Supplementary Material

Table S1

Century extension input parameters. Refer to the extensions user's guide for detailed explanations of each parameter, found on the LANDIS-II website: www.landis-ii.org. Species-specific parameters represent species sensitivity to temperature and drought and estimates of % lignin and C:N ratios in various plant parts. The parameters are drawn from the original CENTURY model (http://www.nrel.colostate.edu/projects/century/manual4/man96.html) or from the literature, where available. Century calculates species-specific establishment probability within each ecoregion based on species sensitivity to growth, temperature, and soil moisture.

Physiological parameters for 11 tree species and 4 shrub functional groups found in the Lake Tahoe Basin, CA, NV, USA. GDD: Growing Degree Days

Species or functional group	Functional type	Nitrogen tolerance	GDD min	GDD max	Min. Jan. Temp. (C)	Max Drought	Leaf longevity (yrs.)	Leaf lignin (%)	Fine root lignin (%)	Wood lignin (%)	Coarse root lignin (%)	Leaf CN ratio	Fine root C:N ratio	Wood C:N ratio	Coarse root C:N ratio	Litter C:N ratio
Pinus jeffreyi	1	N	555	2149	-5	0.94	6.0	0.28	0.2	0.25	0.25	48	48	250	167	100
Pinus lambertiana	1	N	815	2866	-5	0.90	2.5	0.17	0.2	0.25	0.25	53	53	278	185	100
Calocedrus decurrens	1	N	837	2938	18	0.99	4.0	0.1	0.2	0.25	0.25	48	48	500	333	100
Abies concolor	1	N	540	2670	-10	0.93	8.0	0.17	0.2	0.25	0.25	30	30	333	222	100
Abies magnifica	1	N	483	1144	-18	0.87	8.0	0.17	0.2	0.25	0.25	30	30	250	167	100
Pinus contorta	1	N	276	993	-18	0.87	3.5	0.25	0.2	0.25	0.25	48	48	500	333	100
Pinus monticola	1	N	155	1016	-18	0.82	7.0	0.31	0.2	0.25	0.25	37	37	500	333	100
Tsuga mertensiana	1	N	235	894	-18	0.80	4.5	0.24	0.2	0.25	0.25	80	80	333	222	100
Pinus albicaulis	1	N	230	950	-18	0.90	5.5	0.27	0.2	0.25	0.25	80	80	333	222	100
Populus tremuloides	2	N	600	3000	-10	0.82	1.0	0.18	0.2	0.25	0.25	62	62	333	222	100
Non N-fixing resprouting shrubs	3	N	400	4000	-10	0.99	1.5	0.25	0.2	0.25	0.25	56	56	333	222	100
Non N-fixing obligate seeding shrubs	3	N	400	4000	-10	0.97	1.5	0.25	0.2	0.25	0.25	59	59	333	222	100
N-fixing resprouting shrubs	3	Y	400	4000	-10	0.97	1.5	0.25	0.2	0.25	0.25	20	28	333	222	50
N-fixing obligate seeding shrubs	3	Y	400	4000	-10	0.99	1.5	0.25	0.2	0.25	0.25	20	30	333	222	50

Table S2

Functional type parameters for the species list in Table 1. Refer to the extensions user's guide for detailed explanations of each parameter, found on the LANDIS-II website: www.landis-ii.org. The tree species and shrub functional groups were further classified into functional types, where temperature, Leaf Area Index (LAI), and water limitations were parameterized for monthly growth (e.g., NPP) patterns, specifically in response to the dry summers and below-freezing winter temperatures found at the LTB. The vegetation within the LTB is well-adapted to the droughty summer months and benefits mainly from the spring snowmelt and early autumn rainfall. As such, the functional groups were parameterized to allow productivity (hence, minimal water and soil moisture limitations) during the dry summer months. The CENTURY default LAI values were used for conifers and hardwoods, while shrubs were adjusted for reduced NPP.

Name	Functional type index	PPDF1 mean	PPDF2 max	PPDF1 shape 1	PPDF1 shape 2	NPP leaf (%)	BTOLAI	KLAI	MAXLAI	PPRPTS2	PPRPTS3	Wood decay rate	Wood mortality (%/mo.)	Age mortality shape	Leaf Drop Month
Conifers	1	23.0	40.0	0.05	6.0	0.2	0.002	5000	10	0.2	0.1	1.0	0.002	10.0	9.0
Hardwoods	2	23.0	35.0	0.05	7.0	0.3	0.002	5000	20	0.2	0.1	1.0	0.002	10.0	9.0
Shrubs	3	23.0	32.0	0.05	10.0	0.3	0.002	500	5	0.2	0.1	1.0	0.002	10.0	9.0

Table S3

Initial values of carbon and nitrogen in various soil organic pools. Refer to the extensions user's guide for detailed explanations of each parameter, found on the LANDIS-II website: www.landis-ii.org. Also see Fig. S1.

