The Thomas fire (2017) burned a total area of 114,037 ha (281,791 acres) on federal and non-federal land in Santa Barbara and Ventura counties. We report on the portion of Thomas fire that occurred on the Los Padres National Forest, accounting for 60% of the total fire. To query the Thomas fire:

Step 1. Select year
The Thomas fire started on 5 December 2017, so '2017' is selected to display the list of fires that occurred in that year.

Step 2. Select Fire
The 'Thomas (USFS only)' is selected (so data are reported only on the portion of the Thomas fire that overlaps with national forest lands).

Step 3. Select ecosystem services
All six ecosystem services are available to query for the Thomas Fire.

Outputs for each ecosystem service and interpretation

Below we describe the outputs from SoCal EcoServe for the Thomas fire (USFS portion only) and provide some interpretation. A full description of the data and methods for generating these outputs can be found at http://fs2.bioe.orst.edu/EcoServe/Methods.html. Note that SoCal EcoServe includes a comprehensive set of tables, graphs, and maps for each ecosystem service, however, here we only present selected outputs.

1. Water runoff

The SoCal EcoServe water runoff table shows the area of the fire being analyzed is 152,896 acres (the portion of the Thomas fire on the Los Padres National Forest). Water runoff (data from the Basin Characterization Model, Flint et al. 2014) in the year before the fire is 89,781 acre-feet/year, which is less than the 30 year average (1980-2010) at 95,426 acre-feet/year. After integrating the RAVG burn severity data into the runoff data, the total amount of water runoff post-fire is estimated to be 47,931 acre-feet/year (Fig. 1A, for method details see http://fs2.bioe.orst.edu/EcoServe/Methods.html). The first five rows in the table show the amount of runoff associated with each of the Rapid Assessment of Vegetation Condition after Wildfire (RAVG) Canopy Cover loss classes (https://fsapps.nwcg.gov/ravg/, Fig. 1A). The user can toggle between table and graph format to view the total values for pre- and post-fire (Fig. 1B).

A

Cover Loss	Area (acres)	Volumetric total within fire perimeter (acre-feet/year)
0%	14,571	2,365.44
0 - <25%	5,822	1,433.73
25 - <50%	3,297	865.14
50 - <75%	3,909	1,138.67
75 - 100%	125,295	42,128.00
Post Fire (total)	**152,896**	**47,930.99**
Pre Fire (total)	**152,896**	**89,781.29**
Pre Fire (total, 30 yr avg)	**152,896**	**95,426.87**

Download data: Table Chart Data Spatial Data Map

B

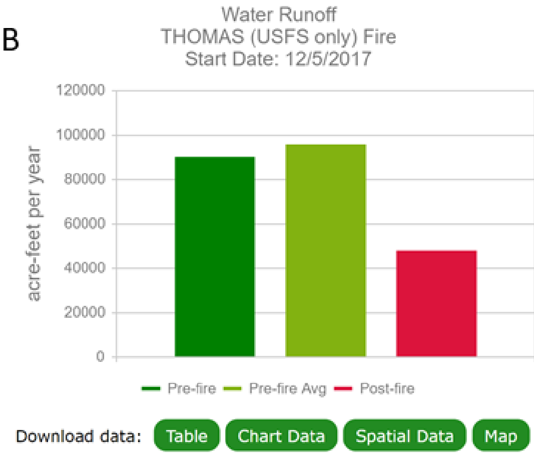


Fig. 1. Selected outputs from SoCal EcoServe for water runoff pre- and post-fire for the Thomas fire in table (A) and graph format (B)

Counter to what is expected post-fire, these estimates show a decrease in post-fire runoff by about one half of the pre-fire estimate. Typically post-fire runoff will increase owing to reduced evapotranspiration by plants and the creation of hydrophobic soils during fire which can reduce infiltration (Cydzik and Hogue 2009; Neary et al. 2003). One explanation for why this pattern is not shown for the Thomas fire is that the postfire year (2018) experienced one of the lowest amounts of annual precipitation of any year between 2000-2019 and the second warmest mean annual temperature (Fig. 2).

