Post-fire Restoration Prioritization Tool for Chaparral Shrublands Technical Guide

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Introduction

The concept and design of the Post-fire Restoration Prioritization (PReP) Tool for chaparral shrublands is based on a tool developed by the Mediterranean Center for Environmental Studies (CEAM) and the University of Barcelona to support forest planning in Spain. The original tool assesses the impact of forest fires based on a variety of spatial data and ecological criteria (Alloza and Vallejo 2005; Alloza et al. 2006; Alloza and Vallejo 2006; Duguy et al. 2012). Using the Copper Fire on the Angeles National Forest as a pilot case study, we collaborated with the original researchers to adapt and apply the Spanish tool to chaparral shrublands in southern California.

The PReP Tool provides a transparent and repeatable framework for USFS resource managers to guide and prioritize post-fire restoration efforts in shrubland, with the following objectives:

- Assess regeneration ability of landscape post-fire
- Predict areas of degradation on the landscape
- Identify priorities for restoration
- Inform species for restoration

Specifically, the tool determines the regeneration capacity of the landscape post-fire based on the relative proportion of seeding, resprouting, and facultative seeding species, and the risk of post-fire soil erosion. Generating this information efficiently is particularly important given the often short timeframes involved in implementing restoration activities, such as the use of fire settlement funds or implementing urgent activities to reduce sediment erosion post-fire.

The PReP Tool uses a Jupyter notebook framework, which allows a reproducible and interactive workflow for conducting geospatial computations. It is well-suited to the overall objectives of the PReP Tool as it allows revisions to be made easily and efficiently, which might be necessary when applying the tool to other fires in southern California. In addition, it uses Python code which allows it to be integrated with a variety of other platforms, such as GIS packages that support Python scripting. Within the PReP Tool there are options to download the spatial data as geotiff rasters which can be viewed in GIS platforms such as ArcGIS, allowing outputs to be viewed with other spatial datasets such as roads, trails, or project area boundaries.

The original tool from Spain required a number of adaptations to apply it to chaparral shrublands in southern California. First, much higher resolution, species level vegetation data are available in Spain compared to our pilot site, which meant we had to develop a database of resprouting and seeding species. Second, the original tool relies heavily on field collected data which, although essential for verifying outputs of the tool, cannot be guaranteed in advance of running the tool owing to limited resources. Third, we have adapted the tool to focus specifically on chaparral shrublands rather than all plant lifeforms, which has involves additional components relating to drought and invasion of non-native grasses that do not exist in the original tool.

Intended users

The PReP Tool is designed to be a straightforward interface, using a conceptually straightforward scoring method, and intended to be used as a management tool by resource staff working on chaparral shrublands. The tool requires some data layers to be downloaded and clipped to the target fire, but after this initial preparation the PReP Tool can be run without any further GIS analysis. Input from a botanist or person familiar with the pre-fire vegetation would be beneficial in Step 1 of the tool where we require information on the proportion of resprouting and seeding species.

Setting up the tool

Running the PReP Tool requires downloading the Jupyter notebook and example data for the Copper fire pilot study: file 'PReP_Tool.zip' from https://github.com/adhollander/postfire. More detailed instructions are provided in the 'Postfire Regeneration Tool_Installation Instructions'.pdf. In summary;

1. The tool requires the installation of the open source Jupyter platform and R software (version 3.7) via the Anaconda Distribution, downloading and installation instructions are detailed at https://jupyter.org/install (select the Python version for Window or Mac as needed using the tabs on the top of the page). Ensure that you download this full version (with all the associated Python libraries).
2. Once downloaded double click the file to install (accepting the default parameters).
3. In addition to the standard packages that come with Anaconda, the user also needs to install several Python libraries, including xarray, ipywidgets, pyproj, gdal, and rasterio. This is done by opening the Anaconda Prompt under the Window Start menu. Directions for installing these packages in Anaconda are available at https://docs.conda.io/projects/conda/en/latest/user-guide/tasks/manage-pkgs.html.
4. From the Windows start menu, open the Anaconda Navigator, and on this screen find the Jupyter Notebook tile and click 'Launch' .
5. In this window you can path to the PReP_Tool.ipynb file under the 'Documents' link and click the ipynb file to open the tool.