Ecoregion	SOM1 C (surface)	SOM1 N (surface)	SOM1 C (soil)	SOM1 N (soil)	SOM2 C	SOM2 N	SOM3 C	SOM3 N	Mineral N
Eastside Forest & Woodland	75.0	3.0	100.0	10.0	3000.0	50.0	300.0	15.0	3.0
Upper Montane	75.0	3.0	100.0	10.0	3000.0	50.0	300.0	15.0	3.0
Subalpine	75.0	3.0	100.0	10.0	3000.0	50.0	300.0	15.0	3.0
Montane shrubland	75.0	3.0	100.0	10.0	3000.0	50.0	300.0	15.0	3.0
Riparian areas	75.0	3.0	100.0	10.0	3000.0	50.0	300.0	15.0	3.0

SOM1: Soil Organic Matter fast pool; SOM2: Soil Organic Matter fast pool; SOM3: Soil Organic Matter passive pool

Table S4

Ecoregion fixed parameters for the Lake Tahoe Basin, CA, NV, USA. Refer to the extensions user's guide for detailed explanations of each parameter, found on the LANDIS-II website: www.landis-ii.org. The spatial ecoregion dataset, initial soil conditions, and soil properties were developed from national soil databases (NRCS, SSURGO).

Ecoregion	Soil depth (cm)	% Clay fraction	% Sand fraction	Field capacity	Wiltin g point	Storm flow fraction	Base flow fraction	Drainage	Atmospheric N (slope)	Atmospheric N (intercept)	Latitude	Decay rate Surface soil	Decay rate SOM 1	Decay rate SOM 2	Decay rate SOM3	Denitrification
Eastside Forest & Woodland	100	0.070	0.714	0.109	0.055	0.4	0.4	0.691	0.08	0.005	39.02	0.4	1	0.02	0.0002	0.5
Upper Montane	100	0.050	0.786	0.090	0.046	0.4	0.4	0.815	0.08	0.005	39.02	0.4	1	0.02	0.0002	0.5
Subalpine	100	0.061	0.744	0.097	0.051	0.4	0.4	0.735	0.08	0.005	39.02	0.4	1	0.02	0.0002	0.5
Montane shrubland	100	0.078	0.718	0.090	0.060	0.4	0.4	0.826	0.08	0.005	39.02	0.4	1	0.02	0.0002	0.5
Riparian areas	100	0.068	0.704	0.123	0.053	0.4	0.4	0.523	0.08	0.005	39.02	0.4	1	0.02	0.0002	0.5

Table S5

References for input parameters to the Century extension as well as species parameters (for Tables 1, S1-4):

Brown JK, Smith JK (2000) Wildland fire in ecosystems: effect of fire on flora. General Technical Report RMRS-GTR-42-vol. 2. Ogden, UT, US Department of Agriculture, Rocky Mountain Research Station, 257 p.

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Burns RM, Honkala BH (1990) Silvics of North America: 1. Conifers; 2. Hardwoods. Agricultural Handbook 654. Vol. 2, pp. 877. USDA Forest Service, Washington, DC.

Chen JM, Rich PM, Gower ST, Norman JM, Plummer S (1997) Leaf area index of boreal forests: Theory, techniques, and measurements. *J. Geophys. Res.*, **102,** 29429-29443.

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Tarnay L, Gertler AW, Blank RR, Taylor GE (2001) Preliminary measurements of summer nitric acid and ammonia concentrations in the Lake Tahoe Basin air-shed: implications for dry deposition of atmospheric nitrogen. *Environmental Pollution*, **113,** 145-153.

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Zinke PJ, Stangenberger AG, Post WM, Emanuel WR, Olson. JS (1998) Global Organic Soil Carbon and Nitrogen. Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee.

Zolbrod AN, Peterson DL (1999) Response of high-elevation forests in the Olympic Mountains to climatic change. *Canadian Journal of Forest Research*, **29,** 1966-1978.

Table S6

Fire regime parameter inputs for the Dynamic Fire extension used for the Lake Tahoe Basin, CA, NV. Please refer to the extensions user's guide for detailed explanations of each parameter, found on the LANDIS-II website: www.landis-ii.org. Also refer to Syphard et al. 2011 for details on fire regime and fuel types for Sierra Nevada, similar to this study. FMC: Foliar moisture content.