The longevity of changes in post-fire water runoff (and groundwater recharge) is uncertain: studies from southern California report a wide range of recovery periods from a couple of years to decades, depending on burn intensity and climate. In fact, runoff and recharge have been found to be more sensitive to the effects of climate than to the period of time post-fire (Flint et al. 2019).

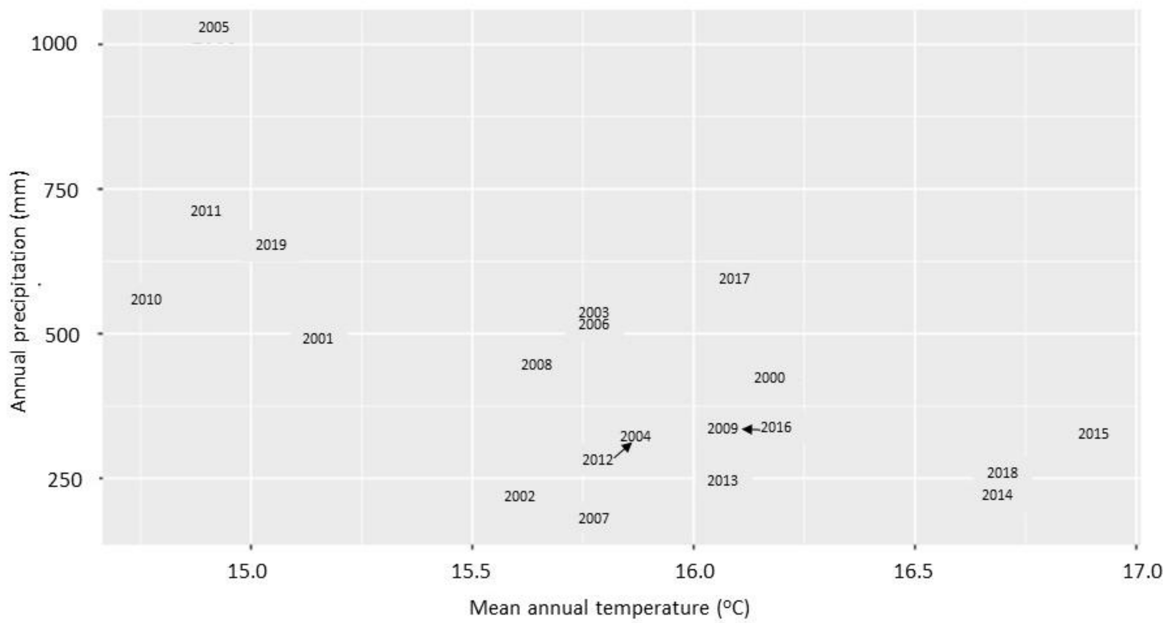
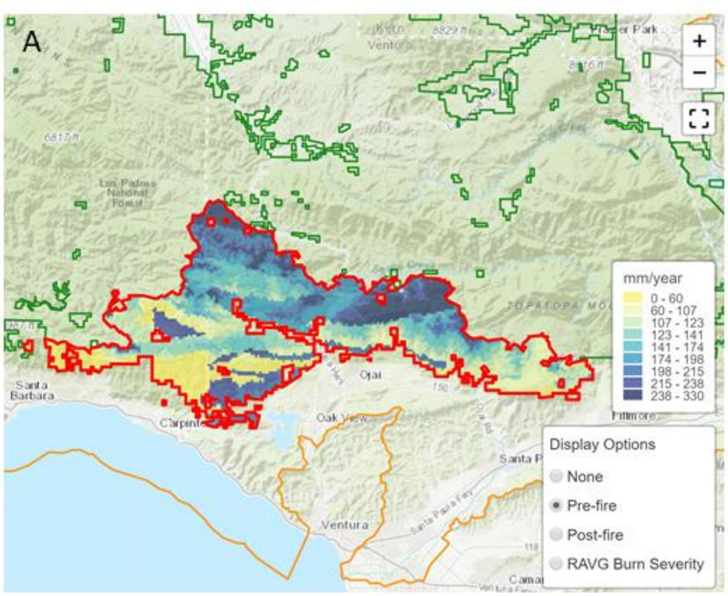


