Appendix 1

This file includes:

- Supplementary methods
- Tables A1.1 to A1.6
- Figures A1.1 to A1.9
- Supplementary references

Supplemental Methods:

Climate projections

A combination of 8 projections were used from 4 different global change models (GCMs) at two relative concentration pathways (RCPs). The RCPs chosen were 4.5 and 8.5, the former representing an emissions-controlled future, while the latter represents an uncontrolled emissions future. The particular combination is based on recommendations from Pierce et al. 2016. The LANDIS model utilizes the following climatological variables: daily precipitation (Figure A1.1 and A1.2), daily maximum temperature (Figure A1.3), daily minimum temperature, daily average windspeed, and daily average wind direction that are averaged across the Level II EPA ecoregions in the study area.

Forest succession

NECN (v6.5) simulates both above and belowground processes, tracking C and N through multiple live and dead pools, as well as tree growth (as net primary productivity--a function of age, competition, climate, and available water and N). Soil moisture, as well as movement across the dead pools: wood and litter deposition and decomposition, soil accretion and decomposition are based on the CENTURY soil model (Parton et al. 1983, Scheller et al. 2011). Carbon estimates by pool were validated against Wilson et al. (2013) at the ecoregion level, where the model overestimated total C for only one region but was within one standard deviation for all others (see supplemental Figure A1.4). Forest growth estimates using the climate data for year 2010-2015 for the region were calibrated against the MODIS 17a3 product annual mean for 2000 – 2015 (Figure A1.5). Mean landscape value for MODIS was 393 g C/m ^2 (sd 134), while for LANDIS the mean value was 320 g C/m^2 (sd 312). Reproductive success is dependent on temperature and water.

Fire modeling

The SCRPPLE extension (v2.1) models ignitions by drawing the number of ignitions from a zero-inflated Poisson distribution and allocates them across the landscape with a weighted ignition surface for each type of fire modeled (Scheller et al. 2019). The weather influence on fire is based on the Fire Weather Index (FWI) measures created by the Canadian Fire Prediction System (1992). There are three categories of fires that can be modeled: lightning, accidental (i.e., human started), and prescribed fire. The extension also includes the ability to explicitly set fire suppression effort levels across the landscape as well as by ignition type, where the suppression parameter reduces the probability of fire spread from one cell to another. Effort levels can range from 0 to 3, where 0 is no suppression attempted, to 3 which represents high effort and was designed to mimic current suppression efforts in the Basin (Figure A1.6). However, suppression effectiveness can be limited by weather as well, a maximum wind speed parameter can limit suppression to days only when resources can be deployed safely. That parameter was set at wind speeds of 11 meters per second (~25 miles per hour) in consultation with regional fire personnel. Prescribed fires follow a set of weather prescriptions for when fires can occur (Table A1.2).

Contemporary wildfires (2000-2016, from CalFIRE FRAP) were used to parameterize fire spread and size from the Central Sierra Nevada in order to increase the sample size of fires. Mean annual fire area (in ha) for observed data was 117 hectares per year (SD = 309), for modeled data, the mean value was 122 hectares per year (SD = 210). In order to move from fire intensity to fire severity (to encompass the mortality associated with fire), five fire experts working in the LTB provided their estimates of mortality for varying species, age, and intensity combinations. More details about the parameterization of the fire extension are found in Scheller et al. (2019). Suppression effort and fire spread are calibrated at the same time in order to try to account for both forces in recreating the contemporary fire regime.

The model calculates three levels of fire intensity, roughly corresponding to flame lengths of: 1) less than 4 ft, 2) between 4 ft. and 8ft., and 3) greater than 8ft. While ignitions are based off of climate, fire intensity is based off of fuel loading within each cell. LANDIS calculates fuel loadings based on the current year's litter, duff, and downed and dead woody debris. When a threshold of fine fuels is exceeded in a cell, the fire intensity increases. This threshold is based off a value of ~1100g/m^2 or about 5 tons per acre of fine fuels. The other threshold is based on ladder fuels: a combination of specific species, under a certain age, and over a certain amount of biomass per area, contribute to intensity. Those species contributing to ladder fuels are: Jeffrey Pine, white fir, and incense-cedar, and the cohorts in the cell have to be younger than 40 with a biomass greater than 2000g/m^2 (9 tons per acre). When one threshold is exceeded, fire intensity increases. When both thresholds are exceeded, fire intensity is at its highest. High intensity fire spreads as high intensity fire. In order to try to validate fire intensity for the Basin, the targeted fire intensity value for any of the larger multi-day fires was 40% high, 40% mid, and a 20% low intensity, with high intensity less than 60% of the total fire area. These percentage targets were based on the thematic burn severity values present within the Basin from Monitoring Trends in Burn Severity website.

Insect modeling

A modified version of the Biological Disturbance Agent extension (Biomass BDA v.2.0) (Sturtevant et al. 2009) was used to simulate insect outbreaks for three species of insects: Jeffrey pine beetle (*Dendroctonus jeffrey*), mountain pine beetle (*Dendroctonus ponderosae*), and fir engraver beetle (*Scolytus ventralis*). The extension requires insect-specific resource requirements and assigns a species-specific vulnerability that varies by age. Cells are probabilistically selected for disturbance based upon the species host density at a given site and the presence of non-hosts reduce disturbance probability. The parameters for spread and mortality are outlined in Kretchun et al. (2016), see Table A1.5 and Table A1.6 below. Mortality at an outbreak site is subsequently determined by species' age and host susceptibility probabilities based from empirical field studies (Egan et al. 2010, 2016) and expert opinion, see Table A1.2 below. The insects had differing rates of spread per year from previous outbreaks. Mountain Pine Beetle had positive neighbor effects, where pheromones promoted more rapid spread when there were neighboring populations. All insects were able to exploit recently burned stands up to 10 years after a fire. Following mortality, dead biomass remains on site and moves to the downed woody debris C pool and the fine woody debris C pool.

