUSSION

In this section we discuss the key environmental variables for each species and present the synthesized results of the species distribution modeling based on stream temperature and stream flow. The six species, which are meant to represent a larger cluster of riparian or riverine dependent fauna, show different responses to the flow and temperature metrics explored in this study. This suggests that managing for one species won't necessarily benefit all species and that climate change may impact species differently. We found that the six species had unique ranges, as expected based on the species occurrence data, and that those ranges shifted differently between groups in response to wet, dry, moderate, and future years. The six species appear to split into two groups: those that occur in higher elevation regions and are vulnerable to climate change, and those that occur in lower elevation regions and appear to either benefit or be unharmed by climate change.

Key Environmental Variables

Results of the biology - stream temperature logistic regression model are shown in Table 7 and results of the biology - flow metric random forest model are shown in Table 8. A selection of the most impactful variables in the flow and temperature biological modeling are shown in Figure 7 (flow) and Figure 8 (temperature). An accompanying logistic regression curve is shown with each of the metrics to display the relationship of the metric with species occurrence.

O. mykiss

O. mykiss were negatively related to maximum 7-day maximum, maximum 7-day average, and minimum 7-day minimum temperatures. They occur in streams with maximum 7-day averages generally below 22°C, minimum 7-day minimums generally below 12.5°C, and that had few numbers of 7-day maximum temperatures greater than 32°C. There were no occurrences in streams that had a maximum 7-day maximum temperature above 32.5°C, a minimum 7-day minimum temperature above approximately 13.75°C, and 75% of presence observations had fewer than 29 instances when the maximum 7-day maximum was greater than 30°C (compared to the streams where 75% of absence instances had fewer than 63 instances of maximum 7-day maximum temperature greater than 30°C). Occurrence had a negative relationship with maximum 7-day range which might suggest an intolerance for large temperature swings. *O. mykiss* occurrence was positively related to average and maximum flows, but negatively related to the number of large events. They were found in streams with gradual recession, perennial flows, and more days of no disturbance. This suggests that they favor consistent high flows throughout the year with minimal disturbance.

Arroyo Chub

Arroyo chub occurrence had a positive relationship with stream temperature, unlike *O. mykiss*, and tended to occur in streams with a higher maximum 7-day maximum temperature. Most chub occurrences were in streams with a maximum 7-day maximum above 30°C and there were no occurrences below a maximum 7-day maximum of 27.5°C. Aside from a single outlier, they did not occur in streams that had a minimum 7-day minimum temperature less than approximately 11°C and most minimum 7-day minimum temperatures were between 11°C and 15°C. Chub did not show any relationship to maximum 7-day temperature ranges (stream temperature variability). They tended to occur in flashy streams with a high number of high flow events with rapid recessions, and a high number of low flow events. They were positively related to minimum and maximum stream flow. Interestingly, they tended to occur in streams that did not have perennial stream flow which suggests that permanent pool refuges are important and that they can successfully recolonize intermittent reaches.

Santa Ana Sucker

Santa Ana sucker showed less of a relationship with stream temperature than the other two fishes. This could be because they occur at low and high elevations and are thus more tolerant of warm and cool water than the other two which primarily occur at either high or low elevations. The maximum 7-day maximum temperatures range from 25°C to 32.5°C. The only moderately significant temperature variables were maximum 7-day average stream temperature and minimum 7-day minimum stream temperature. They both show a positive relationship with sucker occurrence suggesting a preference for warmer water. It is important to note that our species data for sucker was the most limited of the three fishes and was not representative of the entire region (e.g., there were no positive or negative observations in the Santa Monica mountains) and therefore this relationship is not as robust as the other two. The range of minimum 7-day minimum temperatures was like chub, and wider than *O. mykiss*. Sucker tended to occur in flashier streams, showing a preference for streams with a high number of high flow events, rapid recessions, and fewer no disturbance days. They also occurred in streams that had more recent two-year storms. Like chub, they tended to occur in intermittent streams, highlighting the importance of refuges.

Arroyo Toad

Like *O. mykiss*, arroyo toads were more likely to occur in cooler streams and none were observed in streams where the maximum 7-day maximum was greater than approximately 28.4°C - about 4°C lower than the threshold we observed for *O. mykiss*. This is likely an artifact of their occurring in high elevation habitats within our region which have cooler water and this relationship may not hold in the southern portion of their range where they occur in lower more coastal streams. There was no relationship with temperature ranges or minimum temperatures. Like *O. mykiss*, toads tended to occur in streams that had perennial flow, however, they were found in streams with fewer no disturbance days. This could be reflective of their dependence on periodic large flows for depositing coarse substrate and removing encroaching vegetation in their edgewater habitat. They occur in streams with rapid flow recessions. Generally, the relationships with the stream flow metrics were weaker than the other species likely due to the limited species data and the similarly of flow between the presence and absence data.

Southwestern Pond Turtle

Southwestern pond turtle had the least consistent relationship with the temperature metrics. Their occurrence was positively related with the maximum 7-day maximum temperature and the number of 7-day maximums greater than 30°C. The range of maximum weekly maximum temperatures where turtles were observed was from approximately 29.5°C to 34°C, far higher than the three fishes and toad. However, occurrence was negatively associated with the maximum 7-day average and the minimum 7-day minimum stream temperatures. The minimum 7-day minimum temperature range was similar to chub and sucker. As expected based on the temperature preferences, they were found in areas that had a large maximum 7-day temperature range. This could be that they occur in streams that can get very hot, but topographic or other environmental characteristics maintain cool minimum and average temperatures. The broad distribution of turtles within the study region combined with few absence observations yielded vague streamflow preferences. However, they occurred in streams with median flow less than 30cfs, minimum flow less than 10cfs, Q75 less than 50 cfs, and Q90 less than 100 cfs.

Least Bell's Vireo

Least Bell's vireo, unlike the other five species, have an indirect dependence on streamflow because it supports their riparian habitat and insect food source, while they do not have a life history phase where they live in the water. Although they nest in riparian vegetation alongside the stream, not in the water, they had a clear association with warmer streams. This likely reflects the lower elevations they nest in. Vireo were only found in streams that had a maximum 7-day maximum value *greater* than 30°C and were found in locations as high as 34°C, completely outside the range of the toad and largely outside the range of *O. mykiss*. Similarly, they were found in areas with higher minimum temperatures- the lowest minimum 7-day minimum was approximately 12.5°C. There was no association with the maximum 7-day average. Vireo occurred in intermittent streams that had a long duration of low flow. However, occurrence had a positive relationship with the number of high events, RBI, and a negative relationship with days since 10-, 5-, and 2-year storm. This suggests that although they tended to occur in streams that were intermittent with low flow magnitudes, they do select streams that get scouring flows. It also suggests that pools or groundwater seeps are vital to sustain their insect food source.

Table 7: Logistic regression results from the biology - temperature model.

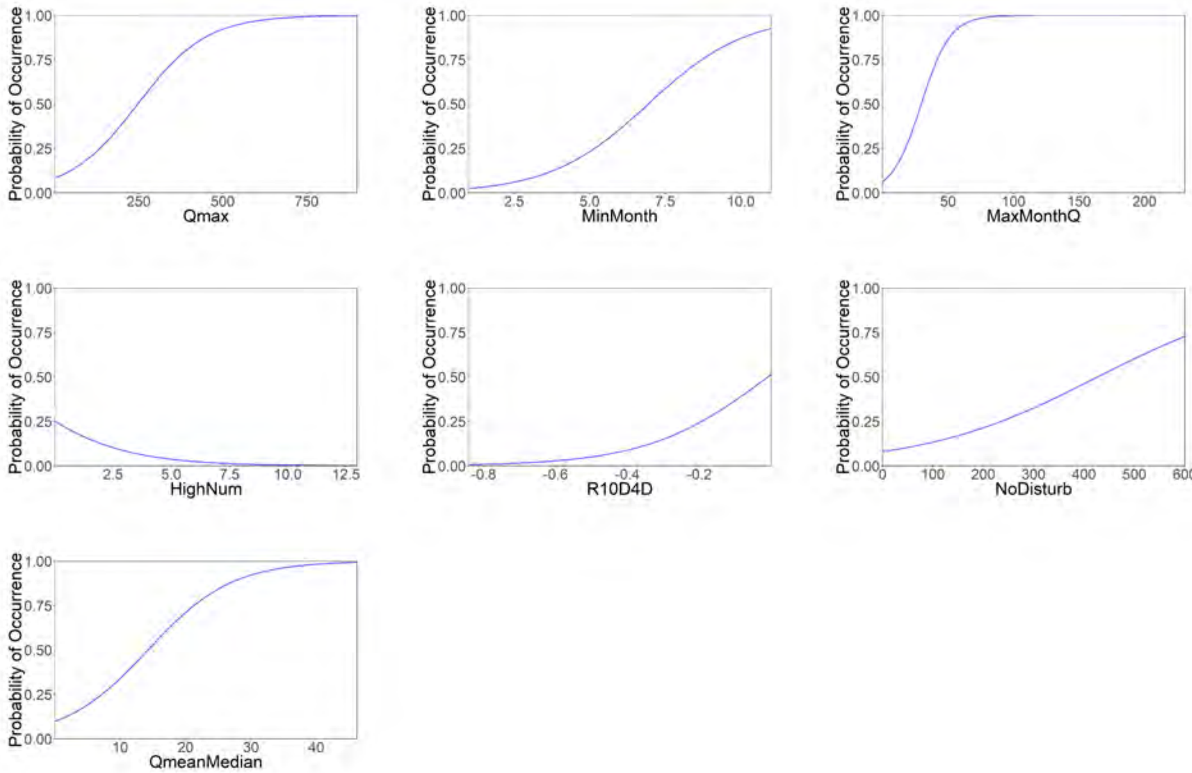
Variable	Coefficient (log odds)	Std. error (log odds)	P-value
O. mykiss			
Maximum 7-day maximum	-0.8189	0.2144	1.34e-4
Minimum 7-day minimum	-1.3128	0.1993	4.53e-11
Maximum 7-day range	1.0909	0.1987	4.03e-08
Arroyo chub			
Minimum 7-day minimum	1.3972	0.2447	1.13e-08
Santa Ana sucker			
Maximum 7-day average	0.4353	0.2566	0.0897
Arroyo toad			
Maximum 7-day maximum	-0.7605	0.4577	0.0966
Southwestern pond turtle			
Maximum 7-day maximum > 30°C	0.05757	0.01775	0.00118

Minimum 7-day minimum	-0.70585	0.37377	0.05897
Least Bell's vireo			
Maximum 7-day maximum	1.6718	0.4621	2.97e-4
Minimum 7-day minimum	1.9528	0.4194	3.22e-06

Table 8: Random forest results for the biology – flow metric modeling. The low accuracy and high error rate of the arroyo toad is reflective of the few observations.

	O. mykiss	Arroyo Chub	Santa Ana Sucker	Arroyo Toad	SW pond turtle	Least Bell's Vireo
Testing data accuracy	0.94	0.93	0.94	0.75	0.97	1.0
Error rate	7.29%	15.73%	8.47%	32%	5.63%	6.12%

(a) *O. mykiss*



(b) Arroyo chub

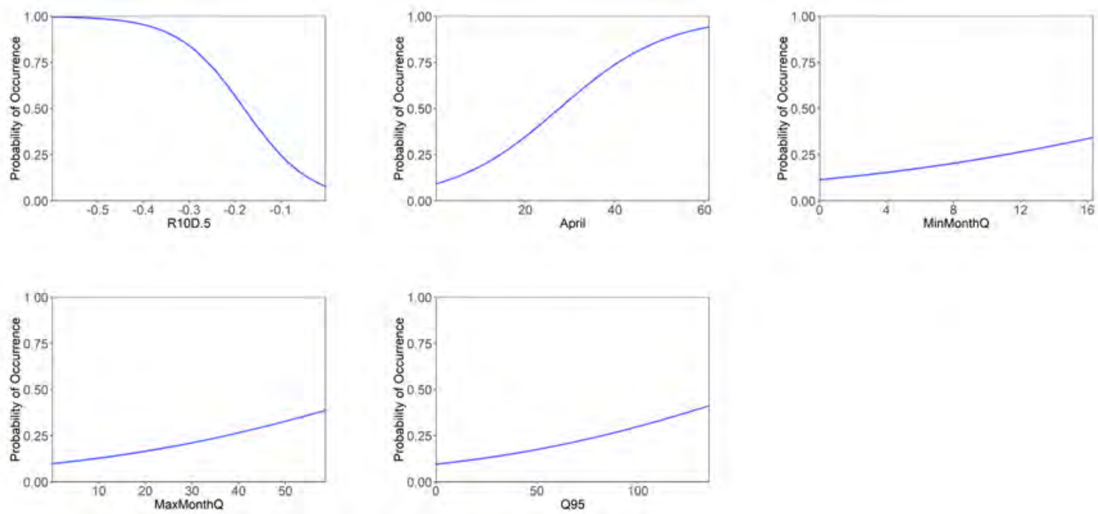
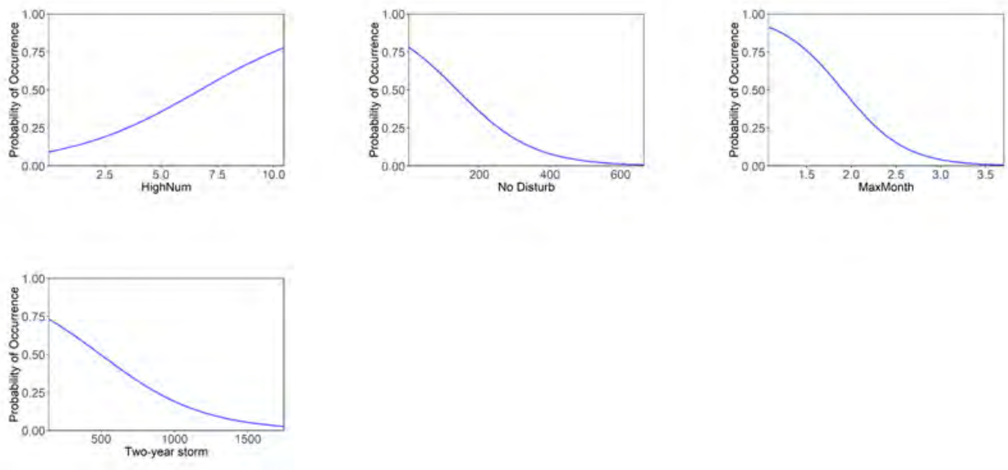
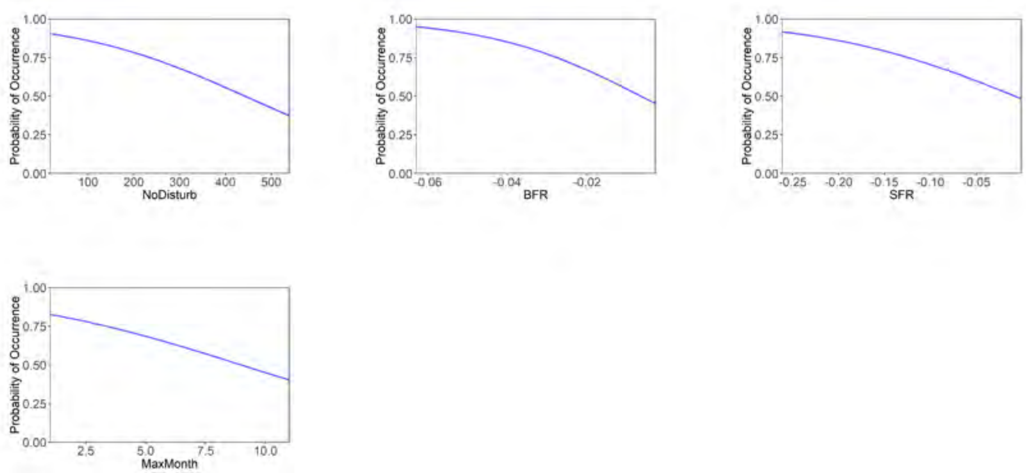


Figure 7: A selection of the top-rated metrics for each species in the random forest biological model. Refer to Table 3 for a definition of these metrics. Log regression curve shows the relationship between the variable's value (x-axis) and the probability of species occurrence on the y-axis, which ranges from 0-1.

(c) Santa Ana sucker



(d) Arroyo toad



(e) Least Bell's vireo

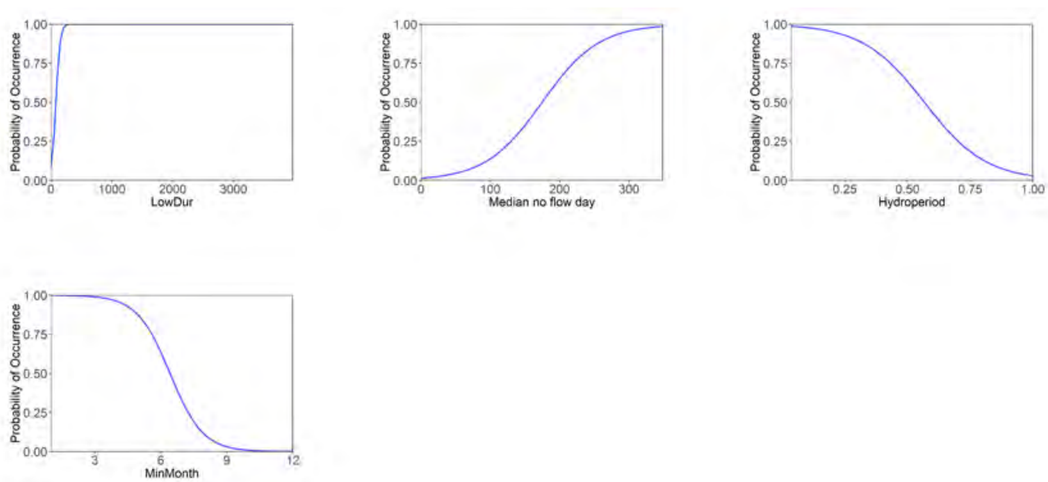


Figure 7: (*continued*)

(f) Southwestern pond turtle

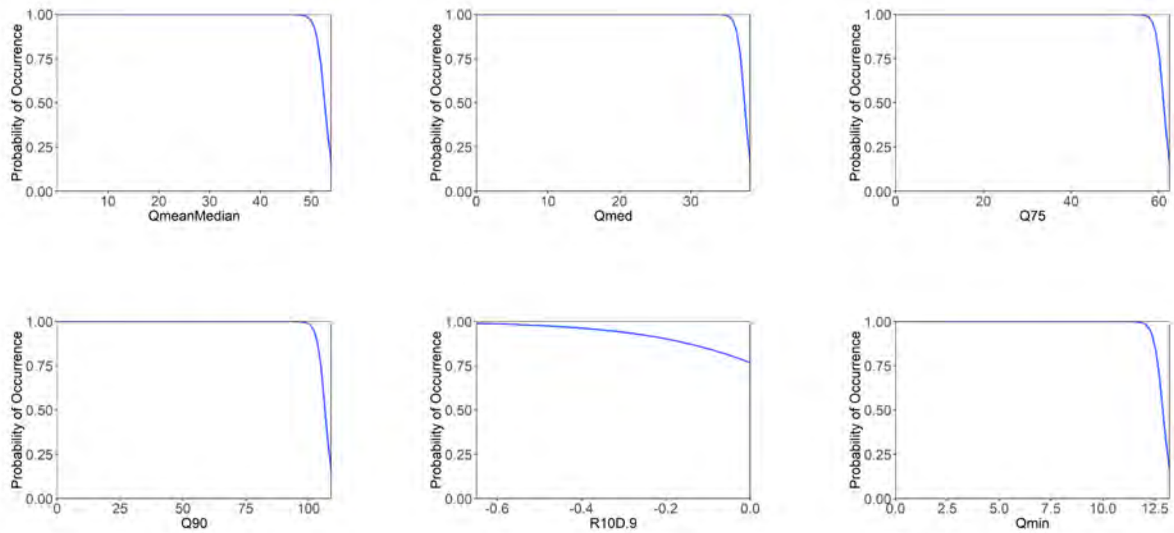


Figure 7: (*continued*)