Fig. 2. Plot of annual precipitation and mean annual temperature for southern California water years 2000-2019 (the years 2012 and 2016 are offset to avoid overlap and arrow indicates correct position)

2. Groundwater recharge

Pre-fire groundwater recharge is relatively high in the northern elevations of the fire and, in general, lower towards the coast (Fig. 3A). The effect of the drought on groundwater recharge can be seen in the table (Fig. 3B): the total for the pre-fire year of 75,280 acre-feet/year is approximately one-third less than the recharge over 30 years (104,785 acre-feet/year). Similar to water runoff, post-fire groundwater recharge (66,695 acre-feet/year) is also less than pre-fire, which again is contrary to the expected pattern when vegetation is removed, but is explained by exceptionally low levels of precipitation in 2018 (Fig. 2).



B

Cover Loss	Area (acres)	Volumetric total within fire perimeter (acre-feet/year)
0%	14,571	3,667.54
0 - <25%	5,822	1,206.66
25 - <50%	3,297	935.30
50 - <75%	3,909	1,445.91
75 - 100%	125,295	59,439.81
Post Fire (total)	**152,896**	**66,695.21**
Pre Fire (total)	**152,896**	**75,280.33**
Pre Fire (total, 30 yr avg)	**152,896**	**104,785.03**

Download data: Table Chart Data Spatial Data Map

Fig. 3. Selected outputs from SoCal EcoServe for groundwater recharge: (A) map of pre-fire recharge and (B) table reporting pre- and post-fire recharge

3. Carbon storage

Biomass data are modeled based on NDVI and EVI derived from Landsat imagery and a suite of other environmental data layers, and a Random Forest machine learning algorithm informed by field measurements of biomass from 723 plots (see http://fs2.bioe.orst.edu/EcoServe/Methods.html). As the Thomas fire burned in December 2017, the pre-fire estimates of carbon storage use aboveground live biomass data from July/August 2017 and post-fire estimates are from July/August 2018.

The total pre-fire carbon storage is 1,873,626 metric tons (approximately one-third more than the 15 year average) which post-fire decreases by two-thirds to 646,586 metric tons (Fig. 4B). The change between pre- and post-fire carbon storage (a downloadable output) varies across the fire perimeter, with changes of up to 8.1km/m^2 (Fig. 4A).