However, unlike Kretchun et al. (2016), the trigger for an outbreak was changed to be responsive to climate signals. This is because for many beetle species climate influences outbreaks in three ways: low winter temperatures cause beetle mortality; year-round temperatures influence development and mass attack; and drought stress reduces host resistance. Here, we modeled climate influences as a function of drought and mean minimum winter temperature, recognizing that the full suite of climatic influences is necessary for a fully mechanistic model. So long as annual climatic water deficit exceeded a set threshold, in conjunction with mean winter minimum temperatures exceeded a certain threshold, outbreaks could occur. A comparison between the modeled and observed outbreak dataset (USFS Aerial Detection Survey: https://www.fs.fed.us/foresthealth/applied-sciences/mapping-reporting/index.shtml) found an overestimation of frequency of occurrence but an underestimation of area impacted by insects (Figure A1.7).

Supplemental Tables:

Table A1.1. Suppression effort levels and effectiveness on fire spread probability.

	Fire Weather Index Thresholds		Effort Level		
Fire Type	Low-mod	Mod-high	Low	Moderate	High
Accidental	40	60	0	5	10
Lightning	40	60	0	5	10
Rx	40	60	0	0	0

Table A1.2. Prescribed fire parameters used for Scenario 5

Prescribed Fire Parameters	
MaximumRxWindSpeed	6.6 (m/s)
MaximumRxFireWeatherIndex	55 (unitless)
MinimumRxFireWeatherIndex	10 (unitless)
MaximumRxFireIntensity	1 (low)
NumberRxAnnualFires	364 (days of year allowable, subject to climate constraints)
FirstDayRxFires	1 (first julian day for allowable fire, subject to climate constraints)
TargetRxSize	72 (hectares)

Table A1.3. Species parameters used in modeling.

Name	**Longevity**	**Sexual maturity age**	**Shade tolerance**	**Fire tolerance**	**Seed effective dispersal distance (meters)**	**Maximum dispersal distance (meters)**	**Vegetative Reproduction Probability**	**Minimum age veg reproduction**	**Maximum age veg reproduction**	**Post-fire regeneration**
Pinus jeffreyi	500	25	2	5	50	300	0	0	0	none
Pinus lambertiana	550	20	3	5	30	400	0	0	0	none
Calocedrus decurrens	500	30	3	5	30	1000	0	0	0	none
Abies concolor	450	35	4	3	30	500	0	0	0	none
Abies magnifica	500	40	3	4	30	500	0	0	0	none
Pinus contorta	250	7	1	2	30	300	0	0	0	none
Pinus monticola	550	18	3	4	30	800	0	0	0	none
Tsuga mertensiana	800	20	5	1	30	800	0.0005	100	800	none
Pinus albicaulis	900	30	3	2	30	2500	0.0001	100	900	none
Populus tremuloides	175	15	1	2	30	1000	0.9	1	175	resprout
Non-N fixing, Resprouting	80	5	2	1	30	550	0.85	5	70	resprout
Non-N fixing, Seeding	80	5	2	1	30	1000	0	0	0	none
N fixing, Resprouting	80	5	1	1	30	500	0.75	5	70	resprout
N fixing, Seeding	80	5	1	1	30	800	0	0	0	none

Table A1.4. Harvest removals prescription tables

		Abies concolor	**Calocedrus decurrens**	**Pinus jeffreyi**	**Abies magnifica**	**Pinus contorta**	**Pinus lambertiana**	**NonnResp**	**NonnSeed**	**FixnResp**	**FixnSeed**
Hand Thinning	Age range	1-60	1-64	1-52	1-60	1-73	1-52	10-200	10-200	10-200	10-200
Scenario 1 - 5	Percent removed	-66%	-66%	-66%	-66%	-66%	-66%	-5%	-5%	-5%	-5%
Trees up to 11” dbh	Age range	61-70	65-78	53-68	61-75	74-88	53-64				
	Percent removed	-39%	-39%	-39%	-39%	-39%	-39%				

Mechanical Thinning		**Abies concolor**	**Calocedrus decurrens**	**Pinus jeffreyi**	**Abies magnifica**	**Pinus contorta**	**Pinus lambertiana**	**NonnResp**	**NonnSeed**	**FixnResp**	**FixnSeed**
Scenario 1, 2, 4, 5	Age range	1-60	1-64	1-52	1-60	1-73	1-52	10-200	10-200	10-200	10-200
Trees up to 24” dbh	Percent removed	-93%	-93%	-93%	-93%	-93%	-93%	-30%	-30%	-30%	-30%
	Age range	61-65	65-71	53-60	61-68	74-80	53-58				
	Percent removed	-70%	-70%	-70%	-70%	-70%	-70%				
	Age range	66-70	72-78	61-68	69-75	81-88	59-64				
	Percent removed	-65%	-65%	-65%	-65%	-65%	-65%				
	Age range	71-75	79-84	69-76	76-82	89-96	65-70				
	Percent removed	-57%	-57%	-57%	-57%	-57%	-57%				
	Age range	76-80	85-91	77-85	83-90	97-105	71-77				
	Percent removed	-45%	-45%	-45%	-45%	-45%	-45%				
	Age range	81-84	92-99	86-95	91-97	106-115	78-83				
	Percent removed	-32%	-32%	-32%	-32%	-32%	-32%				
	Age range	85-89	100-107	96-105	98-104	116-125	84-90				
	Percent removed	-23%	-23%	-23%	-23%	-23%	-23%				
	Age range	90-93	108-115	106-115	105-112	126-136	91-97				
	Percent removed	-17%	-17%	-17%	-17%	-17%	-17%				
	Age range	94-98	116-125	116-126	113-120	137-148	98-104				
	Percent removed	-13%	-13%	-13%	-13%	-13%	-13%				
	Age range	99-103	126-135	127-138	121-127	149-161	105-112				
	Percent removed	-8%	-8%	-8%	-8%	-8%	-8%				
	Age range	104-108	136-145	139-151	128-135	162-176	113-120				