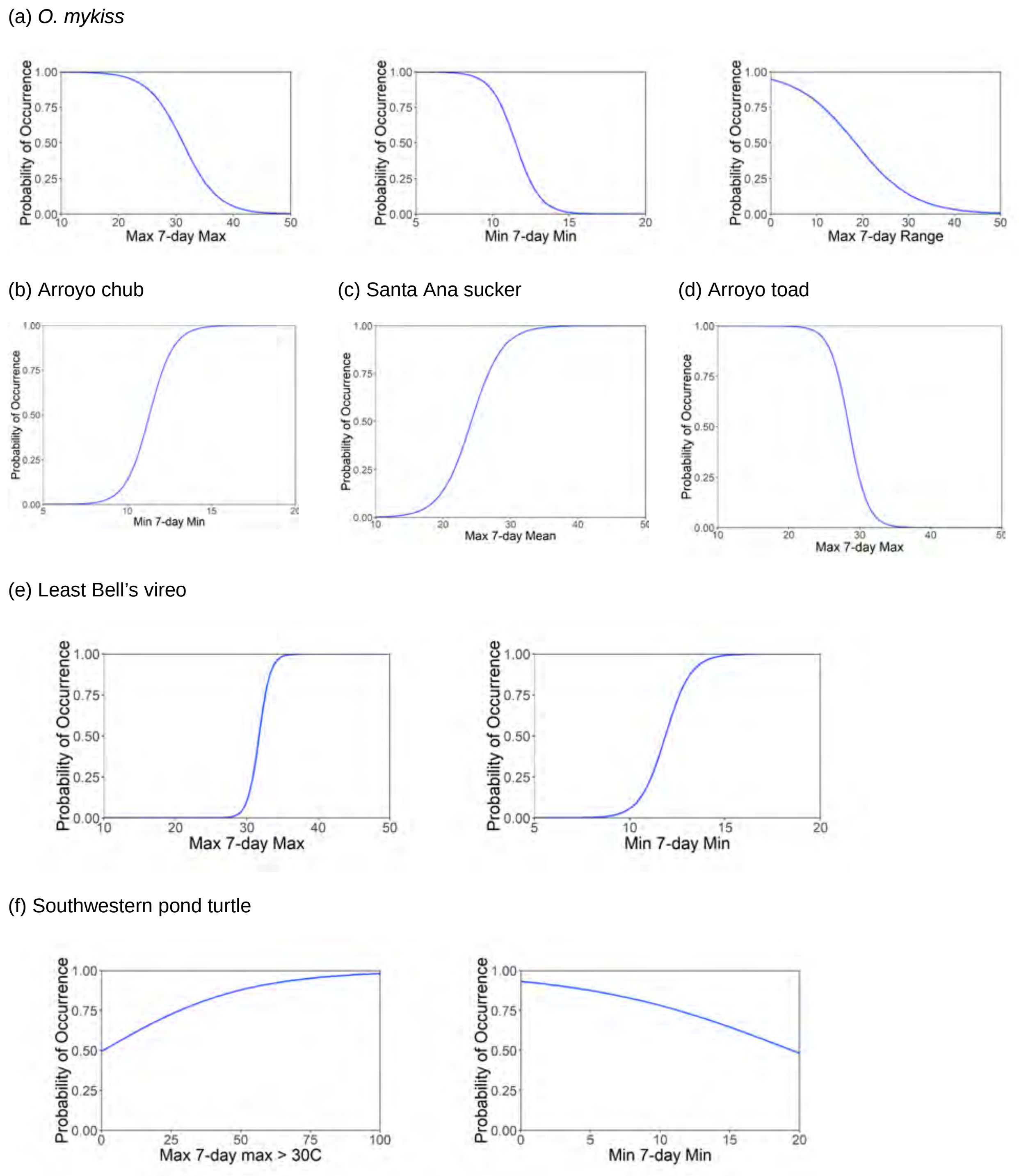


Figure 8: The stream temperature metrics used for each species in the logistic regression biological model. Refer to Table 5 for a definition of these metrics. Log regression curve shows the relationship between the variable's value (x-axis) and the probability of species occurrence on the y-axis, which ranges from 0-1.

Baseline Species Distribution Modeling

Table 9 shows the median probability of occurrence by watershed in the baseline years, and Table 11 and Table 12 shows the regional median probability of occurrence in all the NHD reaches and the unaltered reaches, respectively.

The most suitable regions for *O. mykiss* include the higher elevation sub-watersheds of the Ventura River, Matilija Creek, Sespe Creek, Piru Creek, all forks of the San Gabriel river, and Big Tujunga creek (Figure 9). Observational data largely supports this finding. The major population that our modeling misses is in the Santa Monica mountains which were excluded due to dam presence in the streams that host *O. mykiss*. *O. mykiss* habitat extent decreased in the dry year, 2014, where much of the Sespe and Piru Creek habitat became unsuitable and the median probability dropped to 0.25, from 0.38 (1993) and 0.34 (2010) (Table 12). The probability of occurrence distribution shifted toward the left (zero) compared with 1993 and 2010 (Figure 12). This baseline trend delineates the harm of extended droughts on *O. mykiss* populations. Due to their preference for cool, already high elevation regions, we expect their habitat will be reduced if the current temperature range becomes unsuitable.

The range of arroyo chub excluded the higher elevation regions of the Santa Clara, Los Angeles, and Ventura River. Chub were predicted to occur throughout the Santa Monica mountains, and the unaltered streams in the low elevation portions of the region (Figure 9). Because most of the low elevation regions are urbanized, much of their range is not reflected in the baseline maps. Habitat suitability slightly increased during the wet year (Table 12). The chub had a majority of reaches that had very low probability of occurrence, but also had reaches where probability of occurrence was close to 1.0 (Figure 12). Due to their preference for lower regions in the baseline years, there is potential to move upstream in future years if there are no barriers.

Suitable habitat for Santa Ana sucker excluded the higher elevation regions of the Santa Clara, Los Angeles, Ventura River, and the Santa Monica mountains, but did extend into the Upper San Gabriel sub-watersheds and generally occurred slightly higher in each watershed than chub (Figure 9). Interestingly, the range of sucker did include the lower Ventura watershed despite there not being any observed species occurrences there. Habitat suitability slightly increased during the wet year (Table 12). No reaches had beyond a 0.6 probability of occurrence for sucker which is reflective of the less clear relationship of flow and temperature on species occurrence from our data (Figure 12). Due to their preference for lower regions in the baseline years, there is potential to move upstream in future years if there are no barriers.

Arroyo toad showed a similar, yet more constricted, range as *O. mykiss.* They had a smaller presence in the upper Ventura River watershed and a larger presence in the upper Los Angeles River watershed (Figure 9). The higher probability of occurrence in the Ventura river watershed is an instance where there is no observational data indicating occurrence in that watershed, but perhaps it's an area where managers could consider recolonization. The highest probabilities occurred in mid to high elevation areas and excluded the coastal areas. Although the median probability of occurrence is actually highest in the dry year (Table 12), we can see from the probability distribution that the second peak shifts to the left from 1993, to 2010, to 2014 (Figure 12). This suggests that the most suitable habitat space is available in the wet year, despite some additional moderate habitat becoming available in the dry year.

The range of Least Bell's vireo excluded the higher elevation sub-watersheds and had a high probability of occurrence in the lower tributaries, mainstems, and coastal areas of each major watershed (Figure 9). Much of the baseline vireo range is in altered streams and therefore is not reflected in our baseline maps. Habitat suitability increased in the dry year (Table 12). The upper watersheds had very low probabilities and the lower watersheds had very high probabilities, which creates an explicit threshold between suitable and unsuitable areas (Figure 12).

Southwestern pond turtle had the broadest predicted extent that covers largely the entire region (Figure 9) and highest overall probabilities of occurrence (Table 12). They had a broader distribution in the wet and moderate year, compared to the dry year. In the dry year, the distribution shifted to the left, but a large proportion of reaches did remain favorable (Figure 12). This is likely reflective of pond turtles being widespread within the region and found across a variety of habitat types. This suggests that climate variation, historically, may not have been a limiting factor for southwestern pond turtles, but rather other disturbances may have influenced distributions such as habitat fragmentation and population isolation (Dagit & Albers 2009).

Figure 9 show the baseline predicted probability of species occurrence overlain with the species occurrence data. The species data shows the presence in areas we excluded from the model due to hydrological alteration. Within the unaltered watersheds, there is a high degree of overlap between the species data and the prediction. It is important to note that there are other drivers of species occurrence such as biotic competition, barriers to dispersal such as dams or roads, and habitat loss due to urbanization. We did not account for these other variables which might explain incongruities between the occurrence data and the predictions. There are also other climate change variables which will likely be impactful, such as fire, that were not evaluated in this study. Some possible reasons for a discrepancy between the occurrence data and the predictions:

1. The species is in fact there, it is just not a surveyed area (or we do not have the survey).
2. The species could survive in the stream reach based on flow and temperature, but there is a barrier to dispersal or a different factor, such as invasive species, which inhibits the species.
3. The species is currently found there, but the conditions do not match the conditions modeled in many of the areas the species is also found in.

Table 9: Median probability of occurrence by watershed in the baseline years. Of these watersheds, only the unaltered streams are represented in this table. Wet year is 1993, moderate year is 2010, and dry year is 2014.

Watershed	Year Type	*O. mykiss*	Arroyo chub	Santa Ana sucker	Arroyo toad	Least Bell's vireo	SW pond turtle
Ventura River	Wet	0.42	0.31	0.25	0.10	0.35	0.77
	Moderate	0.41	0.13	0.20	0.07	0.36	0.75
	Dry	0.20	0.10	0.21	0.10	0.50	0.81
Santa Clara River	Wet	0.41	0.11	0.22	0.40	0.00*****	0.76
	Moderate	0.39	0.05	0.13	0.39	0.00*****	0.82
	Dry	0.28	0.07	0.09	0.44	0.00*****	0.63
Calleguas Creek	Wet	0.12	0.49	0.23	0.02	0.90	0.97
	Moderate	0.10	0.52	0.27	0.01	0.94	0.92
	Dry	0.06	0.49	0.25	0.02	0.93	0.97
Santa Monica Bay WMA	Wet	0.07	0.60	0.16	0.05	0.82	0.82
	Moderate	0.04	0.61	0.15	0.03	0.92	0.56
	Dry	0.03	0.63	0.18	0.05	0.93	0.89
Los Angeles River	Wet	0.36	0.15	0.22	0.47	0.00*****	0.74
	Moderate	0.33	0.15	0.20	0.40	0.00*****	0.69
	Dry	0.28	0.17	0.18	0.38	0.00*****	0.58
San Gabriel River	Wet	0.47	0.12	0.25	0.57	0.00*****	0.83
	Moderate	0.43	0.09	0.22	0.49	0.00*****	0.72
	Dry	0.39	0.10	0.23	0.45	0.00*****	0.76

***** Least Bell's vireo do nest in the lower portions of these watersheds as shown in Figure 9. However, we did not model these lower areas because they are heavily altered. The 0 is the median value of the reaches we did model, which are mainly the upper portions of the watersheds, where vireo do not nest.

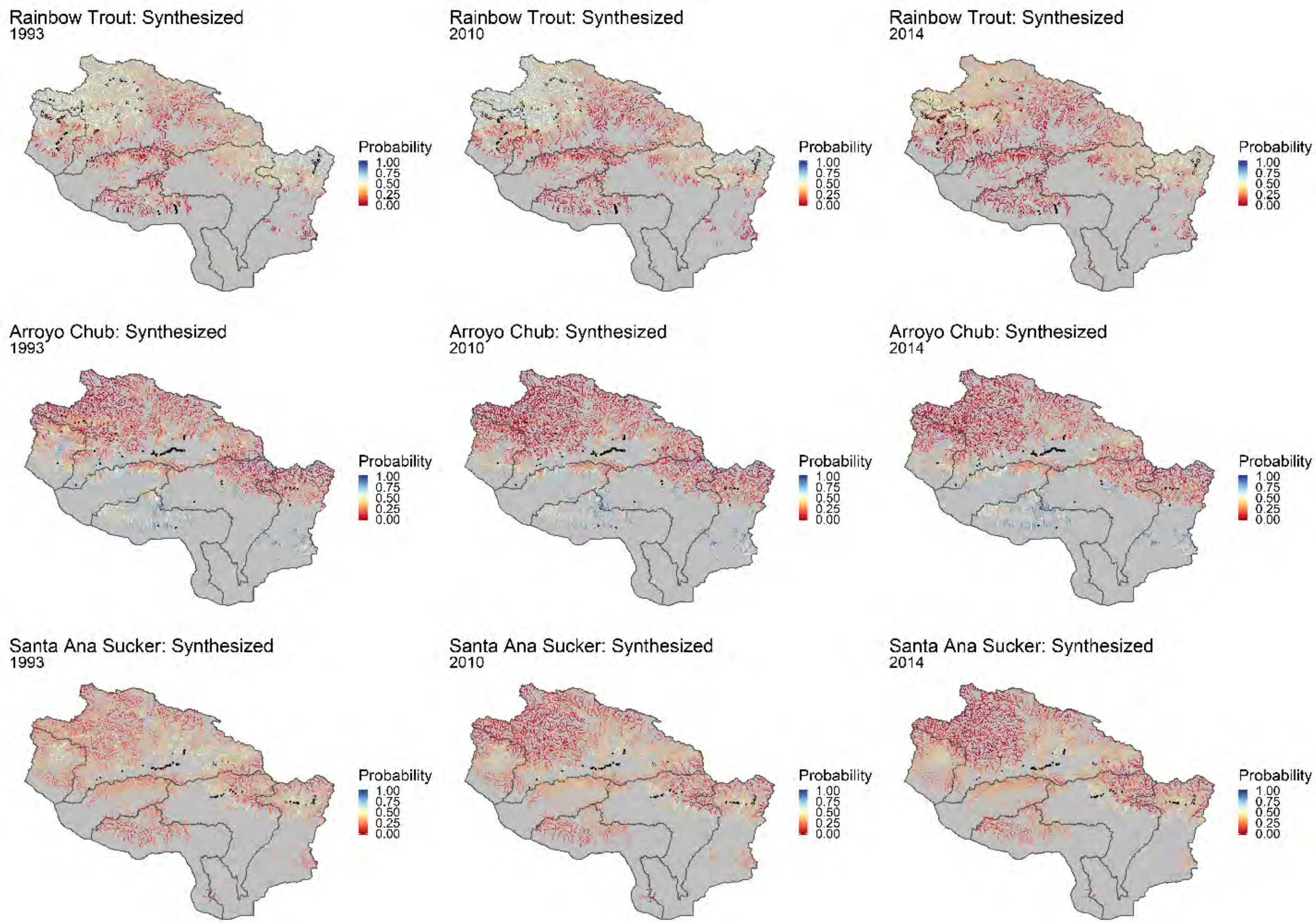


Figure 9: Probability distributions of the six focal species for years 1993 (wet year), 2010 (moderate year), and 2014 (drought year). Blue is a probability of 1, and red is a probability of 0. The black points in each map represent the locations where the species has been observed since 1981. Note that the species observation points are not necessarily the same year as the prediction map, but include all baseline observation years as a reference.

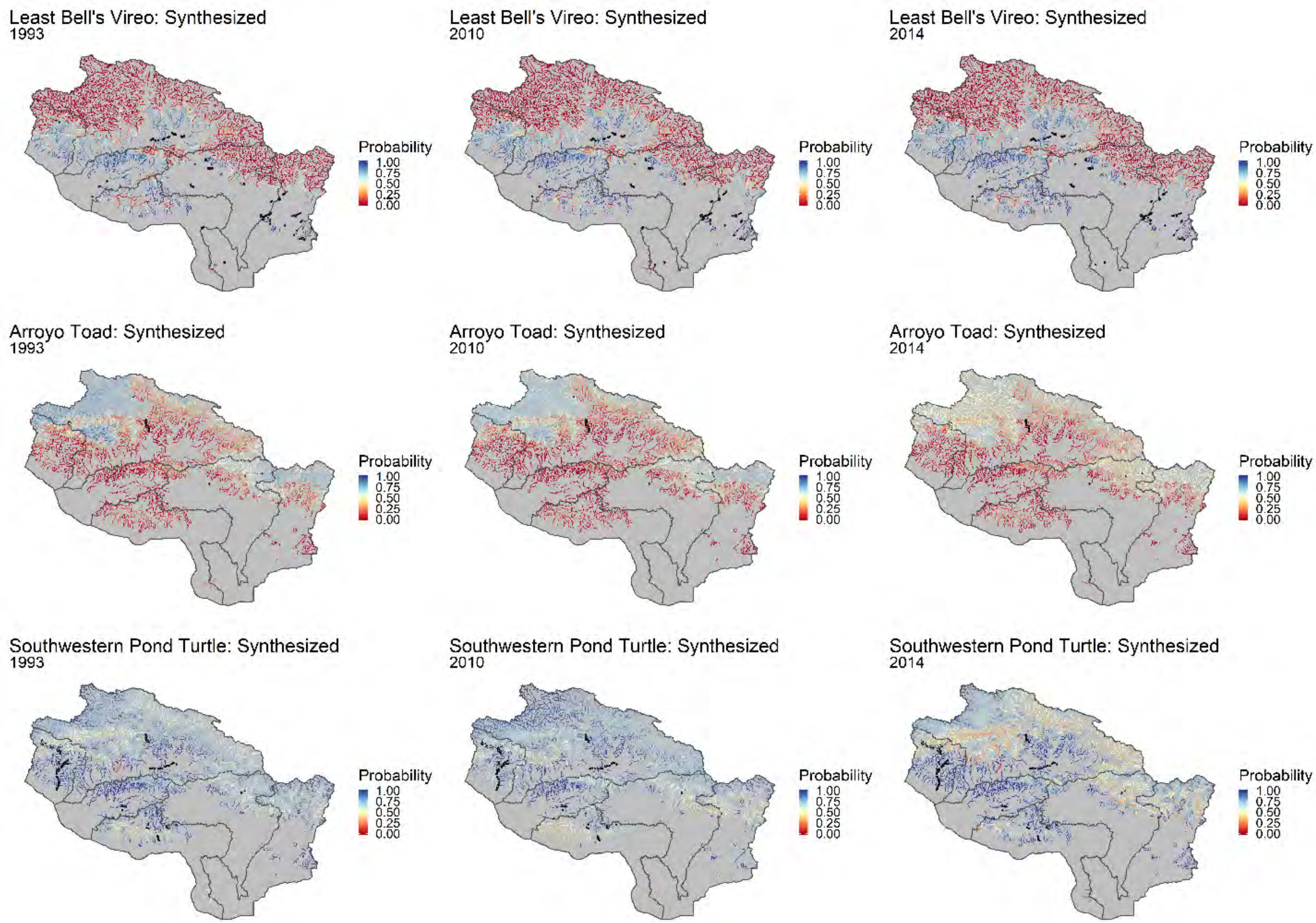


Figure 9: (*continued*)

Future Species Distribution Modeling

This analysis explored the shift in habitat suitability for native and sensitive species in future years, 2040 (dry year) and 2100 (moderate year), under the Representative Concentration Pathway (RCP) 8.5. These years were selected because they show the near- and long-term future. More importantly, year 2040 is a dry year which provides insight into how habitat suitability will be impacted during droughts. Because our analysis did not account for extirpation, we thought it would be important to analyze the impacts of drought years and determine if any species lost substantial habitat in which case the assumption that extirpation did not occur would be invalid. The results presented are based on combined changes in precipitation and temperature. Unlike in the baseline maps, where we removed altered watersheds from our prediction domain, all watersheds are retained because we acknowledge that conditions may change in the future. It is important to understand that these results are limited to future areas that do regain their natural hydrology. Additionally, this shows where, under natural conditions, a species may occur, which has implications for restoration or conservation work.