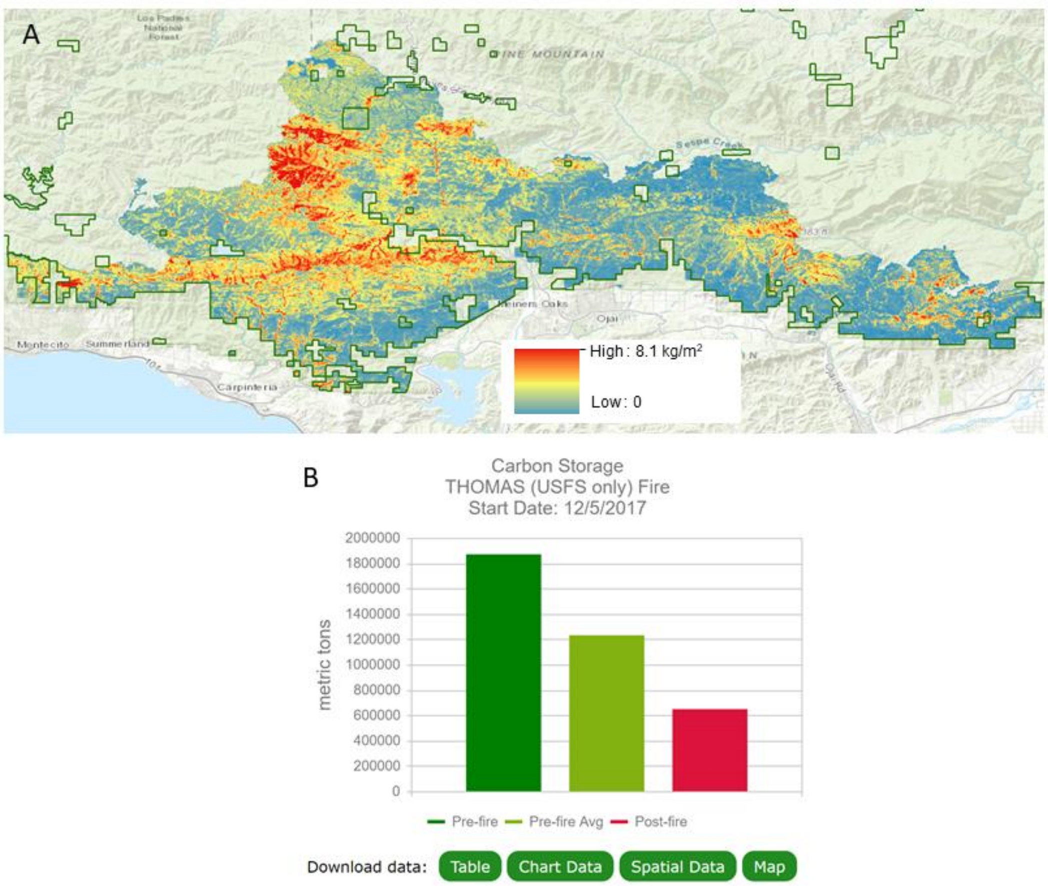


Fig. 4. Selected outputs from SoCal EcoServe for carbon storage: (A) change in carbon storage pre- and post-fire (output downloadable under 'spatial data') shown in kg/m^{2}and (B) graph of change in carbon storage pre- and post-fire in metric tons

By area, the pre-fire mean (live aboveground) biomass in the Thomas fire is estimated at 5.55 kg/m^2 and post-fire at 2.16 kg/m^2. For comparison, a review of field studies by Bohlman et al. (2018) found live aboveground biomass (across all stand ages) in mixed chaparral averaged 3.2 kg/m^2 (25 studies); for chamise chaparral averaged 1.7 kg/m^2 (13 studies); and for coastal sage scrub averaged 0.66 kg/m^2 (10 studies). Note also, that some areas of the Los Padres National Forest have not burned in >30 years and are also relatively high latitude compared to some studies, so productivity is likely to be higher. Further exploration of biomass and carbon storage values can be conducted by downloading the spatial data from the tool and assessing in relation to statewide fire data, such as the Fire Return Interval Departure dataset (USDA 2015).

4. Sediment export (erosion)

Sediment export pre- and post-fire is modeled using the Natural Capital Project's InVEST sediment erosion module (Hamel et al. 2015), tailored to southern California and applying a scaling factor to account for the amount of sediment that reaches the debris basin (see http://fs2.bioe.orst.edu/EcoServe/Methods.html). The pre-fire sediment export data totals 587,656 cubic meter/year and again, as with groundwater recharge, there is a large difference between the single pre-fire year estimate which is approximately one-third of the 30 year estimate (1,901,731 cubic meter/year) (Fig. 5).

After integrating the RAVG Canopy Cover loss data into sediment export data for one year after the fire (2018) sediment export increases approximately 14-fold to 8,017,704 cubic meters/year (Fig. 5B). This increase is due to the loss of native vegetation which stabilizes soils through deep roots, intercepts rainfall, and reduces overland flow.