	Percent removed	-4%	-4%	-4%	-4%	-4%	-4%				
Mechanical Thinning		**Abies concolor**	**Calocedrus decurrens**	**Pinus jeffreyi**	**Abies magnifica**	**Pinus contorta**	**Pinus lambertiana**	**NonnResp**	**NonnSeed**	**FixnResp**	**FixnSeed**
Scenario 3	Age range	1-60	1-64	1-52	1-60	1-73	1-52	10-200	10-200	10-200	10-200
Trees up to 38” dbh	Percent removed	-95%	-95%	-95%	-95%	-95%	-95%	-30%	-30%	-30%	-30%
	Age range	61-65	65-71	53-60	61-68	74-80	53-58				
	Percent removed	-95%	-95%	-95%	-95%	-95%	-95%				
	Age range	66-70	72-78	61-68	69-75	81-88	59-64				
	Percent removed	-85%	-85%	-85%	-85%	-85%	-85%				
	Age range	71-75	79-84	69-76	76-82	89-96	65-70				
	Percent removed	-85%	-85%	-85%	-85%	-85%	-85%				
	Age range	76-80	85-91	77-85	83-90	97-105	71-77				
	Percent removed	-85%	-85%	-85%	-85%	-85%	-85%				
	Age range	81-84	92-99	86-95	91-97	106-115	78-83				
	Percent removed	-75%	-75%	-75%	-75%	-75%	-75%				
	Age range	85-89	100-107	96-105	98-104	116-125	84-90				
	Percent removed	-70%	-70%	-70%	-70%	-70%	-70%				
	Age range	90-93	108-115	106-115	105-112	126-136	91-97				
	Percent removed	-60%	-60%	-60%	-60%	-60%	-60%				
	Age range	94-98	116-125	116-126	113-120	137-148	98-104				
	Percent removed	-35%	-35%	-35%	-35%	-35%	-35%				
	Age range	99-103	126-135	127-138	121-127	149-161	105-112				
	Percent removed	-20%	-20%	-20%	-20%	-20%	-20%				
	Age range	104-108	136-145	139-151	128-135	162-176	113-120				
	Percent removed	-10%	-10%	-10%	-10%	-10%	-10%				
	Age range	109-120	146-180	152-240	136-180	177-230	121-160				
	Percent removed	-10%	-10%	-10%	-10%	-10%	-10%				
	Age range	121-125	181-200	241-252	181-190	231-250	161-180				
	Percent removed	-5%	-5%	-5%	-5%	-5%	-5%				

Table A1.5. Insect disturbance inputs by insect

	Fir Engraver		**Jeffrey Pine Beetle**		**Mountain Pine Beetle**	
	Parameter	Source	Parameter	Source	Parameter	Source
Dispersal Rate	1000 m/year	Jactel (1991)	600 m/year	Egan (personal comm.)	400 m/ year	Safranik (2006)
Neighborhood Effect	N/A	USFS Fir Engraver Facts (2017)	N/A	N/A	Yes, 2x	Safranik (2006)
Disturbance Modifier	Fire: 100%, 10 years	Schwilk 2006	Fire: 100%, 10 years	Schwilk 2006	Fire: 100%, 10 years	Schwilk 2006

Table A1.6: Insect disturbance parameters by insect by host species

		Susceptibility			**Mortality**			
	Target Species	*Age Class 1*	*Age Class 2*	*Age Class 3*	*Age Class 1*	*Age Class 2*	*Age Class 3*	*Source*
Fir Engraver	*Abies concolor*	0-10, 0%	10-60, 65%	60+, 75%	0-10, 0%	10-60, 8%	60+, 12%	Ferrell 1994, Schwilk 2006, Egan (personal comm)
	Abies magnifica	0-10, 0%	10-60, 45%	60+, 55%	0-10, 0%	10-60, 8%	60+, 12%	
Jeffrey Pine Beetle	*Pinus jeffreyi*	0-20, 10%	20-30, 80%	30+, 80%	0-40, 5%	40-120, 18%	120+, 8%	Egan et al. 2016
Mountain Pine Beetle	*Pinus albicaulis*	0-20, 33%	20-60, 66%	80+, 80%	0-20, 5%	20-60, 15%	80+, 20%	Safranik (2006), Cole and Amman (1980)
	Pinus lambertiana	0-20, 33%	20-60, 66%	80+, 80%	0-20, 5%	20-60, 25%	80+, 30%	
	Pinus contorta	0-20, 33%	20-60, 66%	80+, 80%	0-20, 5%	20-60, 15%	80+, 20%	
	Pinus monticola	0-20, 33%	20-60, 66%	80+, 80%	0-20, 5%	20-60, 25%	80+, 30%	

Supplemental Figures:

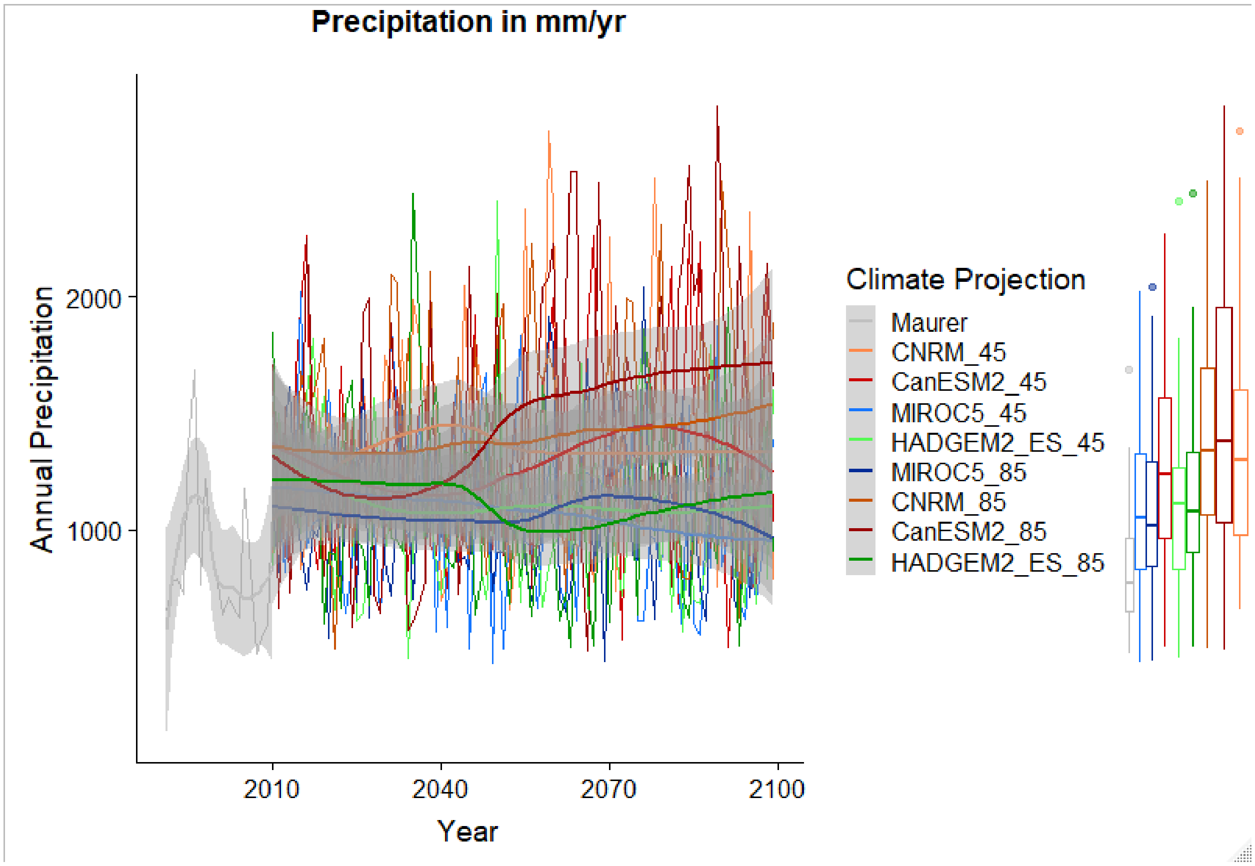


Figure A1.1. Projected precipitation in mm yr^{-1}, lines of best fit are GAM estimated, and boxplots represent distribution of annual precipitation for the years 2090-2100.

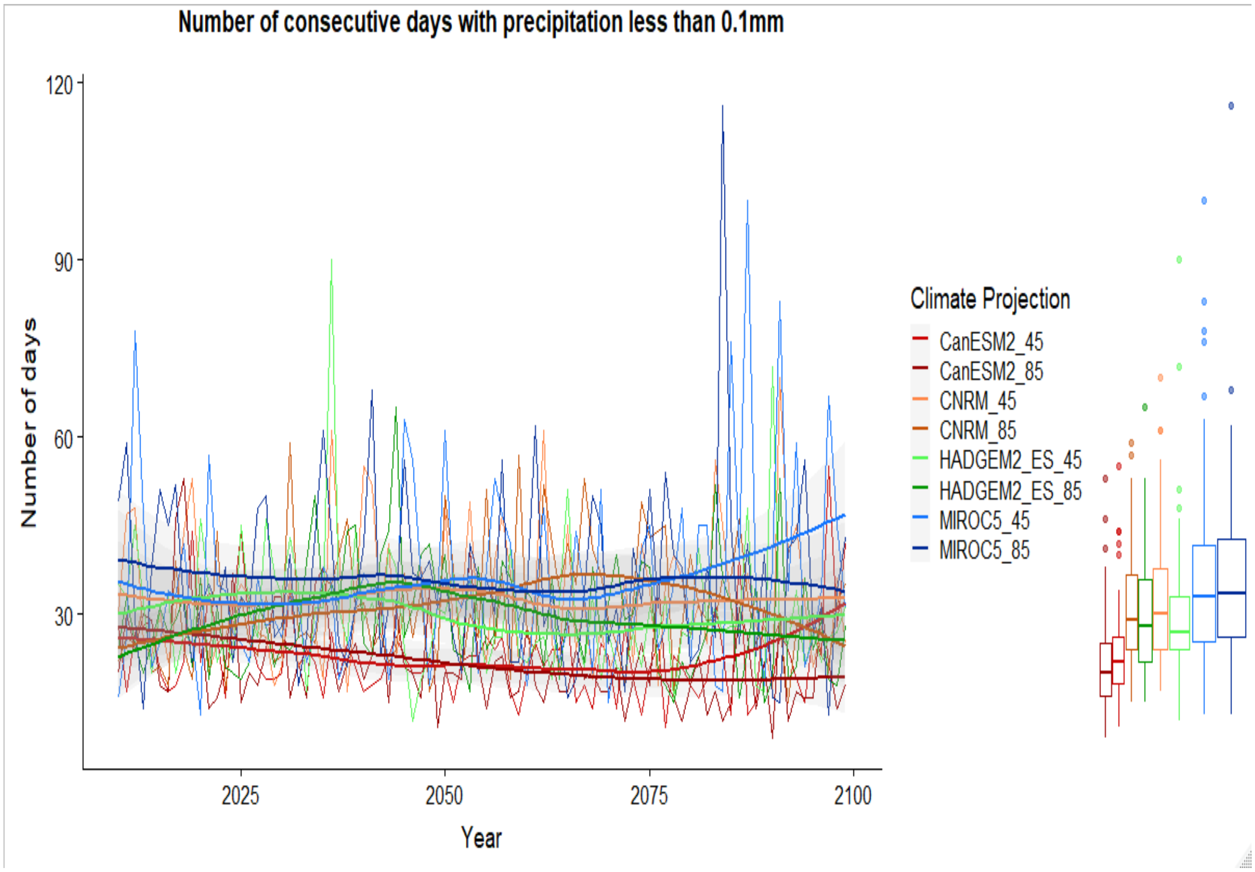


Figure A1.2. Projected number of consecutive days with no precipitation, lines of best fit are GAM estimated, and boxplots represent distribution of consecutive days per year for the years 2090-2100.