Table 10 shows the mean probability of occurrence by watershed in the future years, Table 11 shows the regional median probability of occurrence in the baseline and future years including all of the NHD reaches, and Table 12 shows the regional median probability of occurrence in the baseline and future years including only the NHD reaches that were modeled in the baseline years. Therefore, the changing probability in Table 11 is due to the increased extent and changing climate, whereas the changing probability in Table 12 is reflective of climate change alone. Figure 11 shows the change in probability from the baseline year 2010 to the CanESM2, the more extreme climate change projection, for 2100, which are both moderate precipitation years.

The predicted extent generally decreased from the baseline years to both future years for *O. mykiss*, arroyo toad, and Southwestern pond turtle (Figure 10). The median probability of occurrence stays constant for *O. mykiss* in 2040, but in 2100 drops to the level of the dry baseline year (Table 12). Arroyo toad and Southwestern pond turtle have a reduction in range and suitability from the baseline year to 2040, and further decrease in 2100. The median predicted probability increased in the two future years, compared to the baseline years, for arroyo chub, Santa Ana sucker, and Least Bell's vireo. This expansion is a result of two factors: an expansion of habitat further up into the watershed due to climate conditions *and* the inclusion of suitable altered streams which were excluded in the baseline modeling.

Projections from the three global climate models, CanESM2, CCSM4, and MIROC5, showed similar trends across species and future years, except in year 2100 under CanESM2. The median probability for the southwestern pond turtle, in 2100, was substantially lower based on CanESM2 (0.03), than CCSM4 (0.21) or MIROC5 (0.22) (Table 11). While less extreme, the 2100 CanESM2 also showed lower probabilities for *O. mykiss* and the toad compared to the other two GCMs. These three species had baseline populations in the high elevation sub-watersheds. This could suggest that the three GCMs have similar projections in the lower areas, but that they divert from each other at higher elevations.

Future habitat suitability for *O. mykiss* is lower than the baseline wet year. In 2040, habitat suitability is similar to the baseline moderate year, and in 2100 the habitat suitability is similar to the baseline dry year. In other words, in 2100, a moderate precipitation year, the habitat suitability and range is similar to what it was in year 2014 based on MIROC5 and CanESM2, which was the third year of a historic drought, but for CCSM4 the habitat suitability in 2100 was similar to the baseline moderate year (Table 11). Maximum probabilities decreased for all GCMs and overall, there is a shift toward lower suitability (Figure 12). The distribution stays bimodal throughout each year and each GCM which suggests a clear division between suitable and unsuitable habitat. The regions which appear to remain suitable are in the upper San Gabriel and the upper Santa Clara sub-watershed (Figure 10). The probability of occurrence in the upper watersheds is largely flow limited, compared to temperature limiting in the lower watersheds. Other studies have found Southern California steelhead to be critically vulnerable and coastal rainbow trout to be highly vulnerable to climate change (Moyle 2012).

Future suitable habitat for arroyo chub include the Santa Monica mountains, Santa Clara mainstem, Calleguas creek, and the lower Los Angeles and San Gabriel watersheds (Figure 10). The average probability of occurrence is high suggesting temperature and hydrologic needs are satisfied (Table 11). The chub's distribution dramatically changed from a severe left skew to a bimodal distribution (Figure 12). Across all GCMs, chub show an increased probability and range from the baseline years to 2040, and a further minor increase in 2100, likely because additional suitable streams were included in the analysis and because the upper elevation thresholds appear to be pushed back from the baseline years. There is strong agreement between GCMs, particularly regarding the predicted range. Chub are largely flow limited throughout the region. Castleberry & Cech (1986) found that chub were tolerant of increasing temperature extremes and flow variability which supports that they may be less vulnerable to climate change. Moyle (2012) found chub to be less vulnerable to climate change.

Santa Ana sucker range predicted in the future years includes the lower elevations of the Los Angeles and San Gabriel rivers, and the Santa Clara river mainstem (Figure 10). Sucker generally show low probabilities throughout the region (Table 11) – likely due to less clear divisions between high- and low-quality habitat. The bimodal distribution of probabilities for the sucker remained similar with a shift to the right (Figure 12). Although the range increases from baseline years through 2040 and 2100 across GCMs, with CanESM2 the range increases to include the Calleguas creek watershed and the overall suitability's are higher. The increase in range and suitability is likely because additional suitable streams were included in the future analysis and because the upper elevation thresholds appear to be pushed back from the baseline years. Sucker are limited by temperature in the lower watersheds, and by flow in the upper watersheds. Greenfield, Ross, & Deckert (1970) found that sucker repopulated in a single breeding season following severe flooding in 1969 which suggests their ability to withstand and recolonize after flooding may help them adapt to more extreme future conditions. Moyle (2012) found sucker to be highly vulnerable to climate change.

The future range of arroyo toad decreases substantially from the baseline years. The suitable habitat in future years is approximately limited to upper tributaries of Sespe and Piru creeks, the upper tributaries of the different forks of the San Gabriel river, and a small area in the Santa Paul creek watershed (Figure 10). The median probability of occurrence drops from 0.28 (baseline wet year) to 0.13 (MIROC5, 2040) to 0.05 (MIROC5, 2100) (Table 11). There is agreement among GCMs in the direction and the magnitude of the habitat suitably change. From looking at the probability distribution, in the baseline years there is a subset of stream reaches that are suitable and all the rest of the reaches are not suitable (Figure 12). In the future years this subset of suitable reaches almost goes away entirely. The extent is pushed to higher watersheds and no additional areas become suitable which explains the decrease in range. Temperature is the limiting factor throughout the region, which as discussed above, may be an artifact of the high elevation breeding in this region of the arroyo toad range.

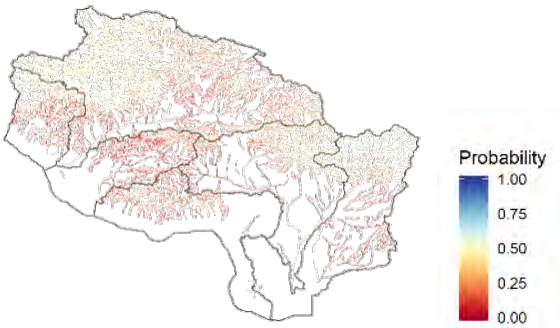
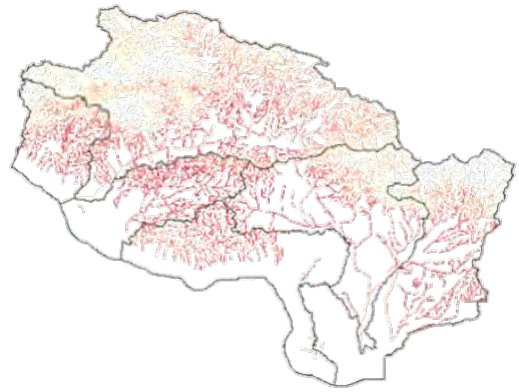
Least Bell’s vireo range included the Santa Monica Mountains, Callaguas Creek, and the low to mid elevation regions of the Ventura river, Santa Clara river, Los Angeles river, and San Gabriel river (Figure 10), which was consistent, but expanded, from the baseline years because the altered stream habitat included in the future years support breeding pairs, and suitability in the unaltered stream habitat was pushed to include higher elevations. With high agreement across GCMs, the median probability of occurrence increased dramatically in 2040 and increased moderately in 2100 (Table 11). The distribution in the baseline years shows most reaches as being totally unsuitable, and a small subset being suitable (Figure 12). In the future years, unsuitable reaches transition to highly and moderately suitable reaches. Compared to the other species, vireo maintain a high probability of occurrence, so they do not appear to be a species of concern with climate change, but rather the other stressors that have been identified in the literature such as cowbird parasitism and habitat loss (Fish and Wildlife Service 1998).

Southwestern pond turtle showed a substantial decrease in habitat extent from baseline years to 2040, and then from 2040 to 2100 (Table 11). The most extreme decrease was year 2100, based on CanESM2, where the extent decreased to 0.03, down from approximately 0.79 in the baseline years. The distribution transitions from left skewed in the baseline years with a majority reaches above a probability of 0.7, to a mostly even distribution in 2040, and ultimately to a right skew in 2100 (Figure 12). The other two GCMs showed less severe, but still large, decreases in habitat suitability and range. The largest area of watershed that remains suitable is in the Santa Monica Mountains (Figure 10). Isolated areas throughout the other five watersheds also remain suitable. The probability of occurrence is temperature limited throughout the region. In the baseline analysis of western pond turtle, it appeared climate was not a limiting factor due to the similar distribution from 1993 through 2014. However, with the analysis of future years we do see a steep decline in habitat extent. This could be because these species have long life spans compared to the other five species, so the interannual variation of the baseline years did not impact the population too much. However, longer climatic trends may be important and climate change may ultimately be an important variable to consider.

Table 10: Mean probability of occurrence by watershed in the future years. This includes all reaches, i.e., the currently altered ones are included.

Watershed	GCM	Year	*O. mykiss*	Arroyo chub	Santa Ana sucker	Arroyo toad	Least Bell's vireo	SW pond turtle
Ventura River	CanESM2	2040	0.32	0.47	0.34	0.13	0.48	0.47
		2100	0.22	0.50	0.44	0.05	0.51	0.11
	CCSM4	2040	0.35	0.41	0.27	0.16	0.47	0.62
		2100	0.29	0.42	0.33	0.11	0.49	0.36
	Miroc5	2040	0.33	0.46	0.32	0.13	0.49	0.53
		2100	0.28	0.46	0.35	0.09	0.52	0.35
Santa Clara River	CanESM2	2040	0.37	0.40	0.31	0.33	0.34	0.43
		2100	0.32	0.42	0.35	0.16	0.41	0.07
	CCSM4	2040	0.35	0.33	0.23	0.35	0.33	0.60
		2100	0.35	0.35	0.29	0.26	0.38	0.25
	Miroc5	2040	0.35	0.39	0.30	0.32	0.35	0.48
		2100	0.32	0.38	0.31	0.22	0.41	0.25
Calleguas Creek	CanESM2	2040	0.17	0.62	0.37	0.01	0.85	0.60
		2100	0.09	0.65	0.59	0.00	0.81	0.08
	CCSM4	2040	0.17	0.56	0.30	0.01	0.88	0.78
		2100	0.14	0.61	0.45	0.00	0.86	0.40
	Miroc5	2040	0.16	0.61	0.35	0.01	0.88	0.67
		2100	0.13	0.64	0.45	0.00	0.89	0.39
Santa Monica Bay WMA	CanESM2	2040	0.21	0.60	0.25	0.02	0.90	0.86
		2100	0.14	0.66	0.50	0.00	0.85	0.31
	CCSM4	2040	0.19	0.57	0.19	0.04	0.91	0.93
		2100	0.19	0.63	0.32	0.01	0.90	0.72
	Miroc5	2040	0.18	0.59	0.22	0.03	0.92	0.89
		2100	0.13	0.67	0.33	0.01	0.94	0.69
Los Angeles River	CanESM2	2040	0.32	0.51	0.34	0.25	0.43	0.43
		2100	0.27	0.54	0.42	0.11	0.50	0.06
	CCSM4	2040	0.30	0.47	0.27	0.29	0.42	0.63
		2100	0.29	0.50	0.35	0.19	0.47	0.26

	Miroc5	2040	0.29	0.49	0.33	0.25	0.44	0.49
		2100	0.25	0.50	0.37	0.17	0.50	0.26
San Gabriel River	CanESM2	2040	0.37	0.49	0.35	0.29	0.42	0.47
		2100	0.31	0.52	0.45	0.20	0.44	0.11
	CCSM4	2040	0.37	0.45	0.30	0.33	0.41	0.66
		2100	0.34	0.48	0.40	0.25	0.45	0.31
	Miroc5	2040	0.36	0.48	0.34	0.30	0.43	0.53
		2100	0.32	0.50	0.40	0.24	0.47	0.32

2040	2100
O. mykiss	
CanESM2	
	
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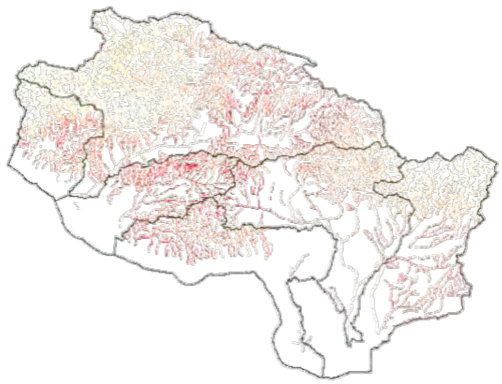	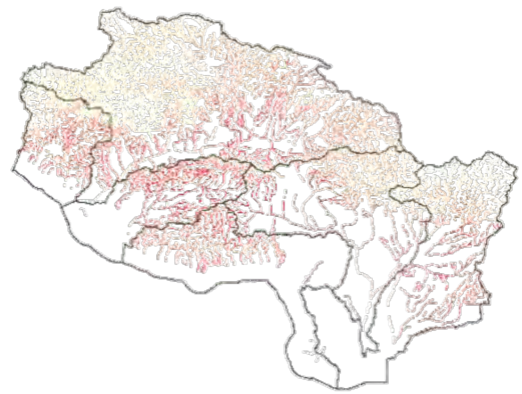
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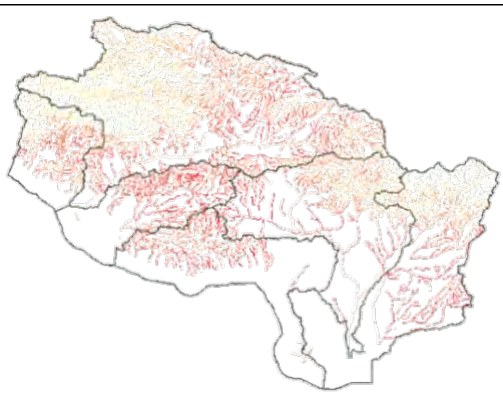
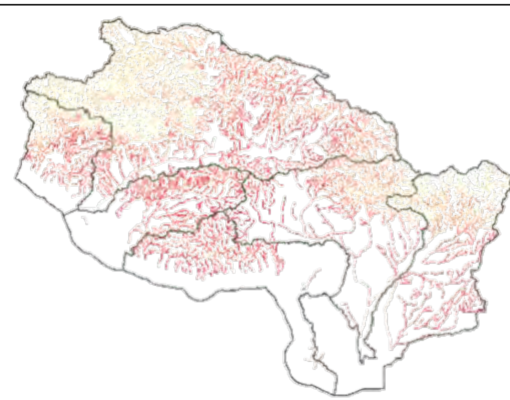
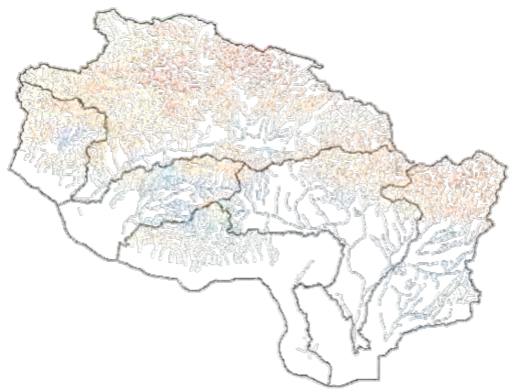
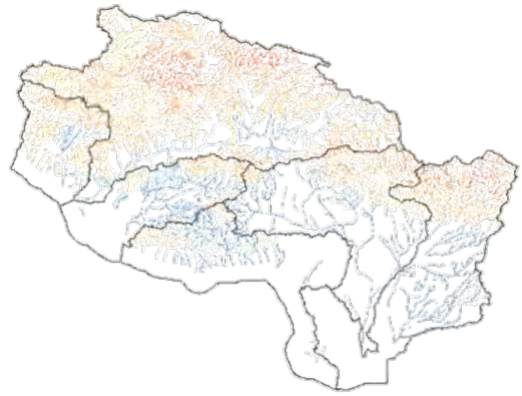
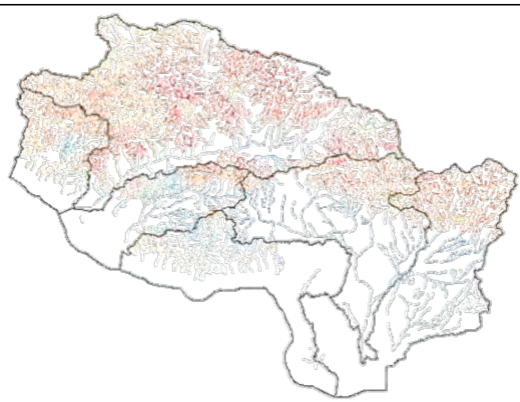
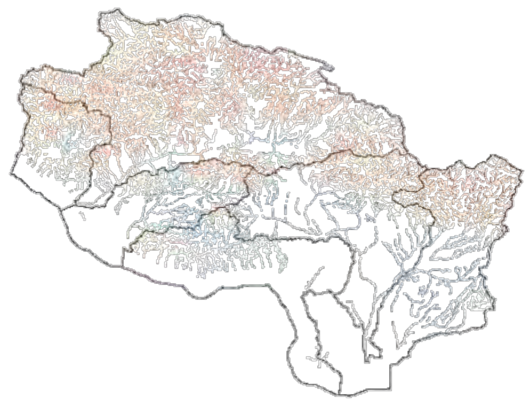
	