Fire Region	Region size (ha)	mu	sigma	Maximum Size/Duration	Spring FMC Low	Spring FMC High	Spring High Proportion	Summer FMC Low	Summer FMC High	Summer High Proportion	Fall FMC Low	Fall FMC High	Fall High Proportion	Default Open Fuel Type Index	Number of Fires (ignitions) yr^{-1}
Lower-elevation	9,603	5.2	0.32	4500	135	175	0.05	85	100	0.89	75	90	0.1	31	1
Mid-elevation	28,777	5.3	0.32	4500	135	175	0.05	85	100	0.89	75	90	0.1	31	1
Higher-elevation	31,194	5.2	0.32	4500	135	175	0.05	85	100	0.89	75	90	0.1	31	1

Notes on fire region delineation: Fire region map was reclassified from a continuous fire ignition density image that was estimated using a spatial point pattern modeling approach (Loudermilk *et al*. 2012, Yang *et al.* 2007) from historical fire occurrence database (http://www.fs.usda.gov/detail/r5/landmanagement/gis/?cid=STELPRDB5327833, accessed 19 June 2012)

Notes on fire ignitions: Although different fire regions possess different fire ignition densities, their number of fire ignitions per year was all set to one (the lowest non-zero integer) after multiplying fire region size. This parameter was set to this low value because we only simulated fires > 0.1 ha, a threshold often used to remove extremely small fires in the analysis that otherwise contribute little in total area burned and fire risk assessment (Miranda et al. 2012).

Loudermilk EL, Stanton, Alison E., Scheller, Robert M., Weisberg, Peter J., Yang, Jian, Dilts, Thomas E., Skinner, Carl (2012) Final Report: Management Options for Reducing Wildfire Risk and Maximizing Carbon Storage under Future Climate Changes, Ignition Patterns, and Forest Treatments In: Southern Nevada Public Lands Management Act. pp 100. Pacific Southwest Research Station, Tahoe Center for Environmental Studies, Incline Village, NV.

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Yang J, He HS, Shifley SR, Gustafson EJ (2007) Spatial Patterns of Modern Period Human-Caused Fire Occurrence in the Missouri Ozark Highlands. *Forest Science*, 53, 1-15.

Table S7

Response of C dynamics to climate change; represented by % difference in mean landscape C between the A2 and base climate scenarios at simulation year 2110 (100 year simulations). Negative values refer to a reduction in, e.g., total C from base climate to A2 climate at year 2110. Refer to Fig. 5 and 6 of original text for graphical representation.

C variable	% Difference at year 2110
Total C	-15%
ANPP	-20%
Live C	-17%
Detrital C	-14%
SOC	-6%

Table S8

Individual species response to climate change, represented here as an approximate positive or negative % difference (to nearest 5%) of mean aboveground live biomass between both A2 or B1 climate and base climate at year 2110. Note that there were some instances were species responded to climate change for a brief period, but illustrated little to no difference in biomass by year 2110. These species are noted by * and see narrative below for details.

Species or functional group	Response to Climate Change			Response type
	+/-	A2	B1	
*Pinus jeffreyi**	-	10%	0%	growth, regeneration
Pinus lambertiana	+	25%	25%	growth, regeneration
*Calocedrus decurrens**	+	0%	0%	growth, regeneration
Abies concolor	+	5%	10%	growth, regeneration
Abies magnifica	-	50%	25%	regeneration
Pinus contorta	-	60%	40%	regeneration
Pinus monticola	-	55%	40%	regeneration
Tsuga mertensiana	-	40%	40%	regeneration
*Pinus albicaulis**	+	5%*	0%	growth, regeneration (-)
Populus tremuloides	+	100%	50%	re-sprout after fire
Non N-fixing resprouting shrubs	+	95%	40%	re-sprout after fire
Non N-fixing obligate seeding shrubs	+	25%	25%	growth
N-fixing resprouting shrubs	+	100%	60%	re-sprout after fire
N-fixing obligate seeding shrubs	+	5%	5%	growth