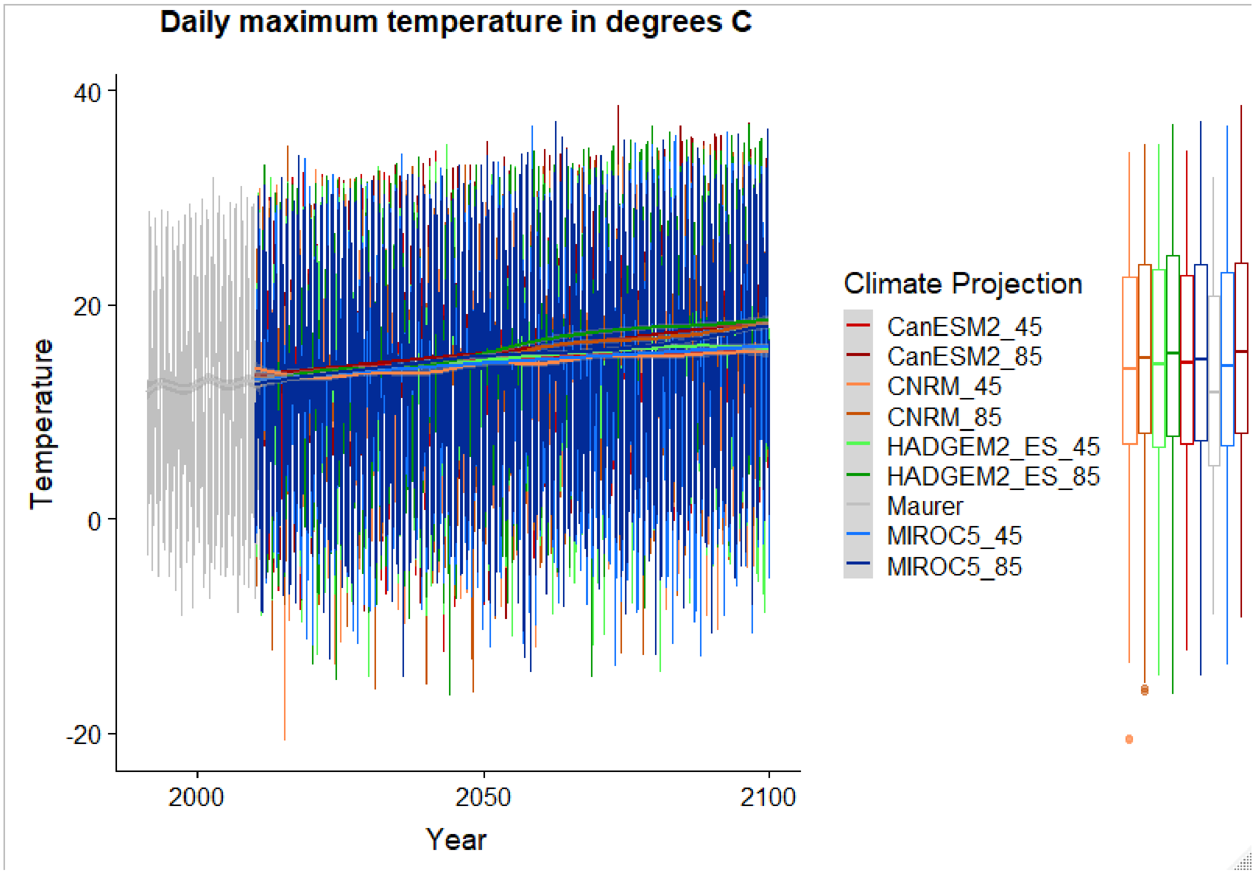


Figure A1.3. Projected daily maximum temperature in degrees C, lines of best fit are GAM estimated, and boxplots represent distribution of daily temperatures for the years 2090-2100 for the future climate projections.