2040	2100
Arroyo Chub	
CanESM2	
	
CCSM4	
	
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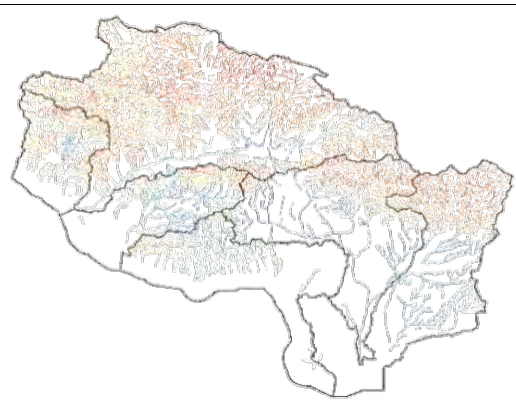
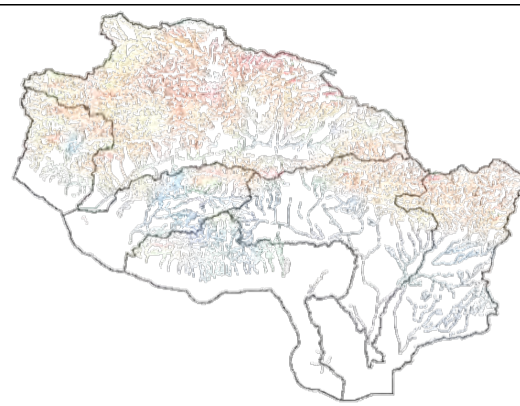
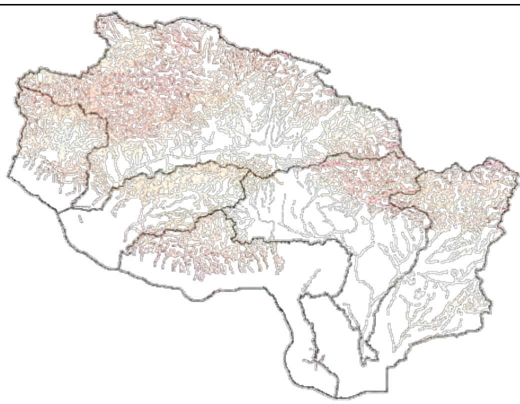
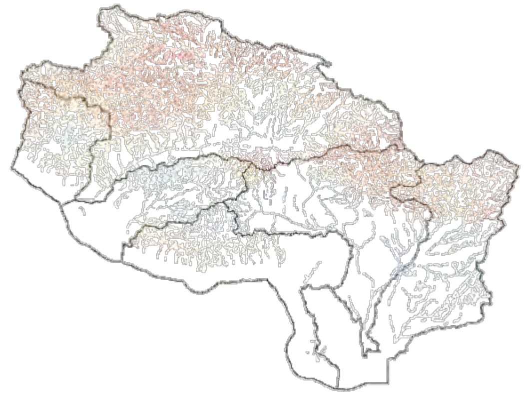
	

Santa Ana Sucker	
2040	2100
CanESM2	
	
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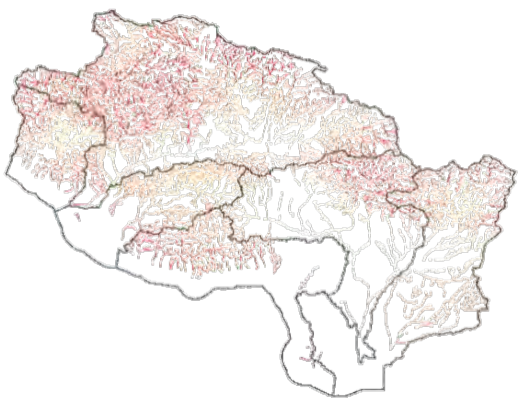	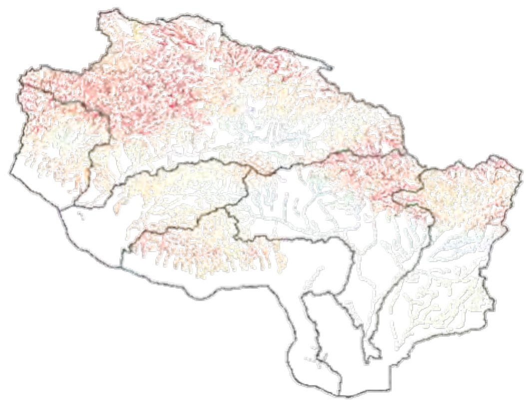
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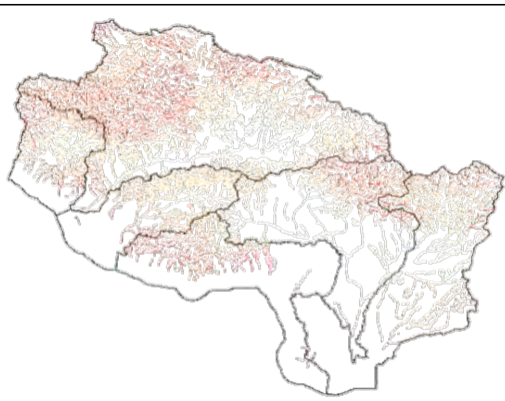	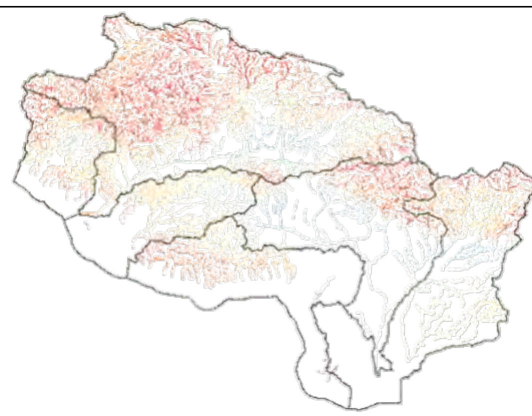

Arroyo Toad	
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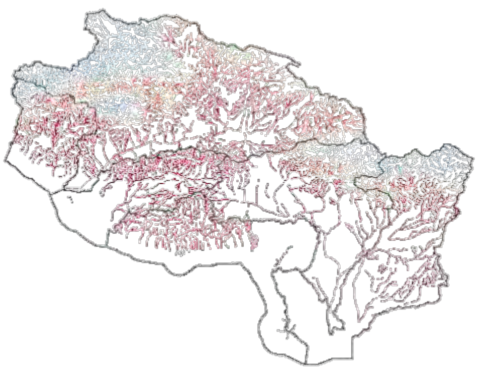
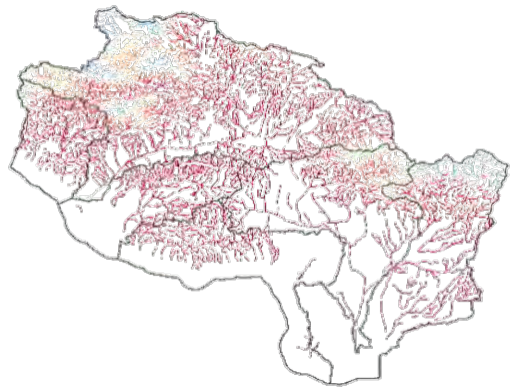
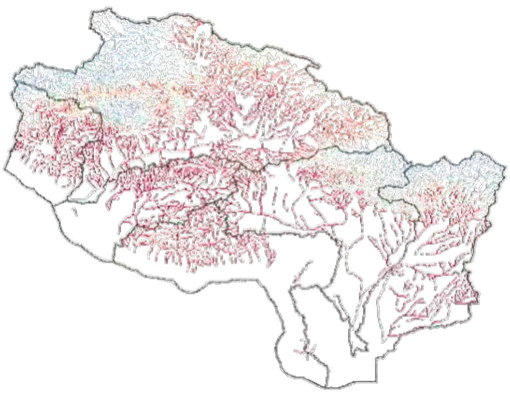
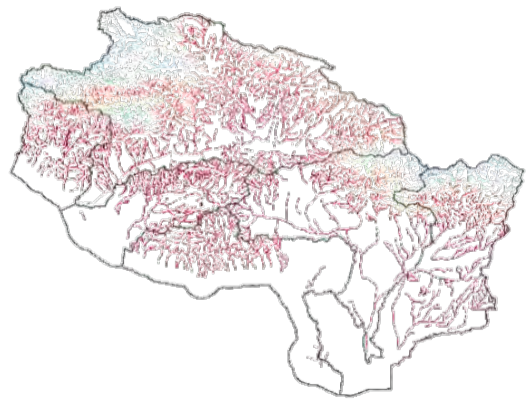
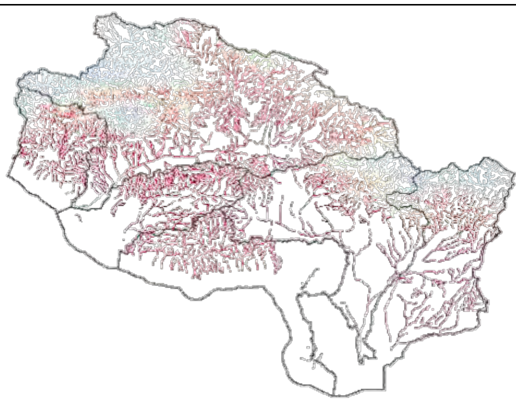
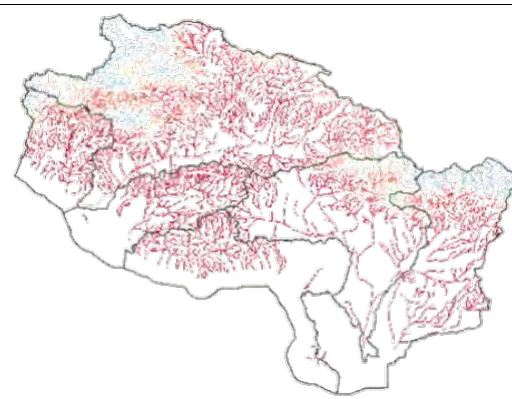
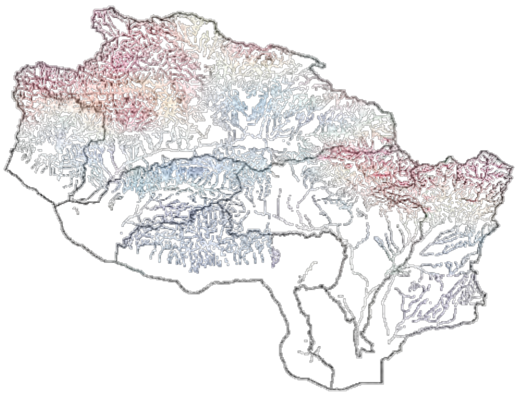
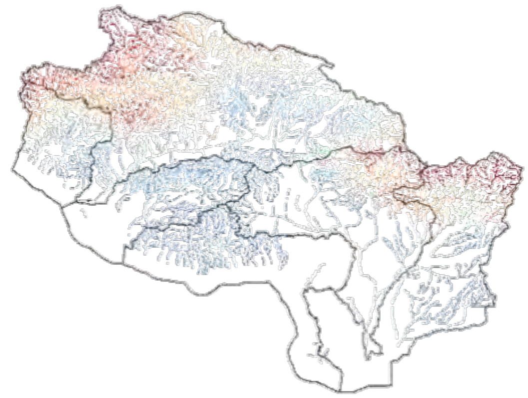
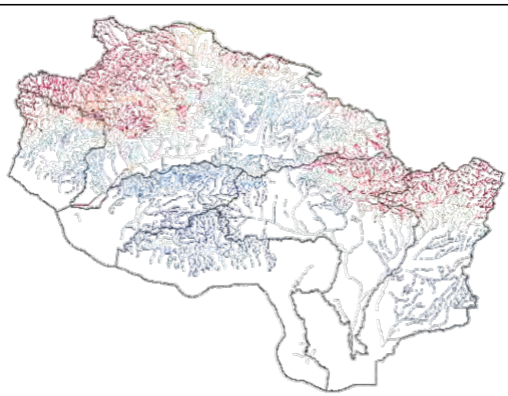
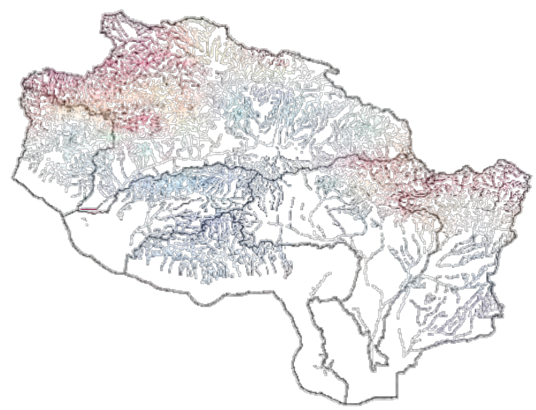
CanESM2	
	
CCSM4	
	
MIROC5	
	

Least Bell's Vireo	
2040	2100
CanESM2	
	
CCSM4	
	
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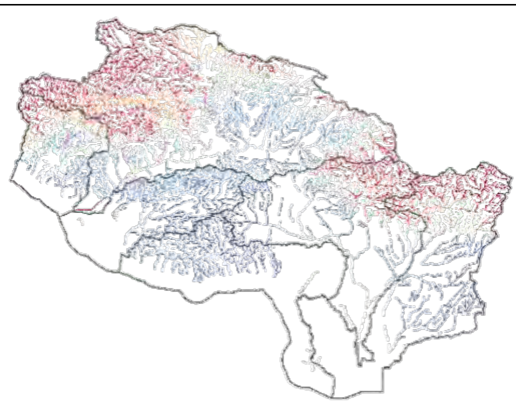
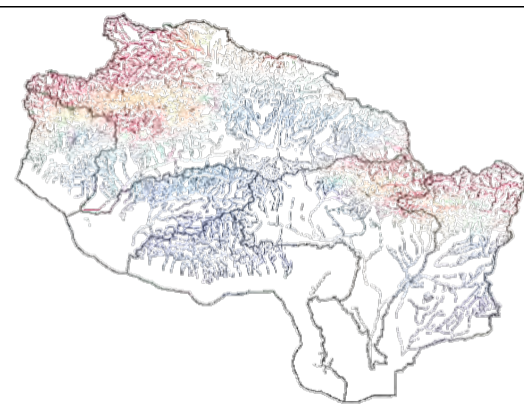
	

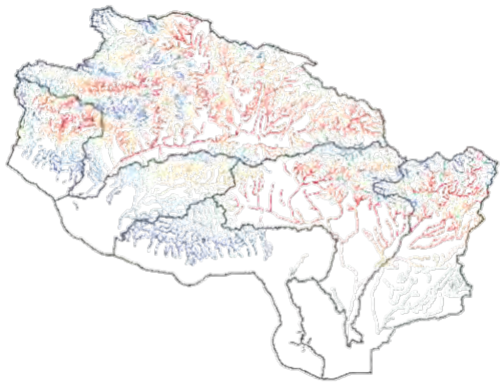
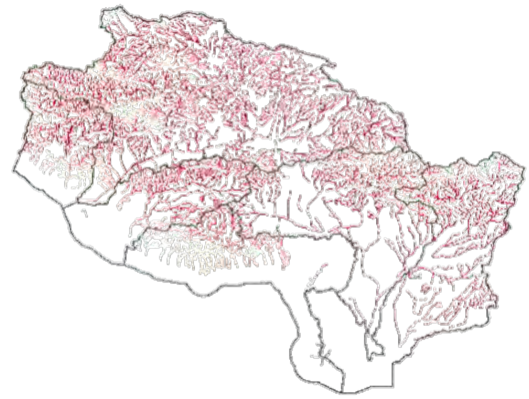
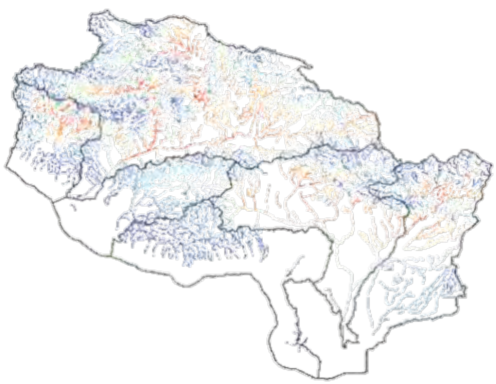
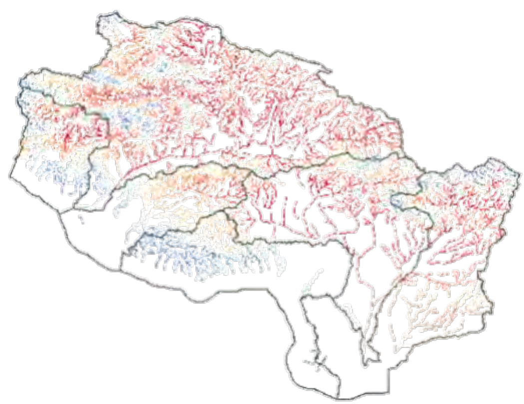
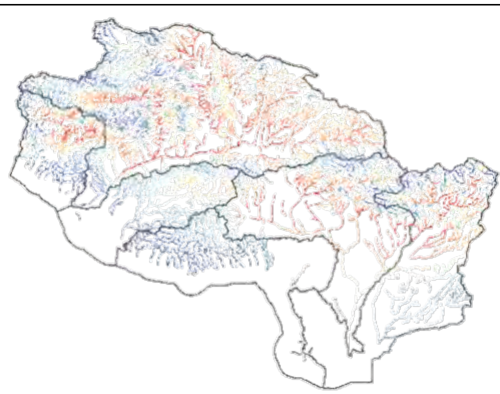
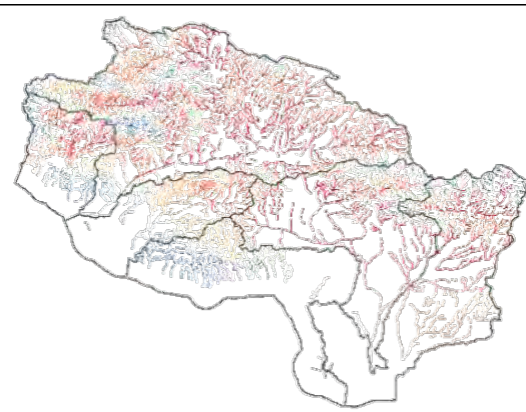
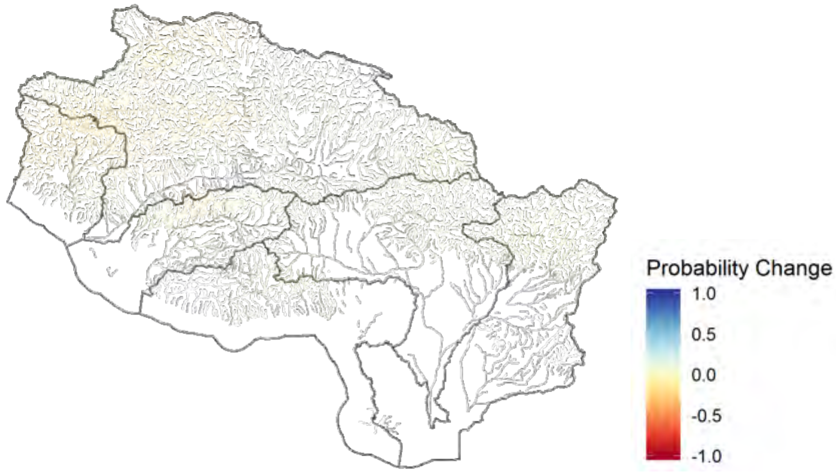
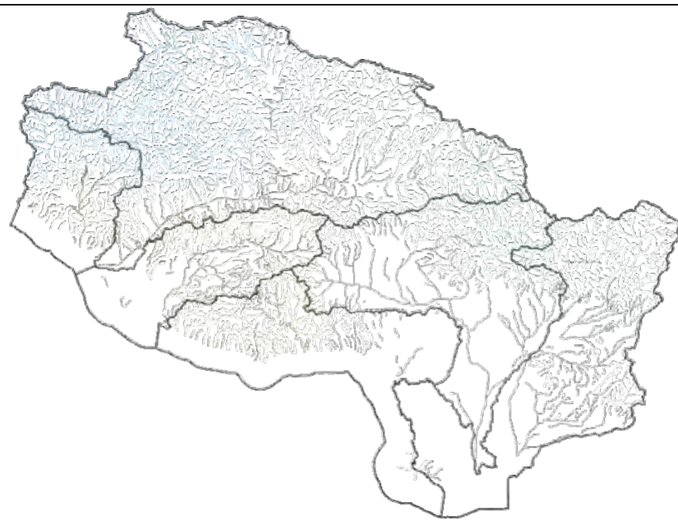
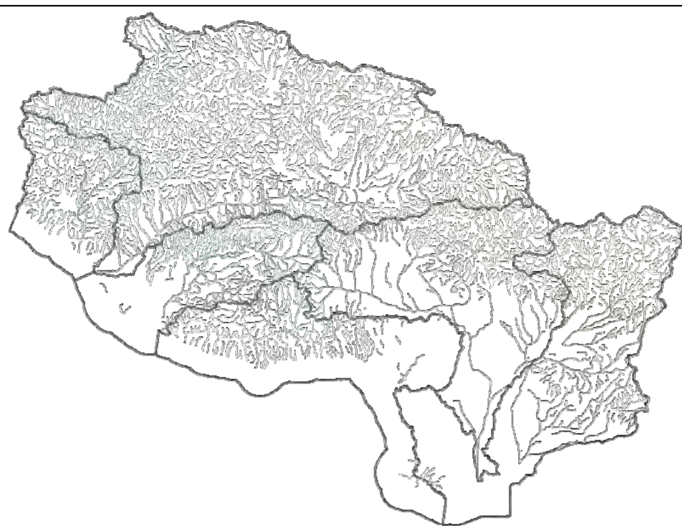
Southwestern Pond Turtle	
2040	2100
CanESM2	
	