It is important to note, however, that the InVEST sediment erosion module only considers annual precipitation and does not account for the intensity of individual winter storm events that characterize southern California and cause substantial erosion. Consequently, our estimates of sediment export are relatively conservative since most sediment moves in these extreme rainfall events (Wohlgemuth and Lilley 2018).

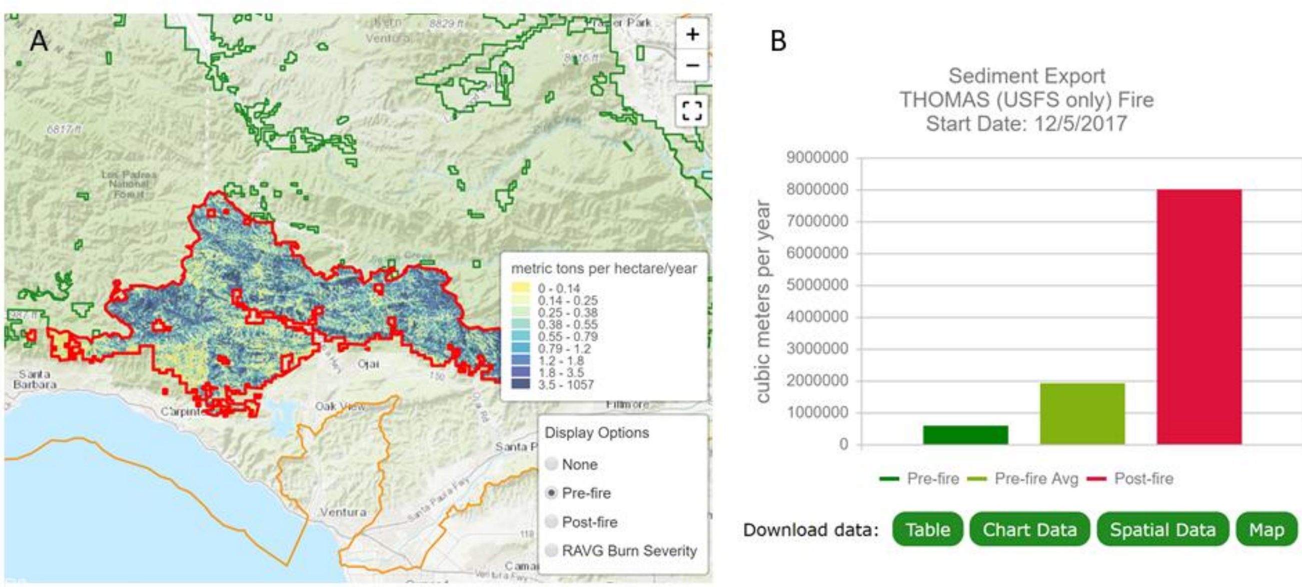


Fig. 5. Selected outputs from SoCal EcoServe for sediment export: (A) map of pre-fire sediment export and (B) graph of pre- and post-fire totals

5. Biodiversity

For biodiversity we report an overall biodiversity score generated using the Marxan conservation planning software (Fig. 6). The Marxan analysis generates a single score based on multiple biodiversity data inputs including landcover type, sensitive species, landscape connectivity, steelhead trout, data from the USDA Forest Service Watershed Condition Class Framework, and native and rare species richness (for details see http://fs2.bioe.orst.edu/EcoServe/Methods.html). The 'Marxan score' represents the irreplaceability score assigned based on the biodiversity data inputs (and associated conservation targets and goals) across the entire southern California study area. Higher values indicate areas of greater importance for meeting conservation goals.