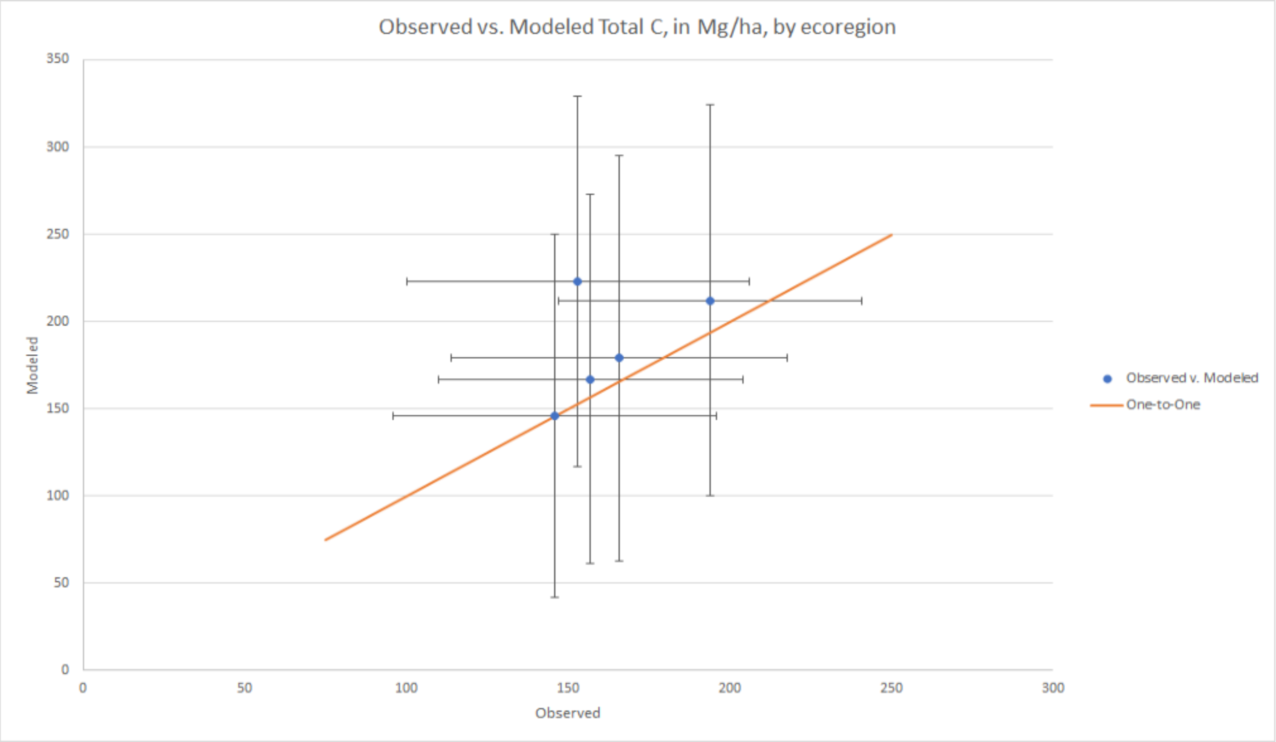
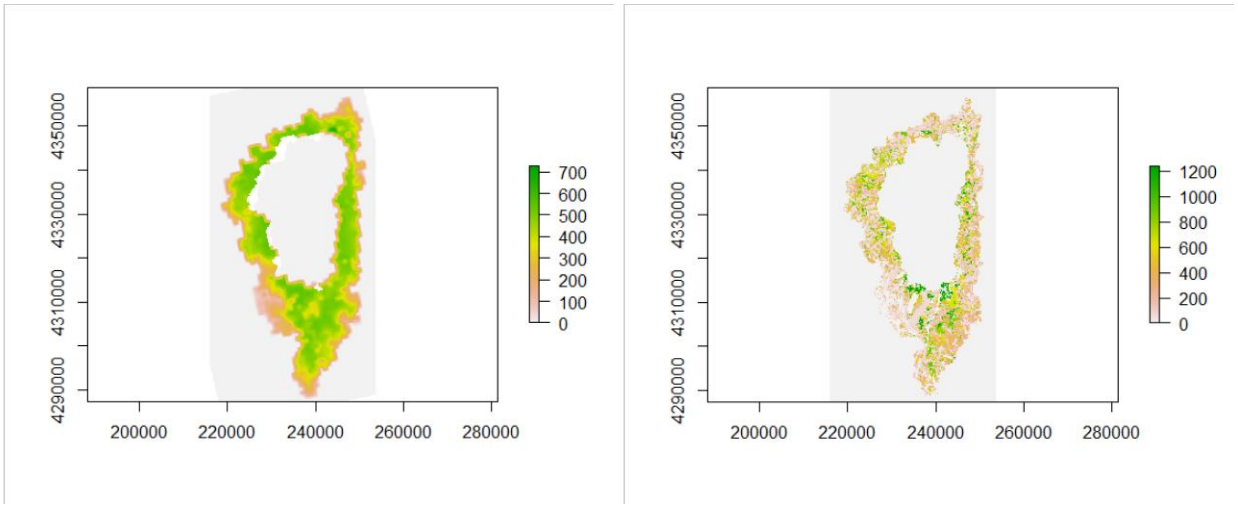


Figure A1.4. Observed versus modeled total C, in egagrams C per hectare, by ecoregion, error m bars represent +/- 1 standard deviation.

Figure A1.5. Comparison of MODIS (left) and LANDIS (right) estimates of Net Primary Productivity in g C/m ^2. Mean landscape value for MODIS was 393 g C/m ^2 (sd 134), while for LANDIS the mean value was 320 g C/m^2 (sd 312).