CCSM4	
	
MIROC5	
	

Figure 10: Maps showing the predicted probability of occurrences for the six species in two future years, based on three different global climate models. Red is probability = 0 and blue is probability = 1.

Species	Change in probability map
O. mykiss	
Arroyo Chub	
Santa Ana Sucker	

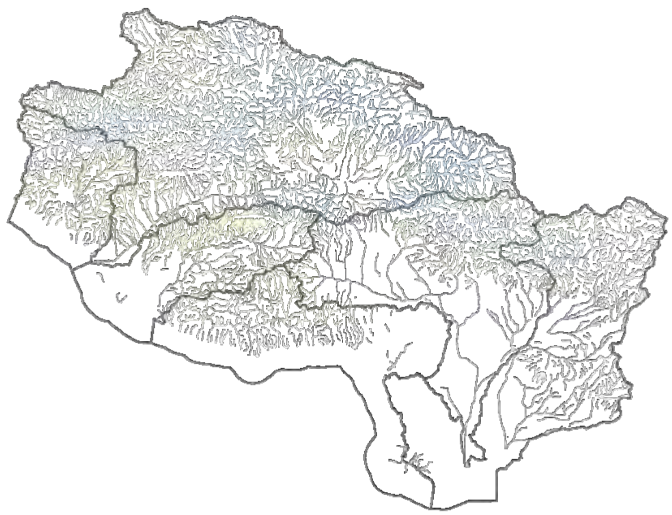
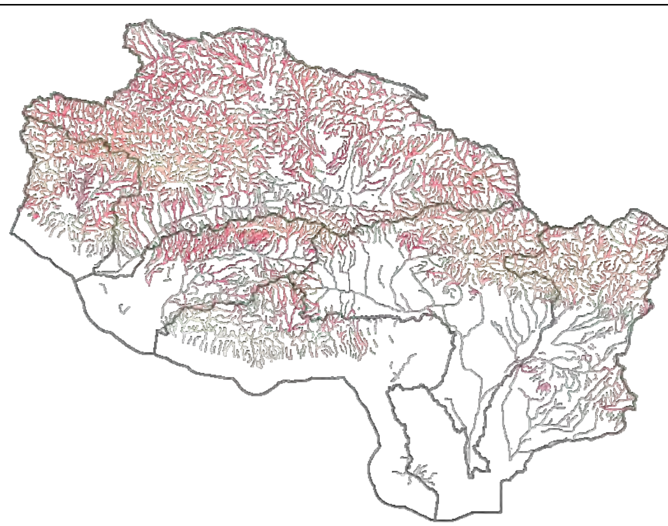
Arroyo Toad	
Least Bell's Vireo	
SW Pond Turtle	

Figure 11: Maps showing the change in probability from baseline year, 2010, through future year, 2100, based on CanESM2. The legend is the same for each map, range -1.0 to +1.0.

Table 11: The median probability of occurrence for each species in the three baseline years (1993, 2010, and 2014) and the two future years 2040 and 2100, for the three GCMs. The highest value(s) of all the years shown is bolded. The future years include all NHD reaches, so the change in probability is due to both the changing climate, and the addition of stream reaches.

Year	GCM	*O. mykiss*	Arroyo Chub	Santa Ana Sucker	Arroyo Toad	Least Bell's Vireo	SW Pond Turtle
1993		**0.38**	**0.16**	**0.22**	0.28	0.004	**0.79**
2010	baseline	0.34	0.09	0.18	0.23	0.003	**0.79**
2014		0.25	0.11	0.16	**0.35**	**0.01**	0.70
	CanESM2	**0.33**	**0.43**	**0.31**	0.09	0.48	0.46
2040	CCSM4	**0.33**	0.35	0.25	**0.13**	0.44	**0.70**
	MIROC5	0.31	0.40	**0.31**	0.10	**0.49**	0.55
	CanESM2	0.24	**0.45**	**0.38**	0.01	0.52	0.03
2100	CCSM4	**0.30**	0.36	0.33	**0.05**	0.53	0.21
	MIROC5	0.26	0.42	0.34	0.04	**0.55**	**0.22**

Table 12: The median probability of occurrence for each species in the three baseline years (1993, 2010, and 2014) and the two future years 2040 and 2100, for the three GCMs. The highest value(s) of all the years shown is bolded. The future years include only the unaltered NHD reaches that were included in the baseline modeling, so the change in probability is due to the changing climate alone.

Year	GCM	*O. mykiss*	Arroyo Chub	Santa Ana Sucker	Arroyo Toad	Least Bell's Vireo	SW Pond Turtle
1993		**0.38**	**0.16**	**0.22**	0.28	0.004	**0.79**
2010	baseline	0.34	0.09	0.18	0.23	0.003	**0.79**
2014		0.25	0.11	0.16	**0.35**	**0.01**	0.70
	CanESM2	**0.35**	**0.39**	**0.29**	0.13	**0.39**	0.48
2040	CCSM4	0.34	0.32	0.22	**0.17**	0.34	**0.71**
	MIROC5	0.32	0.37	0.28	0.13	0.37	0.56
	CanESM2	0.27	**0.41**	**0.36**	0.02	0.44	0.03
2100	CCSM4	**0.33**	0.33	0.29	**0.07**	0.43	0.23
	MIROC5	0.28	0.38	0.30	0.05	**0.48**	**0.24**

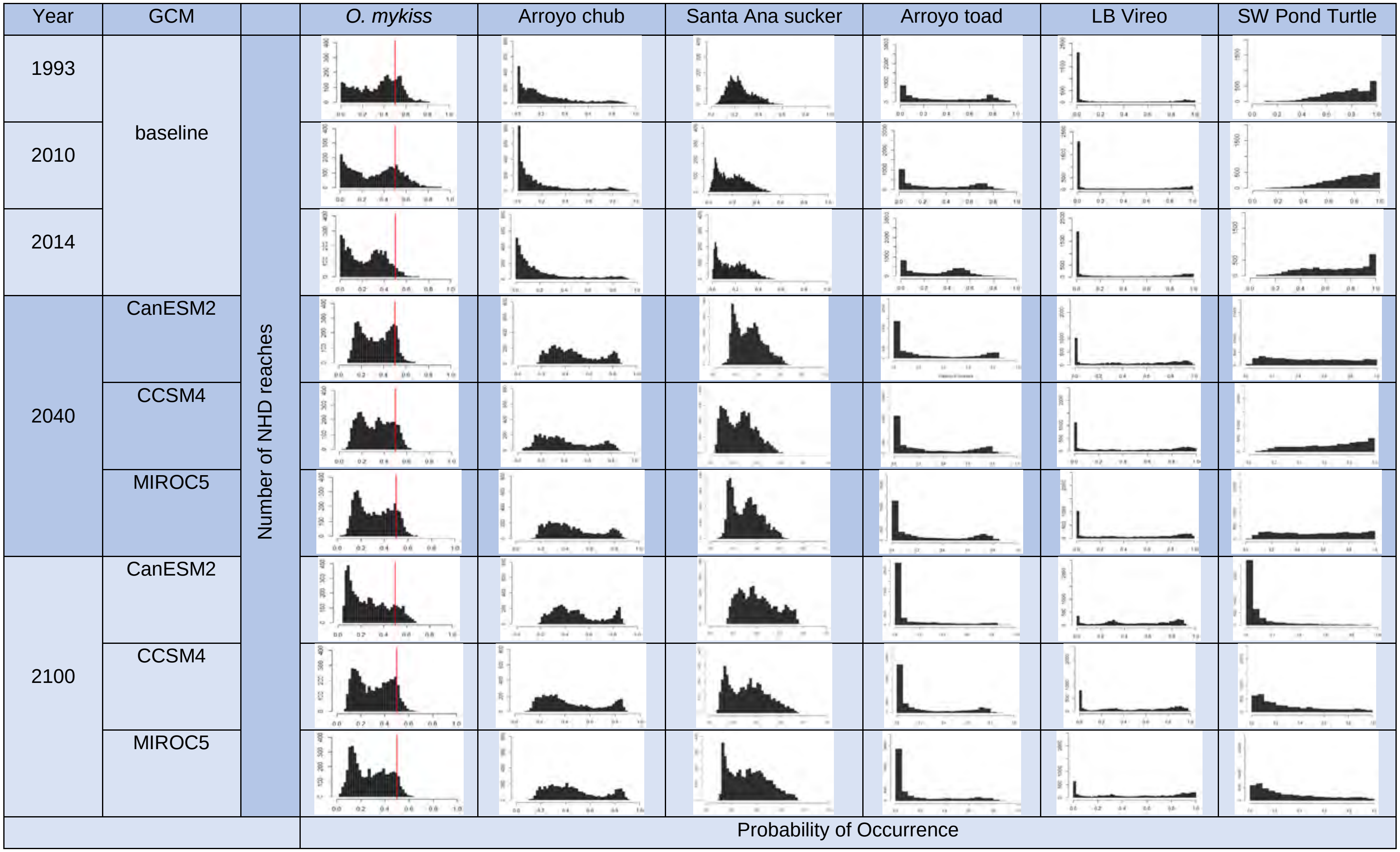


Figure 12: Histograms showing the probability distribution for the NHD reaches. The x-axis is the same for all graphs (0-1). The y-axis is the same for all histograms of a certain species so trends can be observed, but it varies between species. A red reference line is given for O. mykiss at 0.5 to help see the leftward shift.

Temperature and Streamflow Trends

Changes in flow metrics and stream temperature can help explain the differences in species distributions presented in the previous section. This section reports how selected stream temperature and stream flow metrics deviate from baseline conditions for each GCM – additional metrics are shown in the figures from those discussed in the text. We use 2010 as the baseline year because it is a moderate precipitation year, and 2100 as a future year because it is also a moderate precipitation year.

The three main temperature metrics, maximum 7-day maximum, maximum 7-day average, and the minimum 7-day minimum all increased from baseline for all streams across the region, but the magnitude of increase deviated between the three GCMs (Figure 13). There is regional consistency in that all the NHD stream reaches increased their stream temperature, i.e. no stream temperatures decreased. The maximum and average stream temperatures increase the most based on CanESM2, and almost double the increase compared to CCSM4 and MIROC5. The minimum temperatures increase more based on MIROC5, followed by CanESM2, and then CCSM4.

We see similar temperature trends, averaged across the major watersheds, of an increase in 2-4°C from baseline years (regardless of wet, dry, or moderate) to 2100 (Table 12). The ranking of watersheds in terms of the temperature metric stays generally consistent into the future years. For example, in the baseline years, Calleguas Creek has the highest median maximum 7-day maximum temperature and it has the highest in the future years as well. This suggests the watersheds are responding to climate change similarly regarding temperature changes and getting warmer. Figure 16 show the distribution of temperature metrics, and how they change from a moderate baseline year (2010) to a moderate future year (2100). However, at the sub-watershed scale, we see greater warming occurring in the high elevation regions of each major watershed, although these high elevation areas do maintain temperatures below 30°C (Figure 17).

The flow metrics for the stream reaches trended in a similar direction (positively or negatively) from the baseline year, but the magnitudes of deviation depended on the GCM. There was less consistency in the flow metrics than the temperature metrics because certain streams increase, and others decrease in value (Figure 14). Distribution of changes from the baseline year were relatively similar across GCMs, but CanESM2 and CCSM4 were more similar and showed greater deviation from the baseline, whereas MIROC5 generally showed less change from the baseline. There was agreement among GCMs that the hydroperiod decreases for about 75% of streams and increases for approximately 25% of streams, and the distribution across GCMs is relatively consistent. The number of storm events increases for most of the streams in the region, but the distribution is different between GCMs. The increase is greater for CanESM2 and CCSM4, which have an increase of approximately 1.5 storms, than MIROC5, which has an increase of approximately 0.5 storms. Despite the increase in the number of storm events, the duration of the year with low flow generally increases across the region and is relatively consistent across GCMs. For CanESM2 and CCSM4, approximately 75% of streams have an increase in low flow duration, and under MIROC5, it appears that a little over half of the region has increasing low flow duration and the remainder has decreasing low flow duration. The 99th percentile flow increases for all streams in the region, across GCMs, except for a few outliers. The greatest increase in 99th percentile flow is CanESM2, followed by MIROC5, and lastly

CCSM4. Storm flow recessions get more rapid across most stream reaches for CanESM2 and CCSM4, but for MIROC5 the recessions change very little from baseline.

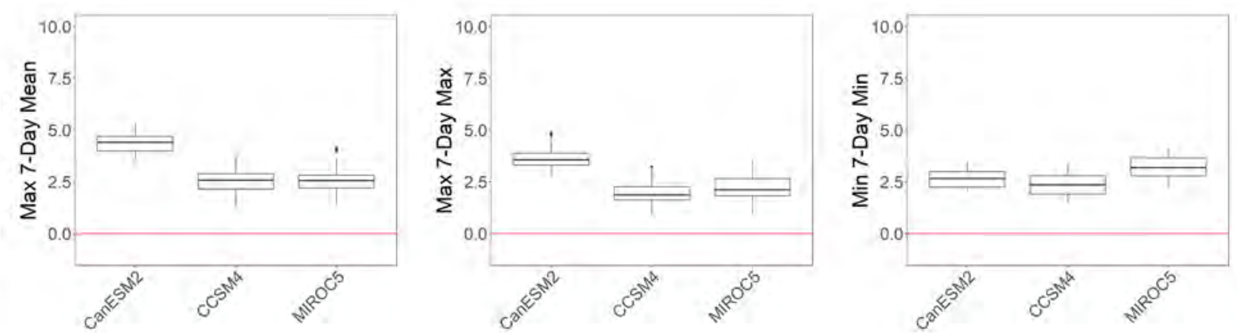


Figure 13: The change in temperature metrics from baseline year 2010, to future year, 2100, for the NHD stream reaches (0 indicates no change), for each GCM. The y-axis shows the change in temperature (°C).

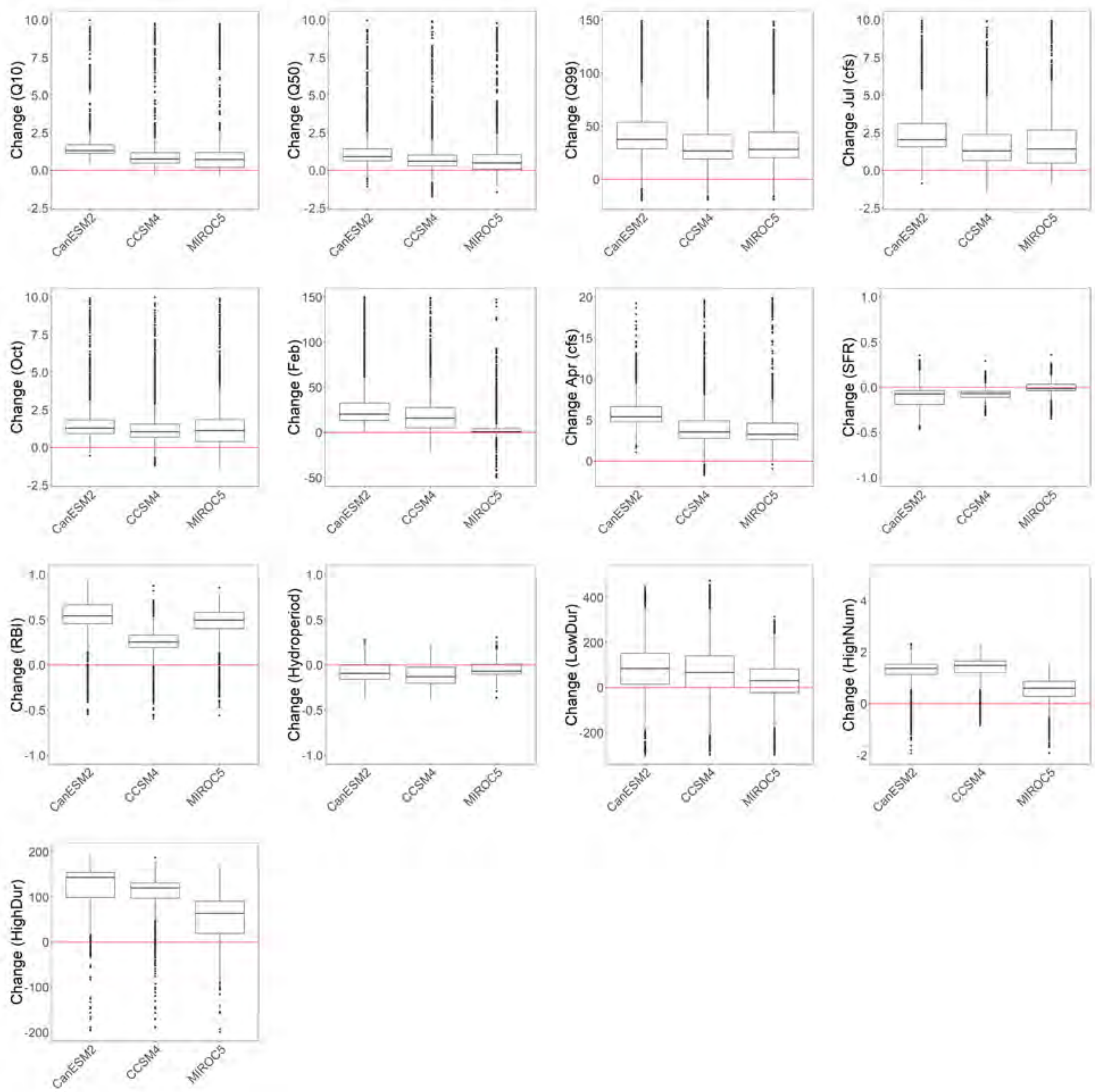


Figure 14: The change in flow metrics from baseline year, 2010, to future year, 2100, (0 indicates no change), across GCMs. The y-axis shows the change in flow metric (units vary).