The downloaded tool consists of:

- Jupyter notebook file that runs the tool (*.ipynb)
- A suite of sample data for the Copper fire (2002) (at 30 m spatial resolution) so the user can test the tool and see the appropriate naming conventions and directory structure, which must be reflected if PReP Tool is run on a new fire. The sample data for the Copper fire include:
    - Landscape_WHR_topo.tif: fine scale landscape units
    - Herbaceous.tif: raster data on the percent herbaceous cover (for 2001)
    - Erosion.tif: Erosion risk data from BAER
    - Firecount.tif: USFS FRID data

In general, these are regional spatial datasets that the user needs to clip to the target fire boundary, rename as shown in the example of the Copper fire rasters above, and store in the correct directory. Regional datasets which require preparation include:

- Percent herbaceous cover for southern California for 1984-2010 (30 m pixels). These data can be downloaded from: https://ucdavis.box.com/s/b3fiisbusof9tr0wa5zrhxum655vqgsi.

- The USFS Fire Return Interval Departure database (FRID, 2018). Note, users should check for annual updates of the FRID available from: https://www.fs.usda.gov/detail/r5/landmanagement/gis/?cid=STELPRDB5327836.
- Landscape_WHR: coarse scale landscape units for the southern California region. Available for the southern California region at: https://github.com/adhollander/postfire.
- Landscape_WHR_topo: fine scale landscape units for the southern California region. Available for the southern California region at: https://github.com/adhollander/postfire.
- BAER erosion risk data needs to be requested from the national forest that the target fire occurred on.

When running the PReP Tool, the user will need an internet connection to access a NOAA website to query the Palmer's Drought Severity Index: https://www.ncdc.noaa.gov/temp-and-precip/drought/historical-palmers/

As is customary with Jupyter notebooks, the tool's content consists of text and graphics which is interspersed with code. On opening the tool, the source coding will be hidden, but the user can click on a link early in the tool to view the code. Accessing the code is intended to allow users to make slight modifications to the PReP Tool, for example to alter the scoring system.

Overview

As with the original tool applied in Spain, the PReP Tool methodology assumes that post-fire vegetation in chaparral shrublands undergoes a self-succession process (Trabaud 1994), reflecting the key influences of the post-fire reproductive strategy of the species and fire frequency. Chaparral shrubland plant species belong to different functional groups based on their mode of post-fire regeneration strategy and recovery (Pratt 2007; Jacobson 2007; Pausas and Keeley 2015). There are three functional groups represented in the PReP Tool:

- Obligate resprouter species regenerate solely by resprouting new shoots from dormant buds. There are different types of resprouting depending on the location of buds (epicormics, lignotuber, rhizome, roots etc.). There is no germination after fire because they lack a fire-resistant seed bank (although reproduction by seed can occur in fire-free intervals);

- Obligate seeder species regenerate through germination of fire-cued seed banks (often profusely), and do not resprout post-fire. Recruitment of seeders is often restricted to a single pulse after a fire;

- Facultative seeder species regenerate through both mechanisms post-fire: seed germination and resprouting from their root crown.

These functional groups have different characteristics which we incorporate into the PReP Tool. For example, obligate seeders are highly dehydration tolerant whereas obligate resprouters include some of the most dehydration-avoidant taxa found in chaparral, and facultative seeders are in between (Jacobson et al. 2007; Pratt 2007).

The PReP Tool walks the user through five main steps and a number of sub-steps (tasks) to determine the relative regeneration capacity of pixels within the fire perimeter, determined by a series of decision rules and associated scoring system. In short, the pixel's regeneration capacity is based on the species present (determined by its reproductive strategy) and modified by its fire history, drought tolerance pre- and post-fire, and presence of non-native grasses. The last step of the tool integrates this modified regeneration capacity with soil erosion risk data to identify areas at risk of ecosystem degradation (Figure 1). The final map (Output Map 5, Figure A2) from the tool is intended to guide post-fire management decisions relating to

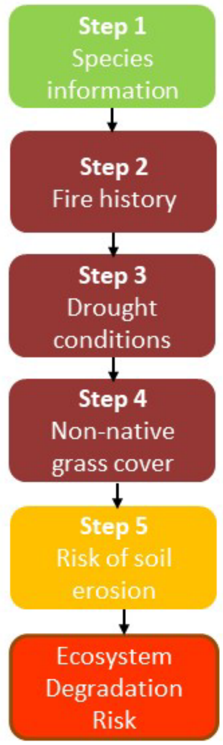

Figure 1. Schematic of the steps involved in the PReP Tool for chaparral shrublands to identify areas at risk of ecosystem degradation and consequently areas for management focus

restoration based on areas that are unlikely to regenerate sufficiently well naturally and have a high risk of erosion.