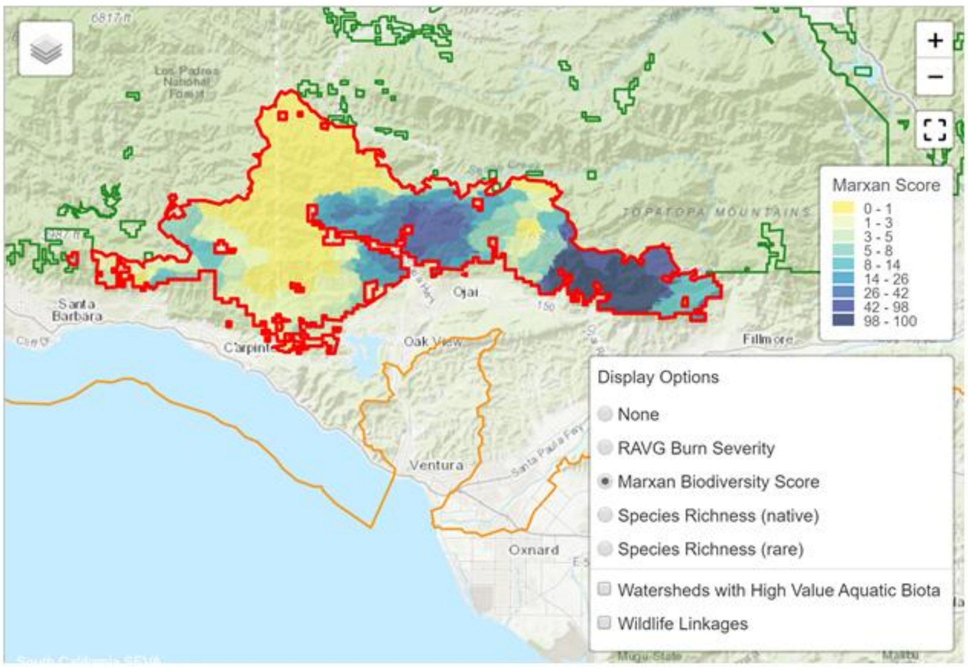


Fig. 6. Marxan scores representing the irreplaceability of areas assigned based on numerous biodiversity input data layers (higher values are more important)

The output table (Fig. 7) compares the biodiversity values of the Thomas fire to the entire Los Padres National Forest and the three other southern national forests. The Thomas fire has similar biodiversity values to the Los Padres, with 87% and 88% respectively classified as low biodiversity (i.e., Marxan scores between 0-50) and only 11% classified as high biodiversity (i.e., scores 76-100) compared to 37%, for example, on the San Bernardino National Forest. Within the Thomas fire, highest biodiversity scores centered on the Santa Paula Creek area, in part because the southern California linkage corridor overlaps. In addition, the Santa Paula Creek watershed is categorized as high for 'aquatic biota' in the Watershed Condition Class Framework which is an input dataset in the Marxan analysis.

While numerous biodiversity elements were captured in this process, future iterations could improve the relevancy of results for managers. For example, additional input from regional experts on the biodiversity data, or the conservation goals specified for these, would result in a different output from Marxan. An important point relating to the biodiversity data is these are calculated in a pre-fire state and do not account for fire or other disturbances on the landscape. Furthermore, the date the input data layers were generated varies (for details see http://fs2.bioe.orst.edu/EcoServe/Methods.html).

Another limitation is the general lack of comprehensive presence/absence data for individual species across large areas such as the study footprint. While presence data were assembled from multiple sources, these were generally collected opportunistically rather than systematically, likely leading to some bias in the final areas identified through the Marxan assessment process. Despite these shortcomings, the analysis represents a first approximation of identifying patterns of biodiversity that can assist with management decision making.

In addition to the overall biodiversity score, the table also reports native and rare species richness within the target fire and the four southern national forests for comparison (Fig. 7). For example, the mean native species richness is 0.78 within the Thomas fire which is similar to three of the national forests (with the Cleveland being higher). One notable point is that 30% of the Thomas fire on the Los Padres National Forest is a wildlife linkage zone, which is relatively high compared the proportion on the entire forest (13%) or the other forests (Fig. 7). Finally, the table reports the number of rare species in different taxonomic groups from the California Natural Diversity Database (2015 version, https://www.wildlife.ca.gov/Data/CNDDB) and again, compares this to the number found in each national forest. A list of the species within each taxonomic group can be downloaded using the 'Table' download button.