Narrative on species response: Simulation results indicated that individual species behaved uniquely in response to changes in climate. Species-dependent effects included both reduced or stimulated establishment ability and positive growth response. This was seen for both A2 and B1 climate. Increased fire activity (from climate change) increased tree mortality and altered dynamics between various shade and fire tolerant species. Positive responses to climate change were found (in decreasing order of magnitude) for sugar pine (*Pinus lambertiana*), white fir (*Abies concolor*), incense cedar (*Calocedrus decurrens*), and Jeffrey pine (*Pinus jeffreyi*). Sugar pine, white fir, and incense cedar illustrated positive growth, and to a lesser degree, enhance regeneration (establishment ability), in response to climate change. Of the four species, Jeffrey pine was least stimulated by changes in climate. For all climate scenarios, Jeffrey pine steadily increased in biomass for about 50 years (2060) then leveled off. Growth was only stimulated during the 1st half of the century (e.g., ~10% more biomass in B1 climate). After 2050, warmer conditions slowed growth and reduced establishment ability. Despite this, enhanced fire activity in the B1 climate allowed enough regeneration to stabilize landscape biomass of Jeffrey pine near base climate values. Incense cedar also illustrated this temporary stimulation from climate change, with 5% more biomass during the 1st half of the century (A2 and B1 climate), but converged the latter half. Aspen (*Populus tremuloides*) and the re-sprouting shrubs responded positively to the increase in fire activity (e.g., A2 climate) due to their innate ability to re-sprout vigorously after fire. Although aspen responded positively to more wildfire activity, it was proportionately still a small component of the landscape. Also, note there is very little whitebark pine (*Pinus albicaulis*) within the study area and there was very little noticeable response to climate change, but recorded a slight positive growth response with the A2 climate. Regeneration (establishment ability) for whitebark pine was still negatively impacted by climate change, as noted in the manuscript text.

Table S9

More details on precipitation effects on Build-Up Index (BUI), continued from the text.

Precipitation effects on BUI were more evident when temperature was lower. This was observed when we applied our second experimental approach (examining temperature and precipitation independently), specifically for the A2 precipitation-only scenario. The A2 precipitation-only scenario simulated the lowest temperature and precipitation of all scenarios. The variability of precipitation associated with the A2 climate reset the BUI throughout the season (more so than the base precipitation), with intermittent ‘bursts’ of rainfall. Therefore, despite the lower annual precipitation of the A2 precipitation-only scenario, the increased seasonal variability in precipitation lowered the overall availability of combustible fuels (lower average BUI). These interacting effects of low ignition potential (FFMC) and low available combustible fuel (BUI) over the season resulted in the lowest overall area burned and fire severity of all scenarios. The effect of rising temperatures dampened the effect of variable precipitation on BUI, where no differences in average BUI were found for either A2 climate or A2 temperature-only. In other words, the increased flammability of fine fuels ultimately outweighed fuel availability. Furthermore, as more area burned throughout the A2 climate, fewer fuels were available simply because more were consumed by fire (as compared to base climate). This effect of precipitation on BUI was ultimately minimal compared to the temperature effects on fine fuel moisture and the overarching impact of rising temperatures driving changes in the system as a whole. In addition, changes in precipitation (increase or decrease) will most likely not have a significant effect on fire weather because most of the rainfall at the LTB either occurs outside the summer season or as snowfall. Essentially, the summers (fire season) are already dry. Changes in temperature that may cause earlier snowmelt may have more impact (extending dry season) than changes in precipitation throughout the year.

Fig. S1

An example of growth response to temperature for the “conifer” functional group developed from the 4 PPDF parameters from Table S2.