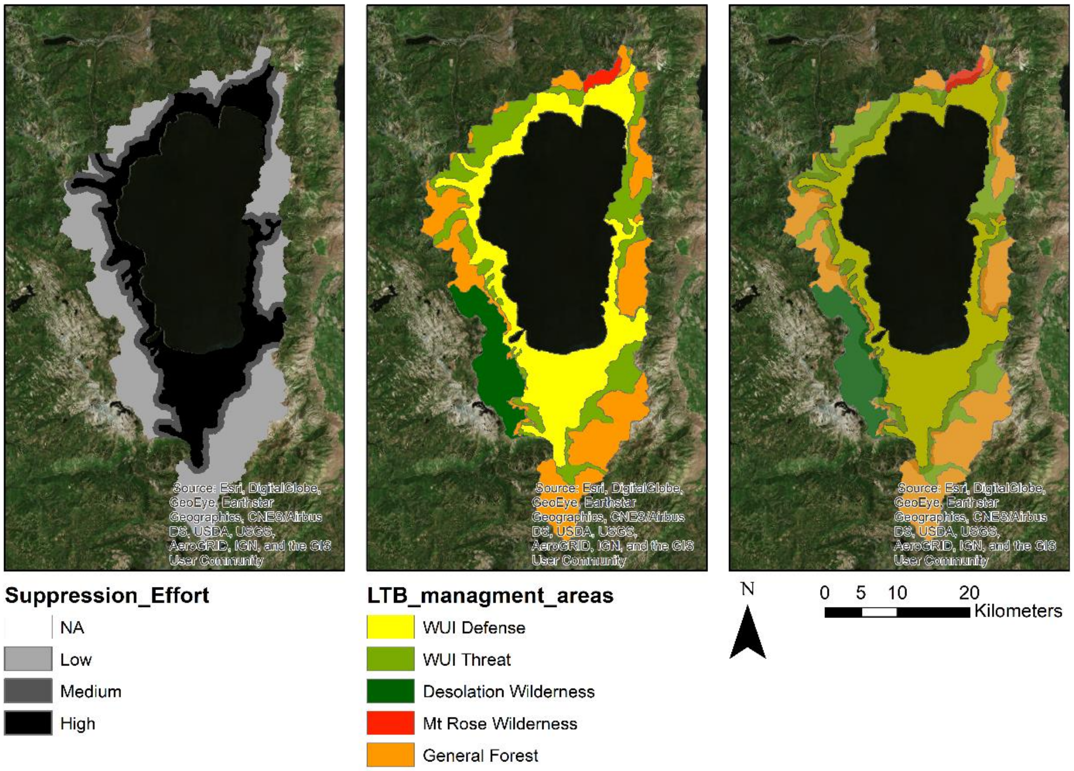


Figure A1.6. Map of suppression (left), management zone (middle), and the overlay of the effort two (right).

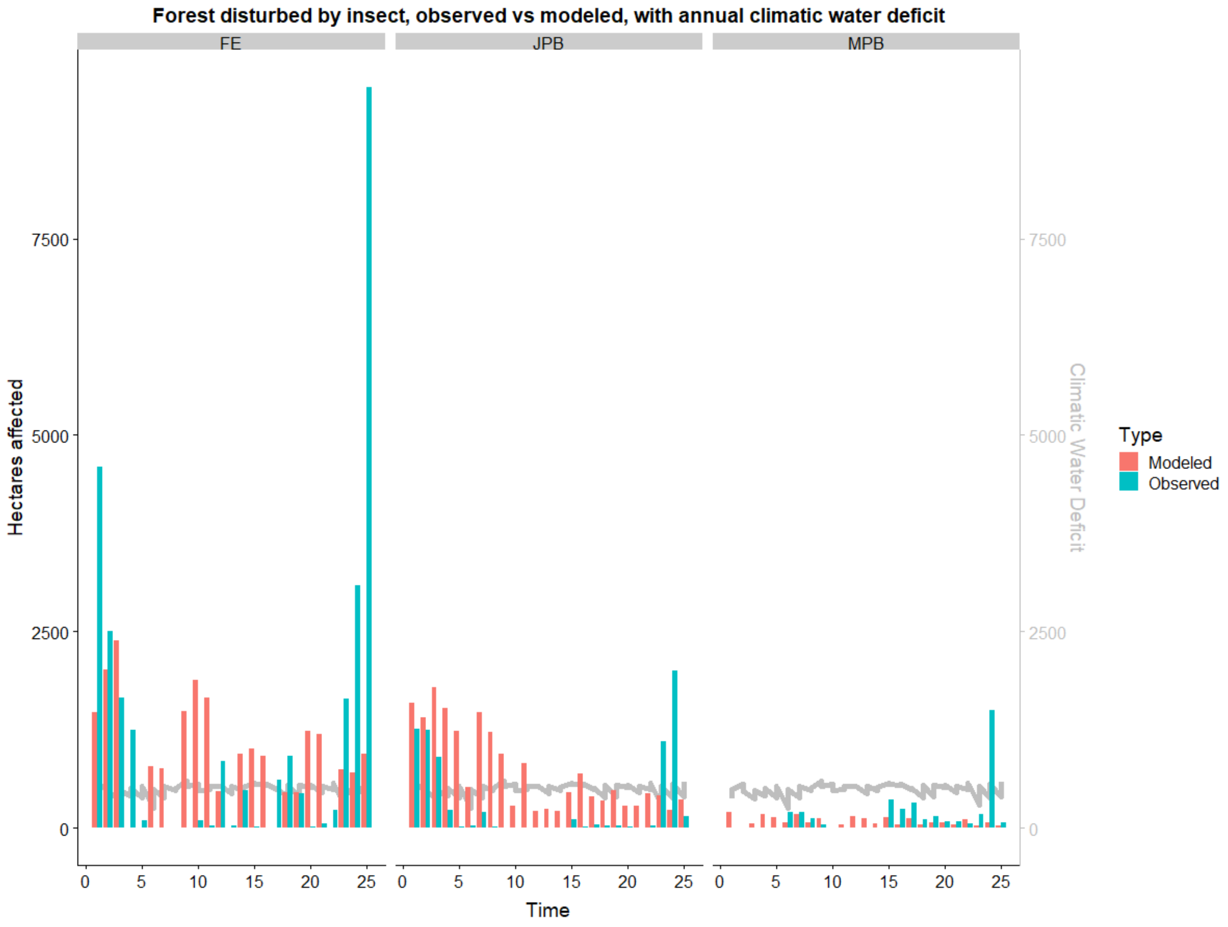


Figure A1.7. Observed versus modeled number of hectares affected by insect/mortality agent. Time 0 is equal to 1990, with Time 22-25 corresponding to the 2012-2015 California drought. FE is fir engraver beetle (*Scolytus ventralis*), JPB is Jeffrey pine beetle (*Dendroctonus jeffrey*), and MPB is mountain pine beetle (*Dendroctonus ponderosae*).