Biodiversity (Independent of Fire Effects)	Fire Perimeter	San Bern-ardino NF	Angeles NF	Los Padres NF	Cleve-land NF
Acres (x1000 for NF)	226,211	663	659	1774	659
Percent of fire area in each NF	NA	0	0	100	0
Mean Marxan Biodiversity	18.18	45.27	25.58	14.95	38.05
Percent Low Marxan Biodiversity	86.65	55.91	76.81	87.89	66.14
Percent Moderate Marxan Biodiversity	2.8	6.76	4.78	3.76	6.01
Percent High Marxan Biodiversity	10.55	37.33	18.40	8.35	27.85
Native species richness (mean)	0.78	0.78	0.79	0.76	0.85
Rare species richness (mean)	0.11	0.15	0.16	0.10	0.20
Percent area with high value aquatic biota	9.86	3.93	17.4	36.4	47.6
Percent area with linkage zone	30.91	18.7	9.1	13.1	4.1
Number of rare plant species	8	112	48	82	74
Number of rare bird species	2	8	6	7	5
Number of rare mammal species	1	15	13	11	16
Number of rare reptile species	2	10	6	5	9
Number of rare amphibian species	4	5	6	4	3
Number of rare fish species	1	4	4	3	1
Number of rare invertebrate species	0	5	2	9	2

Fig. 7. Summary of biodiversity in the USFS national forest portion of the Thomas fire (note, data do not reflect landscape disturbances such as fire and data have been compiled at different dates)

6. Recreation

There are 13 recreation sites in the national forest portion of the Thomas fire including campgrounds, day use sites, trailheads, and the Wheeler Gorge Visitor Center (a subset of sites are shown in Fig. 8A). Of these, eight are USFS National Visitor Use Monitoring Survey (NVUM) sites and analyzed in the study by Garnache and Lupi (2018), and have associated information on the total number of visits a year (Fig. 8B, for details see http://fs2.bioe.orst.edu/EcoServe/Methods.html). The NVUM sites are identifiable in the map by the number that appears after the site name.

In the table display of NVUM sites (Fig. 8B), the Santa Paula Canyon Trailhead had by far the most visits, over 32,000 predicted visits in one year, and the Wheeler Gorge Campground the least with 610 visits. After fire, the assumption is that these sites are impacted and unavailable for recreation use, however, there may be others outside of the fire perimeter that are also impacted, for example, owing to restricted access.