While the trends in streamflow are similar across watersheds, the magnitudes of change differ (Table 13). Figure 15 shows maps of select flow metrics and how they change from a moderate baseline year (2010) to a moderate future year (2100). Flow magnitudes are similar in the mountainous watersheds that are split between coastal and high elevation area (Ventura, Santa Clara, Los Angeles, and San Gabriel) and the two coastal watersheds that do not have inland mountain ranges (Calleguas Creek and the Santa Monica Mountains), when comparing the baseline *wet* year flow, with the averaged GCM 2100 *moderate* year flow. The 99th percentile flow in the mountainous watersheds does not change from the baseline wet year. In contrast, the two coastal watersheds see between a 50% to 67% increase from the baseline wet year. This suggests that the driest watersheds will see the most drastic increase in large stream flow magnitudes, even though all areas will see higher flows (wet year flows in moderate years). Interestingly, if we compare the future moderate year to the baseline moderate year, we see approximately 40% increase in 99th percentile flows for the mountainous watersheds and only about 25% increases for the coastal watersheds. This suggests that the coastal watersheds will be getting flows larger than they have experienced in baseline years, but that while the mountainous watersheds will be experiencing higher flows, the flows will not be unprecedented. Hydroperiod also varies between the watersheds. The mountainous watersheds with high hydroperiods (more days per year of flow) see a decrease and the coastal watersheds see an increase or no change. In general, the hydroperiods for all regions in 2100, a moderate year, resemble what they were in the baseline dry year, except for the Santa Monica Mountains which sees a 50% increase in hydroperiod from the baseline dry year. Across all watersheds, the number of large events increases from the wet baseline year to 2100, more so in the coastal watersheds, suggesting that future moderate years will have more storms than baseline wet years.

Table 13: Median values of selected stream flow metrics for the baseline years and future moderate year, 2100, (bolded) by watershed for each GCM.

Year	Watershed	GCM	Q10	Q50	Q99	Jul	Oct	Feb	Apr	SFR	RBI	Hydroperiod	LowDur	HighNum	HighDur
1993	Calleguas Creek	B_Wet	0.22	0.42	26.05	0.56	0.45	1.87	1.07	-0.36	0.40	0.37	384	2.76	25
2010		B_Mod	0.16	0.35	10.76	0.27	0.36	0.69	0.59	-0.36	0.39	0.31	487	2.49	7
2014		B_Dry	0.14	0.29	6.19	0.15	0.31	0.05	0.38	-0.33	0.34	0.27	560	1.49	2
2100		**CanESM2**	**1.32**	**1.22**	**45.79**	**1.74**	**1.44**	**13.78**	**5.67**	**-0.43**	**0.97**	**0.29**	**506**	**3.51**	**160**
2100		**CCSM4**	**0.59**	**0.80**	**34.02**	**0.85**	**1.22**	**5.34**	**3.74**	**-0.41**	**0.64**	**0.27**	**469**	**3.59**	**129**
2100		**MIROC5**	**0.26**	**0.38**	**36.12**	**0.73**	**0.69**	**1.29**	**3.42**	**-0.27**	**0.82**	**0.27**	**479**	**2.78**	**95**
1993	Los Angeles River	B_Wet	1.49	2.08	54.49	2.98	2.02	23.23	5.95	-0.07	0.28	0.73	254	0.94	61
2010		B_Mod	1.12	1.60	23.52	1.39	1.57	3.82	2.89	-0.04	0.18	0.72	356	0.86	44
2014		B_Dry	1.05	1.22	7.16	1.17	1.42	0.55	1.66	-0.03	0.03	0.63	467	0.06	25
2100		**CanESM2**	**2.84**	**2.42**	**65.28**	**3.52**	**2.92**	**23.13**	**9.86**	**-0.16**	**0.82**	**0.62**	**485**	**2.14**	**183**
2100		**CCSM4**	**2.14**	**2.13**	**50.42**	**2.76**	**2.78**	**14.57**	**8.10**	**-0.13**	**0.52**	**0.60**	**477**	**2.26**	**155**
2100		**MIROC5**	**1.96**	**2.15**	**50.91**	**2.79**	**2.78**	**2.34**	**6.86**	**-0.08**	**0.76**	**0.63**	**447**	**1.28**	**112**
1993	San Gabriel River	B_Wet	1.60	2.44	61.66	2.97	2.21	25.85	6.54	-0.06	0.40	0.79	363	1.10	188
2010		B_Mod	1.21	1.78	23.77	1.62	1.64	5.72	3.28	-0.03	0.31	0.75	525	0.75	140
2014		B_Dry	1.10	1.49	7.24	1.41	1.45	1.08	2.19	-0.03	0.04	0.71	748	0.05	124
2100		**CanESM2**	**2.45**	**2.21**	**67.93**	**3.42**	**2.85**	**25.62**	**9.08**	**-0.13**	**0.83**	**0.65**	**529**	**2.37**	**230**
2100		**CCSM4**	**1.75**	**1.97**	**49.87**	**2.84**	**2.58**	**24.16**	**6.59**	**-0.12**	**0.61**	**0.65**	**546**	**2.34**	**207**
2100		**MIROC5**	**2.11**	**2.28**	**53.15**	**2.78**	**3.01**	**4.01**	**5.51**	**-0.08**	**0.78**	**0.68**	**529**	**1.38**	**175**

1993	Santa Clara River	B_Wet	1.38	2.66	72.51	4.06	2.55	21.58	7.44	-0.12	0.28	0.80	256	1.63	36
2010		B_Mod	0.77	1.57	31.78	1.76	1.59	5.38	3.10	-0.05	0.24	0.78	387	0.92	24
2014		B_Dry	0.73	1.35	10.77	1.00	1.25	0.72	1.53	-0.05	0.05	0.76	523	0.07	15
2100		**CanESM2**	**2.30**	**2.82**	**74.14**	**4.18**	**3.11**	**25.94**	**8.60**	**-0.14**	**0.79**	**0.68**	**482**	**2.32**	**162**
2100		**CCSM4**	**1.72**	**2.48**	**67.26**	**3.69**	**2.93**	**25.45**	**6.89**	**-0.15**	**0.48**	**0.64**	**476**	**2.45**	**148**
2100		**MIROC5**	**1.77**	**2.39**	**68.91**	**3.55**	**3.04**	**6.17**	**6.90**	**-0.08**	**0.74**	**0.75**	**417**	**1.72**	**126**
1993	Santa Monica Bay WMA	B_Wet	0.18	0.31	18.85	0.19	0.36	2.24	1.01	-0.31	0.43	0.23	401	2.95	22
2010		B_Mod	0.14	0.32	9.05	0.12	0.34	0.68	0.50	-0.31	0.51	0.17	484	2.74	5
2014		B_Dry	0.11	0.24	6.11	0.09	0.25	0.31	0.32	-0.30	0.47	0.13	550	1.83	2
2100		**CanESM2**	**1.31**	**1.02**	**44.85**	**1.76**	**1.17**	**16.51**	**5.80**	**-0.44**	**0.97**	**0.26**	**504**	**3.86**	**170**
2100		**CCSM4**	**0.55**	**0.63**	**31.70**	**0.67**	**0.97**	**4.99**	**3.63**	**-0.38**	**0.78**	**0.24**	**434**	**3.84**	**140**
2100		**MIROC5**	**0.09**	**0.11**	**29.38**	**0.39**	**0.34**	**1.27**	**3.08**	**-0.26**	**0.82**	**0.21**	**459**	**3.07**	**24**
1993	Ventura River	B_Wet	1.29	2.64	87.49	4.11	2.33	21.84	8.49	-0.21	0.36	0.53	271	1.57	26
2010		B_Mod	0.82	1.56	37.97	1.65	1.48	5.47	3.42	-0.11	0.28	0.46	422	0.94	12
2014		B_Dry	0.68	1.43	14.65	0.96	1.19	0.92	1.55	-0.15	0.07	0.43	590	0.10	3
2100		**CanESM2**	**2.16**	**2.88**	**91.61**	**4.78**	**3.07**	**36.76**	**9.55**	**-0.37**	**0.84**	**0.40**	**483**	**2.37**	**164**
2100		**CCSM4**	**1.78**	**2.61**	**92.43**	**4.04**	**2.73**	**35.09**	**7.62**	**-0.27**	**0.59**	**0.38**	**486**	**2.81**	**159**
2100		**MIROC5**	**1.75**	**2.33**	**90.42**	**3.95**	**3.18**	**10.48**	**7.59**	**-0.24**	**0.80**	**0.40**	**410**	**1.90**	**86**

Table 14: Median values of stream temperature metrics for the baseline year and future moderate year, 2100, (bolded) by watershed for each GCM.

Year	Watershed	GCM	Max 7-day Mean	Max 7-day Max	Min 7-day Min	Max 7-day Rng	Max7-day Max >30
1993	Calleguas Creek	B_Wet	21.49	33.60	12.50	20.45	78
2010		B_Mod	21.96	34.43	12.60	21.05	68
2014		B_Dry	21.65	33.68	13.30	20.31	96
2100		**CanESM2**	**25.77**	**38.06**	**14.71**	**20.39**	**147**
2100		**CCSM4**	**23.79**	**36.28**	**14.31**	**20.29**	**144**
2100		**MIROC5**	**23.83**	**36.33**	**15.16**	**20.38**	**147**
1993	Los Angeles River	B_Wet	22.43	29.59	11.08	16.12	0
2010		B_Mod	22.08	30.16	11.36	16.68	7
2014		B_Dry	22.31	29.70	12.14	16.59	0
2100		**CanESM2**	**26.46**	**33.68**	**13.91**	**17.16**	**103**
2100		**CCSM4**	**24.65**	**32.08**	**13.70**	**17.12**	**55**
2100		**MIROC5**	**24.61**	**32.11**	**14.54**	**17.20**	**73**
1993	San Gabriel River	B_Wet	22.02	29.23	11.07	15.99	0
2010		B_Mod	21.81	30.17	11.77	16.74	4
2014		B_Dry	22.62	29.79	11.84	16.90	0
2100		**CanESM2**	**26.01**	**33.44**	**14.11**	**17.10**	**87**
2100		**CCSM4**	**24.32**	**31.85**	**13.90**	**17.08**	**47**
2100		**MIROC5**	**24.35**	**31.81**	**14.68**	**17.16**	**54**
1993	Santa Clara River	B_Wet	22.57	29.01	10.37	16.12	0
2010		B_Mod	22.01	29.14	9.71	16.56	0
2014		B_Dry	22.04	28.49	11.24	15.63	0
2100		**CanESM2**	**26.67**	**32.77**	**12.75**	**17.59**	**71**
2100		**CCSM4**	**24.86**	**31.19**	**12.54**	**17.56**	**35**
2100		**MIROC5**	**24.77**	**31.66**	**13.42**	**17.68**	**44**
1993	Santa Monica Bay WMA	B_Wet	20.38	32.35	12.32	19.33	52
2010		B_Mod	20.29	33.04	12.30	19.86	28
2014		B_Dry	20.77	32.56	12.86	19.44	66
2100		**CanESM2**	**24.23**	**36.43**	**14.43**	**18.88**	**147**

2100		**CCSM4**	**22.41**	**34.67**	**13.98**	**18.78**	**139**
2100		**MIROC5**	**22.53**	**34.77**	**14.80**	**18.79**	**143**
1993	Ventura River	B_Wet	22.53	31.16	12.30	17.91	31
2010		B_Mod	22.13	31.77	12.20	17.84	13
2014		B_Dry	22.30	31.30	13.01	17.71	47
2100		**CanESM2**	**26.14**	**35.34**	**14.50**	**18.54**	**130**
2100		**CCSM4**	**24.15**	**33.52**	**14.07**	**18.45**	**85**
2100		**MIROC5**	**24.24**	**33.64**	**14.91**	**18.53**	**112**

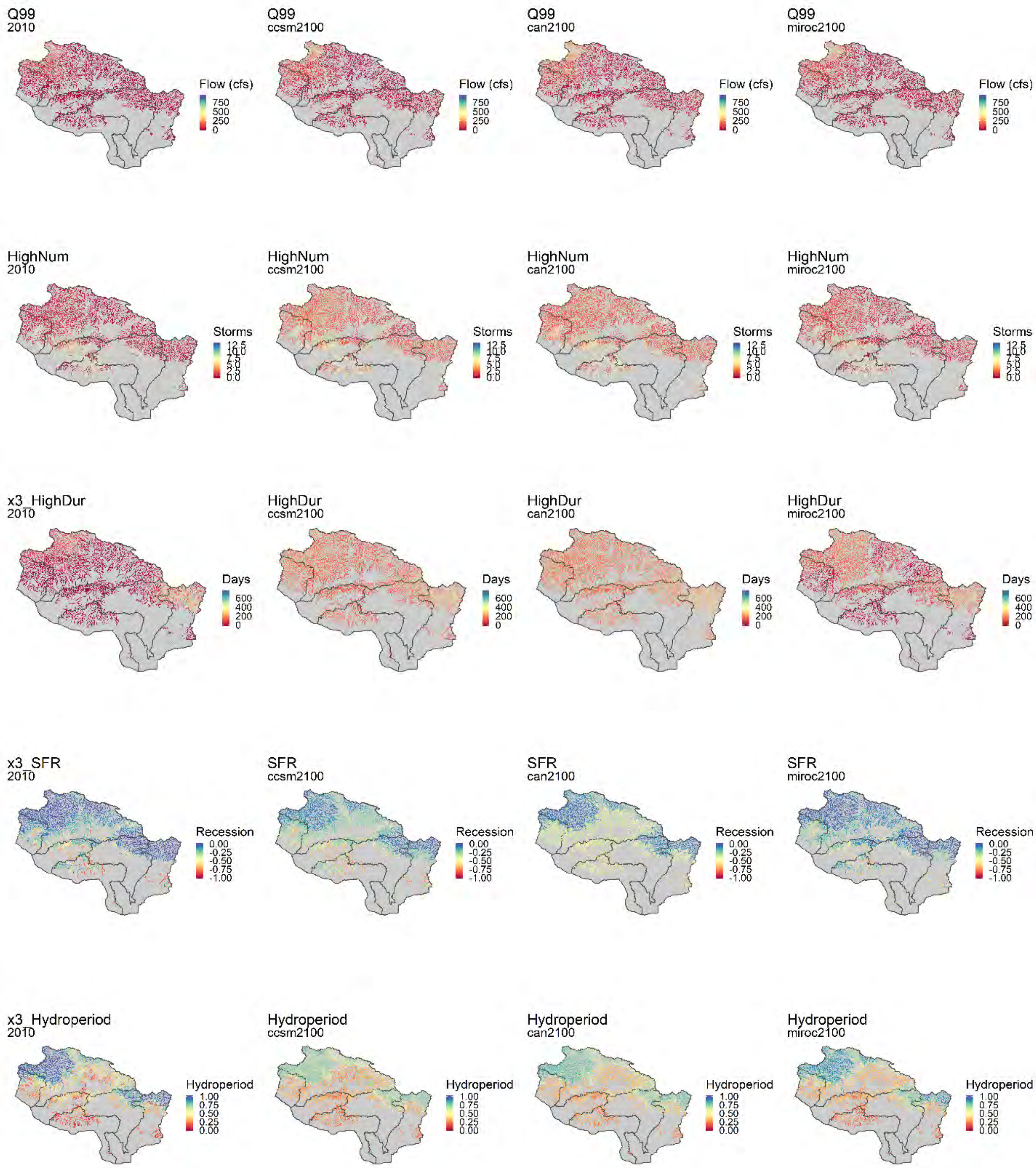


Figure 15: Flow metric values for the moderate baseline year, 2010, and the moderate future year, 2100, for each GCM: 99th percentile flow, HighNum, HighDur, SFR, and hydroperiod.