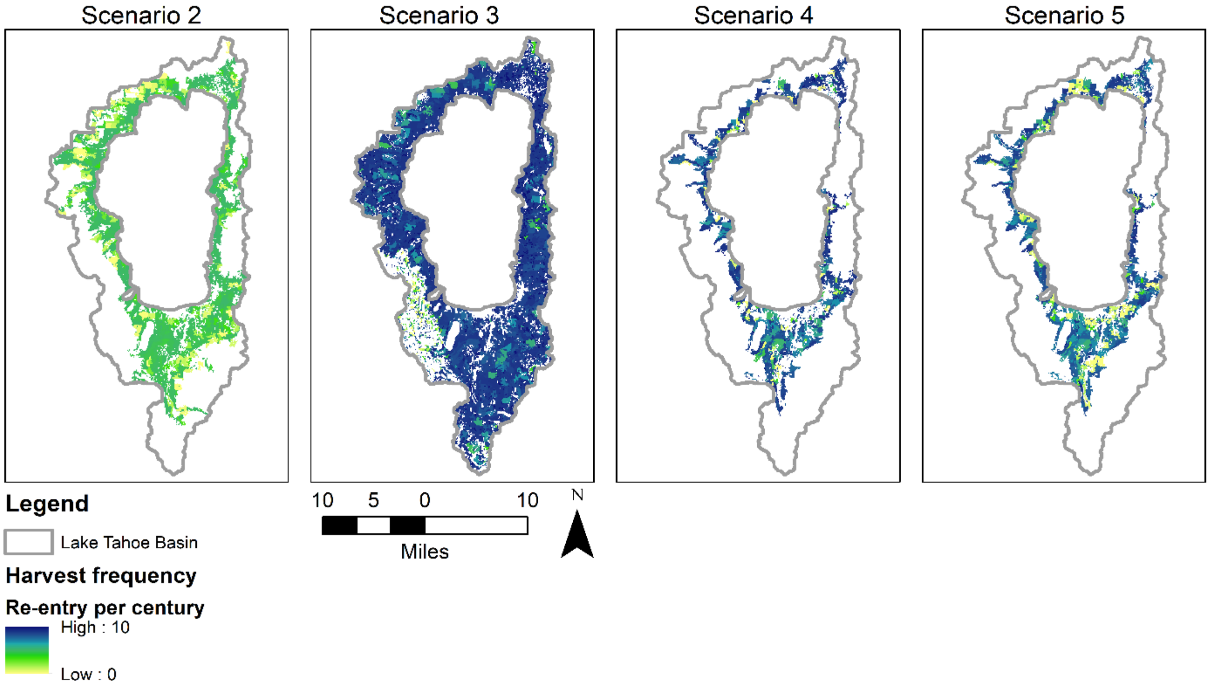


Figure A1.8. Harvest return frequency by management scenario. Treatments were expanded beyond the WUI area in Scenario 3. Scenarios 3 through 5 had a higher intended treatment frequency.

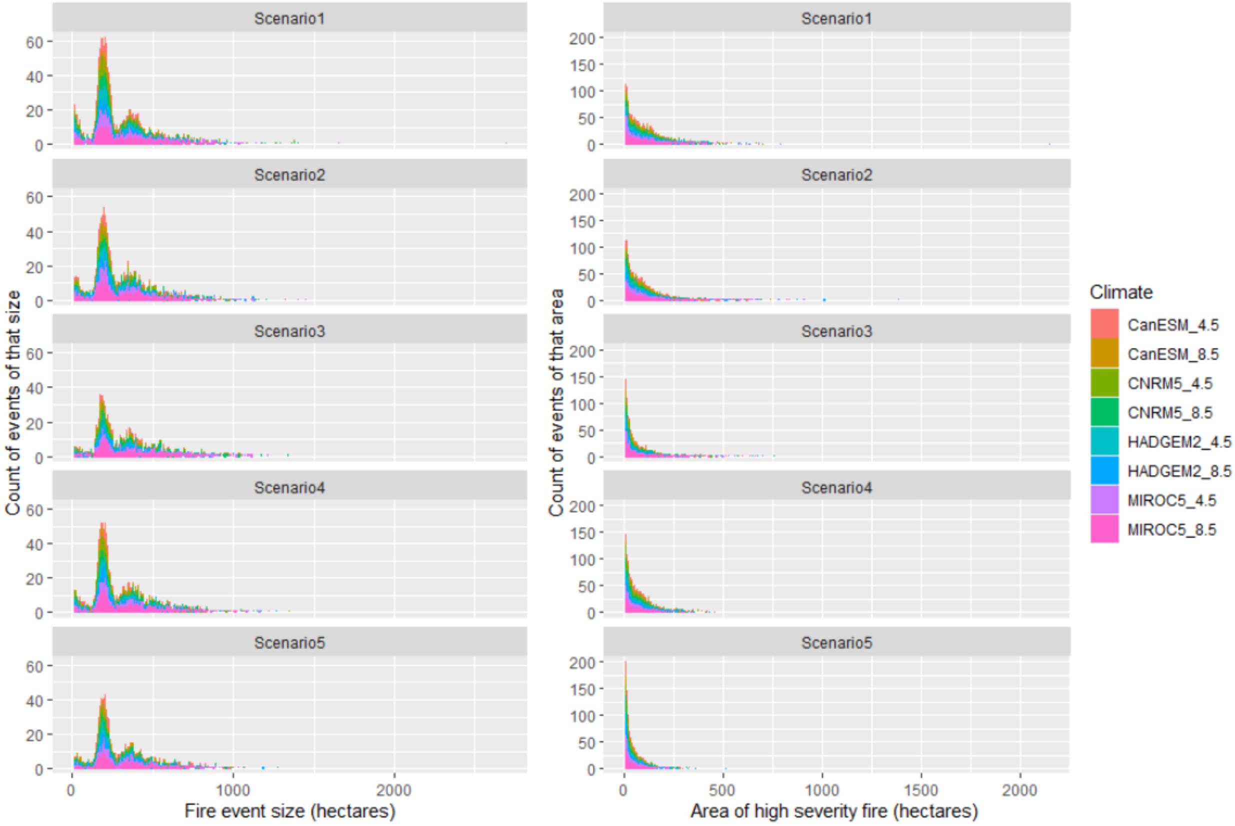


Figure A1.9. Histogram of fire sizes (left) and everity fire area (right) by scenario and by high s climate

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