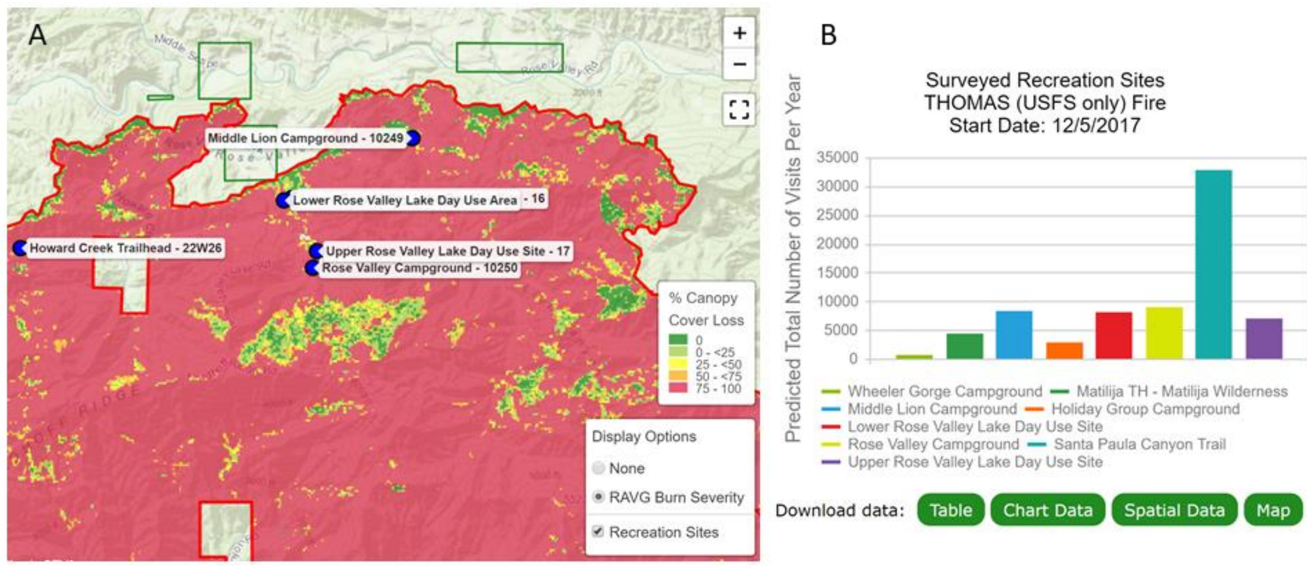


Fig. 8. Selected outputs from SoCal EcoServe for recreation: (A) location, name and NVUM site identification (where present) of recreation sites in the northern part of the Thomas fire underlain by the RAVG Canopy Cover loss data and (B) the predicted total number of visits per year for a subset of recreation sites where data are available

Using outputs from SoCal EcoServe

The table, chart data, and spatial data associated with each ecosystem service can be downloaded. The table and chart data can be used to support graphics and tables in reports while the spatial data (geotiffs and shapefiles) can be used in GIS software to assess with other data layers (for details see Methods http://fs2.bioe.orst.edu/EcoServe/Methods.html and ReadMe associated with the 'spatial data' download).

References

Bohlman, G.N., E.C. Underwood, and H.D. Safford. 2018. Estimating biomass in California's chaparral and coastal sage shrublands. Madroño 65(1): 28-46.

Cydzik, K. and T. S. Hogue. 2009. Modeling postfire response and recovery using the Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS), Journal of the American Water Resources Association (JAWRA) 45(3):702-714. DOI: 10.1111 ⁄ j.1752-1688.2009.00317.x

Flint, L. E., and A. L. Flint. 2014. California Basin Characterization Model: a dataset of historical and future hydrologic response to climate change. U.S. Geological Survey Data Release. http://dx.doi.org/10.5066/F76T0JPB

Flint, L.E., E.C. Underwood, A.L. Flint, and A.D. Hollander. 2019. Characterizing the influence of fire on hydrology in southern California. Natural Areas Journal 39(1):108-121.

Garnache, C., and F. Lupi. 2018. Identifying the effect of fire on the value of forest recreation services, working paper presented at World Congress of Environmental and Resource Economists, Gothenburg Sweden, June 2018.

Hamel, P., R. Chaplin-Kramer, S. Sim, and C. Mueller. 2015. A new approach to modeling the sediment retention service (InVEST 3.0): case study of the Cape Fear catchment, North Carolina, USA. Science of the Total Environment 524-525:166-177.

Neary, D. G., G. J. Gottfried, and P. F. Folliott. 2003. Post-wildfire watershed flood responses. In Proceedings of the 2nd International Fire Ecology Conference, Orlando, Florida (pp. 16-20).

USDA (US Department of Agriculture). 2015. Fire-return interval departure (FRID) geodatabase, calendar year 2014. http://www.fs.usda.gov/detail/r5/landmanagement/gis/?cid=STELPRDB5327836.

Wohlgemuth, P. M. and K. A. Lilley. 2018. Sediment delivery, flood control, and physical ecosystem services in southern California chaparral landscapes. Pages 181-205 in Underwood, E.C, H.D. Safford, N.A. Molinari, and J.E. Keeley, editors. Valuing chaparral: ecological, socio-economic, and management perspectives. Springer Series on Environmental Management. Springer, Cham, Switzerland.