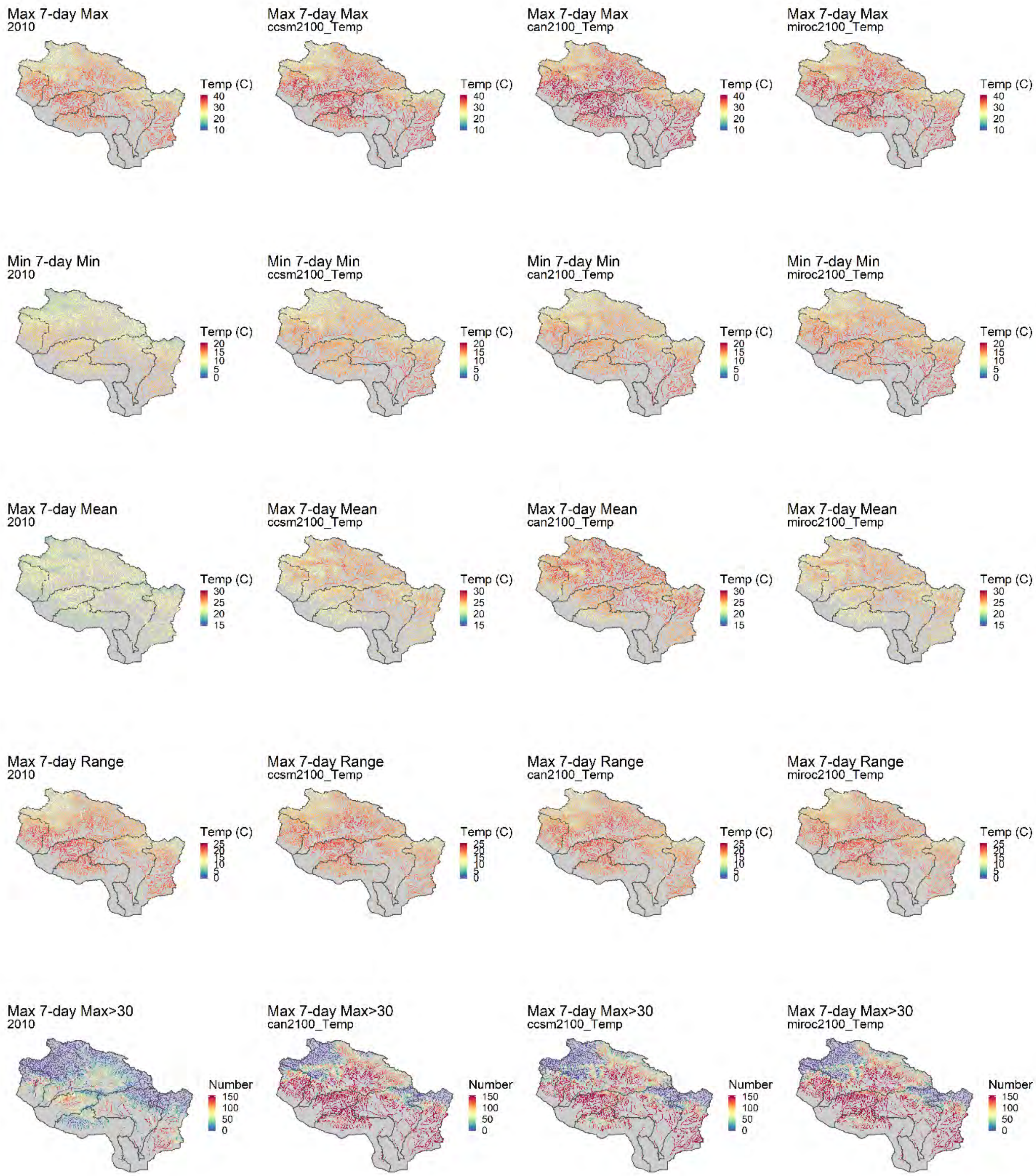


Figure 16: Temperature metrics for the moderate baseline year, 2010, and the moderate future year, 2100, for each GCM: maximum 7-day max flow, minimum 7-day min flow, maximum 7-day mean flow, maximum 7-day range, and number of maximum 7-day maximum's greater than 30°C.

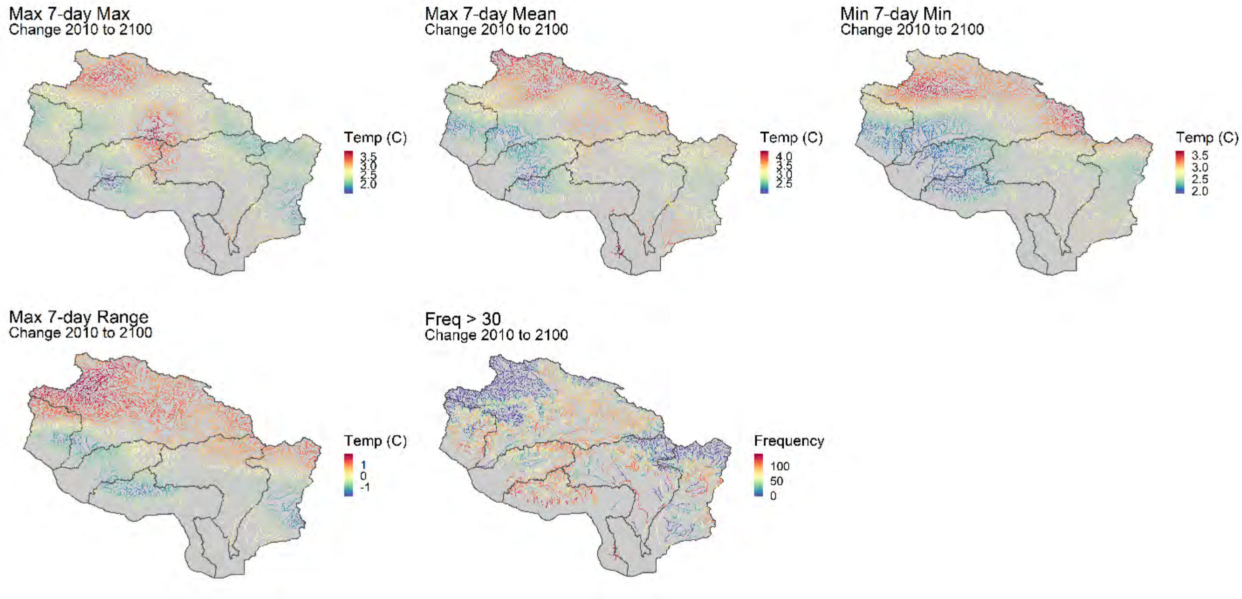


Figure 17: Change in the temperature metrics from baseline year 2010 to 2100. Change calculated as 2100 value minus 2010 value. Future year is the average of the values modeled based on the three GCMs. We see the largest change is generally occurring in the high elevation mountain regions, as opposed to the coast.

MANAGEMENT IMPLICATIONS

This analysis investigated trends in habitat suitability for six species across a relatively large region. The results delineate trends in habitat suitability, and suggestions can be made about regions to initiate monitoring, restoration, conservation, or translocation. Here, we make a few observations and recommendations for managers based on CanESM2. We selected this GCM because it was found to be the most accurate when compared to historical conditions for temperature and precipitation (Rupp et al. 2015), but also because it represented the more extreme scenario for some of the species. A habitat suitability cutoff is defined according to Table 15.

Table 15: The probability threshold used to examine changes in habitat suitability for NHD stream reaches. These thresholds were defined at the natural breaks in the frequency distributions shown in Figure 12.

Species	Probability
O. mykiss	0.3
Arroyo chub	0.6
Santa Ana sucker	0.2
Arroyo toad	0.5
Least Bell's vireo	0.5
Southwestern pond turtle	0.5

Management Recommendations

It will be important to know, for managing wildlife and habitat moving forward, how the suitable regions in the future compare to the suitable regions now. A strong region is one that either becomes suitable or maintains suitability into the future. A vulnerable region is one that is currently suitable today but becomes less suitable in the future. Table 16 shows an overview of the strong and vulnerable regions for each species. In a strong region, goals could include the following activities:

1. Assess these regions for the presence of other stressors
    a. If present, try to mitigate those stressors, or update designation
    b. E.g., passage barriers, coarse sediment scarcity, invasive species
2. If stress is low, conserve those areas
3. Intensity monitoring to track population change

In a vulnerable region, goals could include:

1. Habitat monitoring to determine other types of restoration
    a. E.g., tree planting, pool creation
2. Assisted migration plans

Depending on the limiting environmental variable, stream flow or stream temperature, management could attempt to alter the environment to maintain populations in regions that would otherwise become less suitable, although this would be a large investment depending on the scale of the project. For example, in regions where temperatures get too hot, riparian tree planting would offer shading or in regions where periods of no flow are projected to occur, pool creation or other creative solutions could be considered. Table 17 shows which species are generally flow or temperature limited in the regions where the species has a high probability of occurrence versus regions where they have a low probability of occurrence for baseline and future years.

Table 16: Strong and vulnerable regions for each species. Major watersheds are bolded.

Species	Strong regions	Vulnerable regions
O. mykiss	**San Gabriel** (Tributaries to West Fork San Gabriel and San Gabriel river, upper San Gabriel River)	**Ventura** (Upper North Fork Matilija). **Santa Clara** (Sespe, Tule, Willow, Piedra Blanca, Piru, Lockwood)
Arroyo chub	Low elevation regions in LA river and San Gabriel, Calleguas creek, Santa Monica Mountains, Santa Clara mainstem, **Ventura** (San Antonio, Ventura River Mainstem)	None
Santa Ana sucker	Low elevation regions in LA river and San Gabriel, Calleguas creek, **Ventura** (San Antonio), **Santa Monica Mountains** (Madea, Las Virgenes Creek)	None
Arroyo toad	**Santa Clara** (Upper Piru: Amargosa, middle/north Lockwood, Snowy, Alamo, Little Mutau; Upper Sespe: Piedra Blanca; headwaters Santa Paula) **San Gabriel** (headwaters Bear, Soldier and Cedar, South Fork Iron Fork, Iron Fork, headwaters San Gabriel, Prairie Fork, Fish Fork)	**Santa Clara** (Piru and Sespe mainstems and watersheds) **LA River** (Alder, Mill, Fox, West Fork Fox, headwaters Big Tujunga) **Ventura** (headwaters Matilija and Upper North Fork Matilija)
Least Bell's vireo	Santa Monica Mountains, Calleguas creek, all regions excluding the highest elevations in the remaining watersheds (Ventura, Santa Clara, Los Angeles, and San Gabriel). General expansion into higher elevations of all watershed.	None
SW pond turtle	Santa Monica Mountains	All regions except the Santa Monica mountains

Table 17: The limiting variable for species occurrence probability: streamflow, temperature, NA if probability of occurrence is very high, or both if probability of occurrence is low based on each

variable. This is an overview of the entire region and it might vary on a reach by reach basis. For the Santa Ana sucker, there was a split between limiting variables in the future low condition. High or low refers to whether it's a region where there is high probability of occurrence or low probability of occurrence.

Species	Baseline: High	Baseline: Low	Future: High	Future: Low
O. mykiss	Flow	Flow	Flow	Temperature
Arroyo chub	NA	both	NA	Flow
Santa Ana sucker	Temperature	Flow	NA	High elevation: Flow SMM: Temperature
Arroyo toad	Flow	Temperature	Flow	Temperature
Least Bell's vireo	NA	Temperature	Flow	Temperature
SW pond turtle	Temperature	NA	Temperature	Temperature

Future Monitoring Efforts

We also recommend additional support for wildlife surveys both for sensitive and non-sensitive species (i.e. preventative surveys). Overall, the mainstems of rivers and major tributaries are well surveyed, but not the smaller tributaries. Calleguas Creek was the most underrepresented watershed in the region. We found there to be a data limitation of Arroyo toad in all watersheds within the region; Santa Ana sucker in the Ventura River, Calleguas Creek, Santa Monica Mountains, eastern Santa Clara River, and the Los Angeles River; arroyo chub in the Ventura River, Calleguas Creek, Santa Monica Mountains, eastern Santa Clara River, and the Los Angeles River; southwestern pond turtle in the Santa Clara River, Calleguas Creek, Los Angeles River, and the San Gabriel River watersheds; and least Bell's vireo in the Ventura River, Calleguas Creek, Santa Monica Mountains, and the Santa Clara River. Rainbow trout/ Steelhead sampling is well distributed across the region.

Absence data is important for these types of analyses so noting when species are not observed is helpful, even if confidence is not 100%. Count and abundance data are also helpful for these types of analyses, as opposed to presence/absence data, which help differentiate locations with large populations from locations with few individuals.

Lastly, repeated surveys annually in the same location are valuable to analyze trends. Some surveys were repeated annually, such as Santa Clara river by the Freeman Diversion and the Middle Piru creek surveys, whereas most were isolated surveying efforts. This type of data allows analysis of population trends in response to environmental fluctuations.

Future Study Enhancements

Other environmental factors impact species occurrence and this study only accounted for stream flow and stream temperature. These other factors include stream velocity/grade, invasive or competitor species occurrence, habitat barriers, sediment type, and cover availability, among others. It was out of the scope of this analysis to include all these additional variables, but an interesting follow up study would include an analysis of these variables in locations where we find the future climate to the suitable. This analysis was meant to provide guidelines for entire species clusters, not just the individual species studied. However, if these other variables impact some of the species in the cluster and not the one studied, then the results of this analysis are less likely to transfer within clusters well.

This analysis was rooted entirely in species presence and absence data and therefore the completeness of this data is extremely important. A follow up analysis could be a similar study but making assumptions of presence and absence based on local knowledge to better represent the entire region, such as including absence data of arroyo toad in the Santa Monica mountains or the Ventura watershed.

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APPENDIX B

Variables used in characterizing species habitats.

Table 18: These variables were selected as the most important for grouping species based on their habitat and flow related preferences. For definitions of categories and life history, see the associated Access database.

Life History	Categories
General habitat	Main channel, backwater, riparian, wetland, variable
Foraging behavior	Dabble, dive, fly, run, stalk, swim
Vegetation preference	Aquatic, overhanging, scrub, woodland, none
Prey preference (birds only)	Fruit, seed, grain, plant, fish, bird/mammal, terrestrial invertebrate, aerial invertebrate, aquatic invertebrate, amphibian
Water velocity	Fast, medium, slow, NA
Preferred substrate	Fine, sandy/gravel, cobble, boulder, NA
Nest location	Submerged substrate, emergent vegetation, nest at the bottom of a channel, cavity within a channel, ground, tree, shrub, bank, variable, NA
Stream category	Permanent, temporary, NA
Stream depth (fish and herps only)	Shallow, average, deep
Stream temperature (fish and herps only)	Cool, warm, hot

APPENDIX C

Final clusters of species.

Table 19: Documented taxa in the Los Angeles Regional Board area that are at least partially dependent on riverine/riparian habitats such as the Great Blue heron, or fully dependent on riverine/riparian habitats such as the American dipper. Species dependence on riverine/riparian habitats, listing as threatened or endangered, and origin are all listed followed by the cluster grouping. Bolded species are those chosen as focal species, and highlighted clusters are those that are represented. Note: additional species can be added in during future iterations.

Common name	Name	Group	Sensitive	Native	Cluster
African clawed frog	*Xenopus laevis*	Amphibian			1
American bullfrog	*Lithobates catesbeianus*	Amphibian		Y	1
Baja California treefrog	*Pseudacris hypochondriaca hypochondriaca*	Amphibian		Y	1
Western spadefoot	*Spea hammondii*	Amphibian	Y	Y	1
Red-eared slider	*Trachemys scripta elegans*	Reptile			1
Snapping turtle	*Chelydra serpentina*	Reptile			1
Western painted turtle	*Chrysemys picta bellii*	Reptile			1
Fathead minnow	*Pimephales promelas*	Fish			1
Golden shiner	*Notemigonus crysoleucas*	Fish			1
Western Mosquitofish	*Gambusia affinis*	Fish			1
Red shiner	*Cyprinella lutrensis*	Fish			1
Green Sunfish	*Lepomis cyanellus*	Fish			1
Two-striped garter snake	*Thamnophis hammondii*	Reptile		Y	2
Texas spiny softshell	*Apalone spinifera emoryi*	Reptile			2
Arroyo chub	***Gila orcuttii***	**Fish**	**Y**	**Y**	**2**
Threespine stickleback	*Gasterosteus aculeatus*	Fish	Y	Y	2
California treefrog	*Pseudacris cadaverina*	Amphibian		Y	3

California toad	*Anaxyrus boreas halophilus*	Amphibian		Y	3
Western pond turtle	***Emys marmorata***	**Reptile**		Y	3
Santa Ana sucker	***Catostomus santaanae***	**Fish**	Y	Y	3
California newt	*Taricha torosa*	Amphibian	Y	Y	3
California red-legged frog	*Rana draytonii*	Amphibian	Y	Y	3
Black bullhead	*Ameiurus melas*	Fish			4
Bluegill sunfish	*Lepomis macrochirus*	Fish			4
Brown bullhead	*Ameiurus nebulosus*	Fish			4
Largemouth bass	*Micropterus salmoides*	Fish			4
Tilapia spp	*Oreochromis*	Fish			4
Yellow bullhead	*Ameiurus natalis*	Fish			4
Common carp	*Cyprinus carpio*	Fish			4
Brown trout	*Salmo trutta*	Fish			5
Channel catfish	*Ictalurus punctatus*	Fish			5
Steelhead trout/rainbow trout	***Oncorhynchus mykiss***	**Fish**	**Y**	**Y**	**5**
Santa Ana speckled dace	*Rhinichthys osculus*	Fish	Y	Y	5
Mountain yellow-legged frog	*Rana muscosa*	Amphibian	Y	Y	5
Arroyo toad	***Anaxyrus californicus***	**Amphibian**	**Y**	**Y**	**6**
California least tern	*Sterna antillarum browni*	Bird	Y	Y	7
Spotted sandpiper	*Actitis macularius*	Bird		Y	7
Black-necked stilt	*Himantopus mexicanus*	Bird		Y	7
Bank swallow	*Riparia riparia*	Bird	Y	Y	8

Common yellowthroat	*Geothlypis trichas*	Bird		Y	8
Least Bell's vireo	***Vireo bellii pusillus***	**Bird**	**Y**	**Y**	**8**
Lincoln's sparrow	*Melospiza lincolnii*	Bird		Y	8
MacGillivray's warbler	*Geothlypis tolmiei*	Bird		Y	8
Swainson's thrush	*Catharus ustulatus*	Bird		Y	8
Willow flycatcher	*Empidonax traillii*	Bird	Y	Y	8
Wilson's warbler	*Cardellina pusilla*	Bird		Y	8
Yellow warbler	*Setophaga petechia*	Bird		Y	8
Yellow-billed cuckoo	*Coccyzus americanus*	Bird	Y	Y	8
Yellow-breasted chat	*Icteria virens*	Bird	Y	Y	8
Black-crowned night heron	*Nycticorax nycticorax*	Bird		Y	9
Great blue heron	***Ardea herodias***	**Bird**		**Y**	**9**
Great egret	*Ardea alba*	Bird		Y	9
Green heron	*Butorides virescens*	Bird		Y	9
Pied-billed grebe	*Podilymbus podiceps*	Bird		Y	9
Snowy egret	*Egretta thula*	Bird		Y	9
Wilson's snipe	*Gillinago delicata*	Bird		Y	9
Cinnamon teal	*Anas cyanoptera*	Bird		Y	10
Mallard	*Anas platyrhynchos*	Bird		Y	10
Northern pintail	*Anas acuta*	Bird		Y	10
Song sparrow	*Melospiza melodia*	Bird		Y	10
Wood Duck	*Aix sponsa*	Bird		Y	10

Brown-headed cow bird	*Molothrus ater*	Bird	Y	10
Cooper's hawk	*Accipiter cooperii*	Bird	Y	11
Long-eared owl	*Asio otus*	Bird	Y	11
Red-shouldered hawk	*Buteo lineatus*	Bird	Y	11
American dipper	*Cinclus mexicanus*	Bird	Y	12

APPENDIX D

Methods descriptions used for modeling daily flow in ungauged streams within the study region.

Stream reaches of interest were chosen based on data availability throughout the study region. Stream reaches with data present, particularly with presence absence data, were selected for flow modeling totaling 67 study reaches. Contributing watersheds for each stream reach were delineated using a 1/3 arc-second Digital Elevation Model (DEM) obtained from the United States Geological Survey (USGS) and ESRI ArcMap software.

Ensemble Models developed in Sengupta et al. 2018 were used to model hydrology in each watershed. The Ensemble Models are comprised 26 Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS) models that are collectively representative of the variety of hydrologic conditions across southern California. A watershed is assigned to a model from the Ensemble Model set according to land cover composition and soil characteristics criteria. Once assigned, rainfall, watershed area, time of concentration (T_c), Storage Coefficient, and percent impervious area are the only watershed-specific parameters that must be input into the model.