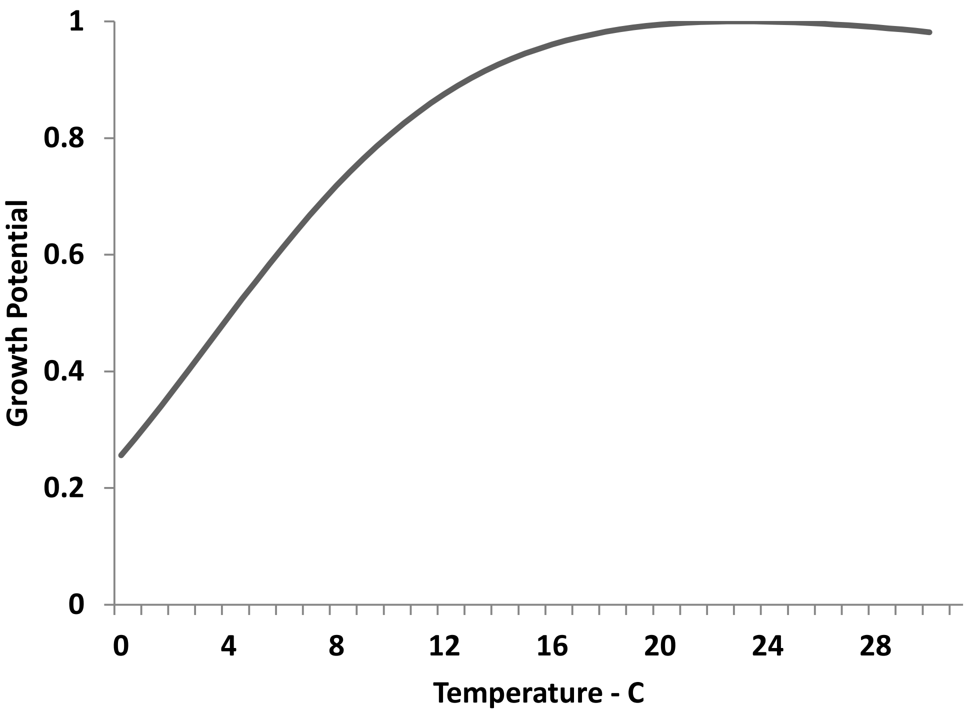


Fig. S2

Range of soil organic matter (SOM) decay rates explored when calibrating initial soil organic carbon initial conditions and accumulation rates. SOM2 represented the slow soil pool (SOM2) in the Century extension in LANDIS-II. See Table S3. Decay rate of 0.02 was chosen for this study.

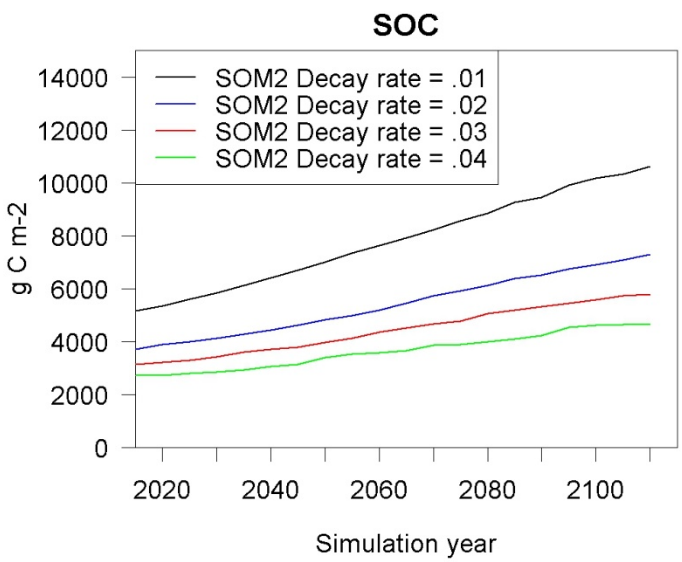
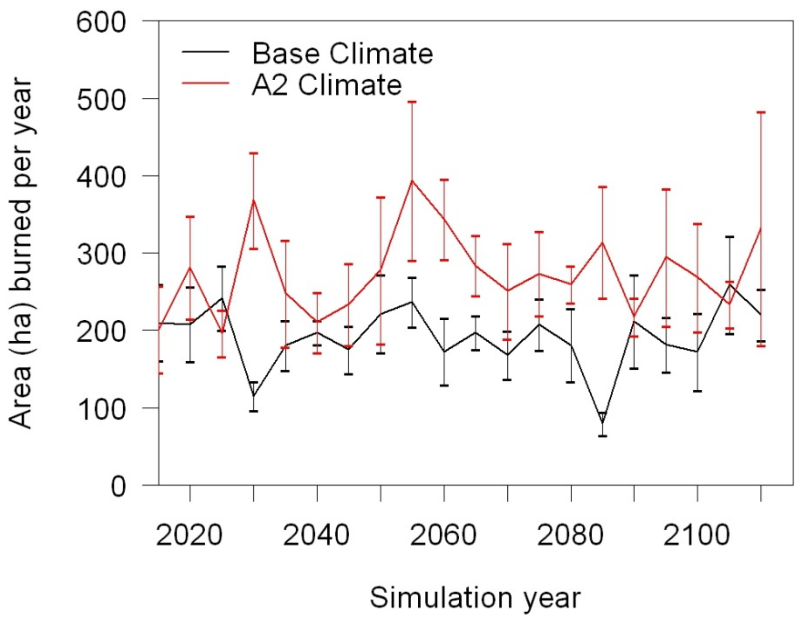


Fig. S3

Area burned (ha) per year comparison between base and A2 climate scenario simulations.



Output fire summary statistics, mean (standard deviation) across 100 year simulations and five replicate runs.

Climate Scenario	**Fire Rotation Period (yrs.)**	**Mean Fire Size (ha)**	**Max Fire Size (ha)**	**Mean Annual Area Burned (ha)**
Base Climate	360 (12)	62 (110)	848 (212)	192 (91)
B1 Climate	338 (30)	70 (128)	1141 (247)	205 (105)
A2 Climate	293 (19)	89 (150)	1295 (774)	274 (130)