Each of the 67 study watersheds was assigned a model from the Ensemble model set and required watershed-specific parameters were calculated. Watershed area was calculated using ESRI ArcMap software. T_c values were estimated using the Kirpich Method and Storage Coefficient was calculated a $0.6T_c$, which is consistent with methodology used in development of the Ensemble Models. Percent impervious area was derived from the National Land Cover Database (NLCD) 2011 Percent Developed Imperviousness dataset using ESRI ArcMap software. The NLCD 2001 to 2006 and NLCD 2006 to 2011 Percent Developed Imperviousness Change datasets were referenced to confirm that developed land area had remained relatively consistent throughout the portion of study period for which NLCD data is available.

Precipitation time series for each model were derived from a 90-meter, gridded precipitation dataset provided by Alex Hall's team from University of California, Los Angeles (UCLA). The precipitation dataset consisted of a continuous, 3-hourly time series spanning water years 1982-2014 for the entire study region. Gridded precipitation values were averaged over each study watershed to produce a 3-hourly time series for each watershed. The resulting time series were used as input into the HEC-HMS models. Each HEC-HMS model was run at an hourly time-step, consistent with development of the Ensemble Models. The HEC-HMS models produced hourly flow time series. The hourly flow time series were averaged into daily average flow values in post-processing, resulting in a daily flow time series spanning water years 1982-2014 for each study watershed at its downstream terminus.

To validate results of the hydrologic portion of this study, daily average flow time series for 25 of the study watersheds were compared to daily average flow time series produced in a previous SCCWRP hydromodification study. The sites selected from the hydromodification study have identical or nearly identical contributing watersheds as their corresponding stream reaches from the current study. The validation period covered calendar years 1991-2013.

APPENDIX E

Validation data performance for the stream temperature model. Residual plots show a normal distribution which ensure that a linear regression model was appropriate.

Table 20: Validation metrics of the air to stream temperature modeling. Root-mean-square error (RMSE) and the Nash–Sutcliffe model efficiency coefficient (NSE) are shown.

	RMSE (°C)	NSC (UNITLESS)
Mean	2.141971	0.6335249
Min	2.206111	0.6935738
Max	3.325838	0.46993

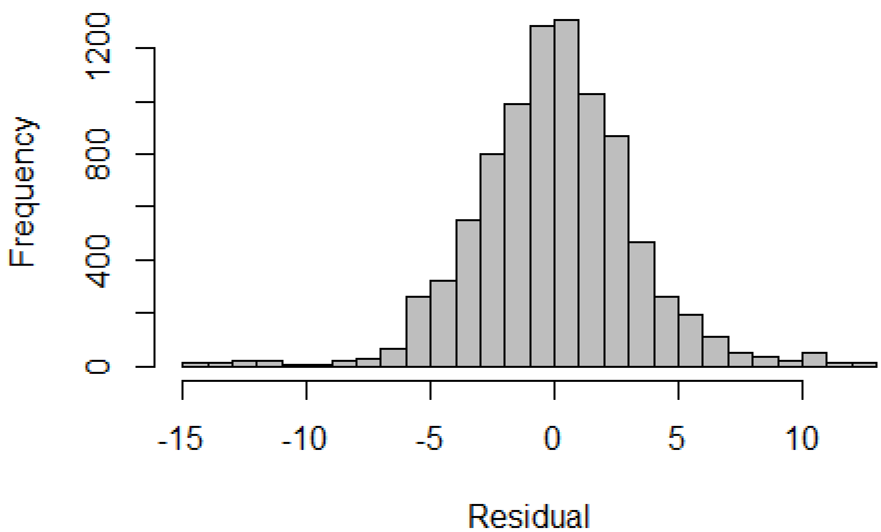

Figure 18: Residual plot for the 7-day maximum stream temperature modeling. Normally distributed residuals confirm that linear regression was appropriate.

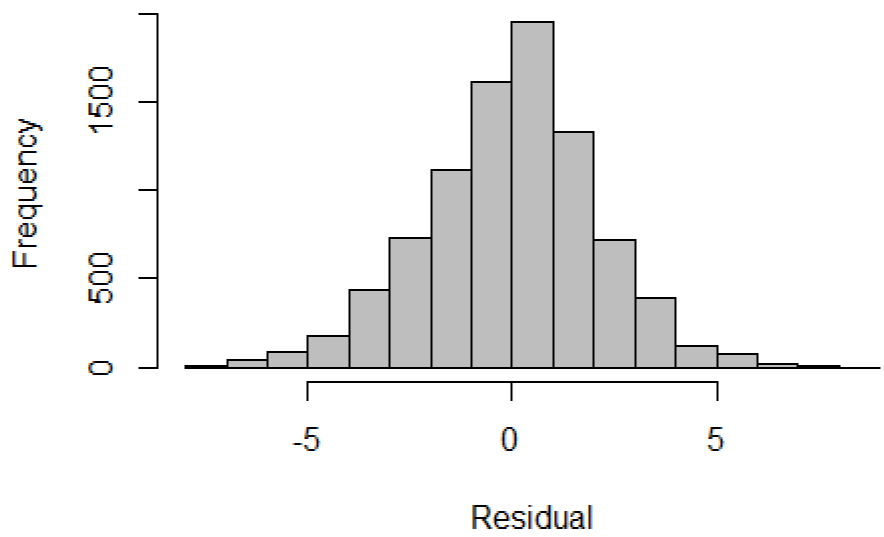

Figure 19: Residual plot for the 7-day mean stream temperature modeling. Normally distributed residuals confirm that linear regression was appropriate.

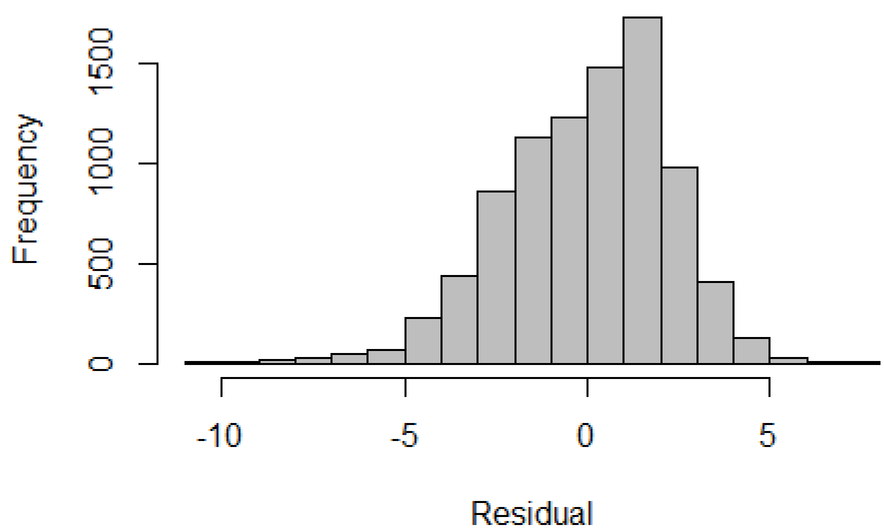

Figure 20: Residual plot for the 7-day minimum stream temperature modeling. Residuals are slightly skewed to the left, however we found it to be sufficiently normal to justify linear regression.

APPENDIX F

Validation data performance for the flow metric random forest models.

Table 21: Performance of random forest models for each flow metric and time frame. Performance estimates are separated by calibration and validation data sets based on a random 3:1 split of the training data. Performance is based on root mean squared error and R-squared values comparing observed and predicted flow metrics and is shown only for the July model. The predictor column shows whether the full set of predictors or the top ten from the full model produced the best performance. Rows are arranged by r-squared values based on the average between time frames for the validation datasets.

Flow Metric	Time Frame	Predictors	Cal RMSE	Val RMSE	Cal R^2	Val R^2	Average val R^2
R10D.5	3	full	0.00	0.00	0.98	0.99	1
	5	full	0.00	0.00	0.99	0.99	
	10	full	0.00	0.00	1.00	1.00	
	all	full	0.00	0.00	1.00	1.00	
R10D.9	3	full	0.00	0.00	0.99	0.99	1
	5	full	0.00	0.00	0.99	0.99	
	10	full	0.00	0.00	1.00	1.00	
	all	full	0.00	0.00	1.00	1.00	
HighNum	3	full	0.02	0.02	0.96	0.95	0.98
	5	full	0.00	0.03	0.98	0.99	
	10	full	0.00	0.01	1.00	1.00	
	all	full	0.00	0.01	1.00	1.00	
Q90	3	full	0.11	0.36	0.96	0.96	0.98
	5	full	0.04	0.24	0.98	0.98	
	10	full	0.01	0.09	1.00	1.00	
	all	full	0.02	0.01	1.00	1.00	
LowNum	3	full	0.03	0.05	0.94	0.95	0.98
	5	full	0.02	0.09	0.97	0.97	
	10	full	0.01	0.02	1.00	1.00	
	all	full	0.00	0.01	1.00	1.00	
Qmean	3	full	0.08	0.27	0.96	0.96	0.98
	5	full	0.05	0.18	0.97	0.97	
	10	full	0.00	0.07	0.99	0.99	
	all	full	0.00	0.01	1.00	1.00	

Hydroperiod	3	full	0.00	0.00	0.94	0.95	0.98
	5	full	0.00	0.01	0.96	0.96	
	10	full	0.00	0.00	0.99	0.99	
	all	full	0.00	0.00	1.00	1.00	
Q75	3	full	0.04	0.18	0.95	0.94	0.98
	5	full	0.03	0.13	0.97	0.97	
	10	full	0.01	0.05	0.99	0.99	
	all	full	0.01	0.01	1.00	1.00	
SFR	3	full	0.00	0.00	0.93	0.93	0.97
	5	full	0.00	0.01	0.95	0.96	
	10	full	0.00	0.00	1.00	1.00	
	all	full	0.00	0.00	1.00	1.00	
Q50	3	full	0.04	0.14	0.95	0.94	0.97
	5	full	0.02	0.09	0.95	0.95	
	10	full	0.00	0.03	0.99	0.99	
	all	full	0.00	0.00	1.00	1.00	
tenyr	all	full	5.42	27.33	0.96	0.97	0.97
FracYearsNoFlow	3	full	0.00	0.01	0.92	0.92	0.97
	5	full	0.00	0.00	0.96	0.96	
	10	full	0.00	0.00	0.99	0.99	
	all	full	0.00	0.00	1.00	1.00	
Q99	3	full	0.50	3.74	0.93	0.93	0.97
	5	full	0.48	2.35	0.95	0.95	
	10	full	0.07	0.65	0.99	0.99	
	all	full	0.06	0.12	1.00	1.00	
QmeanIDR	3	full	0.13	0.32	0.92	0.92	0.97
	5	full	0.07	0.22	0.96	0.96	
	10	full	0.03	0.27	0.99	0.99	
	all	full	0.02	0.02	1.00	1.00	

QmeanMEDIAN	3	full	0.03	0.21	0.90	0.91	0.97
	5	full	0.02	0.13	0.97	0.97	
	10	full	0.01	0.04	0.99	0.99	
	all	full	0.00	0.01	1.00	1.00	
Qmed	3	full	0.03	0.11	0.93	0.92	0.96
	5	full	0.03	0.11	0.95	0.95	
	10	full	0.01	0.04	0.99	0.99	
	all	full	0.00	0.00	1.00	1.00	
Q95	3	full	0.28	1.20	0.89	0.91	0.96
	5	full	0.21	1.37	0.94	0.93	
	10	full	0.06	0.35	0.99	0.99	
	all	full	0.01	0.03	1.00	1.00	
MedianNoFlowDays	3	full	0.32	2.83	0.90	0.91	0.96
	5	full	0.49	2.06	0.93	0.93	
	10	full	0.33	1.68	0.97	0.98	
	all	full	0.24	0.20	1.00	1.00	
MinMonthQ	3	full	0.04	0.10	0.92	0.92	0.96
	5	full	0.02	0.06	0.92	0.92	
	10	full	0.01	0.03	0.98	0.98	
	all	full	0.00	0.00	1.00	1.00	
Qmin	3	full	0.05	0.13	0.90	0.89	0.96
	5	full	0.03	0.09	0.94	0.94	
	10	full	0.01	0.02	0.98	0.99	
	all	full	0.00	0.00	1.00	1.00	
Q25	3	full	0.03	0.09	0.93	0.91	0.95
	5	full	0.03	0.09	0.92	0.92	
	10	full	0.01	0.03	0.97	0.97	
	all	full	0.00	0.00	1.00	1.00	
LowDur	3	full	0.67	5.03	0.86	0.86	0.94

	5	full	0.77	4.75	0.92	0.92	
	10	full	0.42	4.05	0.97	0.97	
	all	full	0.95	0.86	1.00	1.00	
BFR	3	full	0.00	0.00	0.84	0.85	0.93
	5	full	0.00	0.00	0.90	0.90	
	10	full	0.00	0.00	0.98	0.98	
	all	full	0.00	0.00	1.00	1.00	
NoDisturb	3	full	0.32	6.13	0.87	0.87	0.93
	5	full	0.76	4.02	0.92	0.92	
	10	full	0.98	5.06	0.93	0.94	
	all	full	0.86	0.85	1.00	1.00	
MaxMonthQ	3	full	0.09	0.78	0.82	0.85	0.92
	5	full	0.17	0.55	0.89	0.89	
	10	full	0.02	0.26	0.97	0.96	
	all	full	0.00	0.01	1.00	1.00	
Q05	3	full	0.03	0.09	0.87	0.86	0.92
	5	full	0.02	0.03	0.90	0.91	
	10	full	0.01	0.02	0.93	0.93	
	all	full	0.00	0.00	1.00	1.00	
QminIDR	3	full	0.05	0.22	0.83	0.82	0.92
	5	full	0.05	0.12	0.91	0.90	
	10	full	0.01	0.07	0.98	0.98	
	all	full	0.00	0.00	1.00	1.00	
Q10	3	full	0.02	0.09	0.87	0.86	0.92
	5	full	0.02	0.03	0.89	0.92	
	10	full	0.01	0.06	0.94	0.91	
	all	full	0.00	0.00	1.00	1.00	
Q01	3	full	0.03	0.08	0.87	0.85	0.91
	5	full	0.01	0.04	0.92	0.92	

	10	full	0.01	0.03	0.90	0.88	
	all	full	0.00	0.00	1.00	1.00	
R10D4D	3	full	0.00	0.01	0.78	0.79	0.9
	5	full	0.00	0.00	0.84	0.85	
	10	full	0.00	0.00	0.95	0.96	
	all	full	0.00	0.00	1.00	1.00	
HighDur	3	full	1.65	6.05	0.79	0.80	0.89
	5	full	1.64	3.25	0.84	0.85	
	10	full	1.28	3.22	0.93	0.91	
	all	full	0.00	0.00	1.00	1.00	
Qmax	3	full	1.37	6.04	0.76	0.79	0.89
	5	full	1.42	3.49	0.84	0.84	
	10	full	0.30	4.63	0.91	0.92	
	all	full	0.03	0.03	1.00	1.00	
QmaxIDR	3	top 10	0.90	54.82	0.78	0.74	0.88
	5	full	4.77	19.10	0.87	0.87	
	10	full	4.58	24.85	0.89	0.92	
	all	full	0.55	0.30	1.00	1.00	
May	all	full	0.07	0.27	0.88	0.87	0.87
Apr	all	full	0.17	0.36	0.85	0.86	0.86
RecessMaxLength	3	full	2.57	10.15	0.72	0.71	0.85
	5	full	1.48	5.92	0.79	0.80	
	10	full	0.63	5.75	0.85	0.89	
	all	full	0.29	0.27	1.00	1.00	
Jun	all	full	0.06	0.28	0.87	0.84	0.84
Jan	all	top 10	0.69	1.31	0.81	0.83	0.83
Mar	all	full	0.32	1.78	0.77	0.83	0.83
RBI	3	full	0.01	0.01	0.70	0.71	0.82
	5	full	0.00	0.01	0.66	0.68	

	10	full	0.00	0.01	0.90	0.90	
	all	full	0.00	0.00	1.00	1.00	
Jul	all	full	0.05	0.28	0.86	0.82	0.82
MinMonth	3	full	0.03	0.12	0.68	0.68	0.81
	5	full	0.01	0.12	0.72	0.73	
	10	full	0.02	0.07	0.81	0.82	
	all	full	0.00	0.00	1.00	1.00	
Feb	all	top 10	0.44	1.81	0.79	0.78	0.78
Aug	all	full	0.15	0.38	0.73	0.75	0.75
Oct	all	full	0.14	0.33	0.73	0.74	0.74
Sep	all	full	0.14	0.34	0.72	0.74	0.74
Nov	all	full	0.13	0.30	0.72	0.73	0.73
Dec	all	top 10	0.05	0.43	0.69	0.67	0.67
twoyr	all	full	13.56	21.00	0.66	0.65	0.65
fivyr	all	full	12.14	60.23	0.61	0.62	0.62
MaxMonth	3	full	0.06	0.11	0.53	0.55	0.59
	5	full	0.07	0.15	0.46	0.44	
	10	full	0.04	0.09	0.34	0.37	
	all	full	0.00	0.00	1.00	1.00	

APPENDIX G

Validation data performance for the biological random forest models. Confusion matrices are shown for each species training and testing data.

Table 22: Validation data for the arroyo chub biological flow model. The first table shows the accuracy of predicting presence or absence on the training data and the second shows the accuracy for the testing data. The columns across the top (blue) are the numbers based on the species observation data and the rows (tan) show the model prediction. For example, in this first table, based on the observations, 32 arroyo chub were present. The model correctly identified 30 of them and mislabeled two as absent. Based on the observations 146 locations did not have chub present, and our modeled mislabeled one as being present.

Training	Presence	Absence
Presence	30	1
Absence	2	145

Testing	Presence	Absence
Presence	4	2
Absence	2	51

Table 23: Validation data for the *O. mykiss* biological flow model.

Training	Presence	Absence
Presence	78	0
Absence	5	342

Testing	Presence	Absence
Presence	18	2
Absence	6	115

Table 24: Validation data for the Santa Ana sucker biological flow model.

Training	Presence	Absence
Presence	23	0
Absence	0	163

Testing	Presence	Absence
Presence	10	1
Absence	1	50

Table 25: Validation data for the southwestern pond turtle biological flow model.

Training	Presence	Absence
Presence	177	0
Absence	8	28

Testing	Presence	Absence
Presence	54	0
Absence	2	15

Table 26: Validation data for arroyo toad biological flow model. Accuracy was lower for this species due to the small number of observations in the testing data set.

Training	Presence	Absence
Presence	18	0
Absence	0	7

Testing	Presence	Absence
Presence	6	2
Absence	0	0

Table 27: Validation data for the least Bell's vireo biological flow model.

Training	Presence	Absence
Presence	28	1
Absence	0	20

Testing	Presence	Absence
Presence	9	0
Absence	0	7