The tool starts with characterizing the proportion of functional groups of species by landscape units (created based on vegetation, slope, and topography) within the fire perimeter. The subsequent steps and analyses serve to modify the rankings assigned to landscape units, on a pixel by pixel basis.

STEP 1. DETERMINE POST-FIRE EXPECTED REGENERATION RATE

The original tool has three different categories of regeneration capacity associated with different lifeforms – shrub, forest, and herbaceous. In this first phase of adapting the tool to southern California we only focus on chaparral shrublands, which are the dominant vegetation type in the four southern USFS national forests. Relative to other lifeforms such as pines in the sapling stage or conifers, shrubs have a high regeneration capacity post-fire: some species resprout while the seeds of other shrub species are stimulated by fire, meaning that the site can reproduce by itself. Details of the regeneration capacity of other lifeforms associated with the original tool in Spain can be found in the Alloza et al. (2016) technical report.

Assign pre-fire proportion of resprouters and facultative seeders

The foundation for the application of the original tool in Spain are species-level maps which are tied to the post-fire reproductive strategy of those species. In the absence of high resolution vegetation data for many areas in southern California, including the Copper fire, the PReP Tool offers users two spatial scales to assign information on the functional groups occurring there:

1. Coarse landscape (vegetation) units defined by the California Wildlife Habitat Relations (WHR) classification (Mayer et al. 1988);
2. Fine scale landscape units where the WHR classification is intersected with aspect (two classes: north or south facing) and topography (three classes: summit and ridges, slopes, valleys and depressions based on Jasiewics et al. 2013). These combinations are used to indicate warmer, more exposed WHR vegetation types versus cooler, less exposed WHR types which are associated with different regeneration rates. For example, ’mixed chaparral south-facing slopes, summits, and ridges’ are warmer, versus the cooler ‘mixed chaparral north-facing slopes, valleys, and depressions’.

The fine scale landscape units recognize the importance of slope aspect and angle in determining chaparral shrubland vegetation communities. For example, moderately steep, south facing slopes receive the most direct sunlight for longer periods than other slope aspects such as north aspects which are comparatively cool and shady during most of the year owing to low rates of solar insolation and PET (Barbour et al. 1987; Gordon and White 1994). Field studies suggest that south facing slopes that stay dry for longer are dominated by seeder species, which have a relatively high tolerance of tissue dehydration, while resprouters predominate in sites with more reliable water supply throughout the year (Keeley et al. 2012; Meentemeyer and Moody 2002).

Once the scale of the landscape units to use is selected, these are characterized by the proportion of resprouter and facultative seeder species that occur within them. For each landscape unit, either coarse (WHR vegetation only) or fine scale (WHR x aspect x topography), the tool presents a pre-populated table of the proportion (surface cover percentage) taken up by the resprouter and facultative seeder species that occur. The pre-populated table shows landscape units and proportions for the Copper fire as a default, which the user can modify. These data have been developed based on a number of sources, including an analysis of percent cover of resprouter, facultative seeder, and seeder species in USFS Forest Inventory and Assessment (FIA) shrubland plots; reference to ecological field guides for the Angeles, San Bernardino, and Cleveland national forests (Gordon and White 1994) and the Los Padres National Forest (Borchert et al. 2004); and input from a botanist from the Angeles National Forest. Note that these pre-populated tables only provide a guideline and field surveys are highly recommended to confirm the accuracy of these classes for the target fire being assessed.

The regeneration rate category of each landscape unit (high, moderate, low, and no data) is determined by the proportion of post-fire reproductive strategies (i.e., functional groups) of the species present (Vallejo and Alloza 1998):

- **High**: presence of ≥40% of resprouting (R) and/or facultative seeding (FS) species in the landscape unit. This 30-40% threshold is considered effective soil protection (Thornes 1995). The assumption is that a rapid post-fire response from resprouters will provide rapid protection from soil erosion;
- **Moderate**: presence of 10 to 40% of resprouting (R) and/or facultative seeding (FS) species;
- **Low**: presence of fewer than 10% of resprouting (R) and/or facultative seeding (FS) species or only seeding species present;
- **No data**: insufficient data to assess landscape unit.

Within each landscape unit, scores are assigned to each pixel (30 m resolution) relative to their regeneration rate (Table 1).

Table 1. Assignment of scores based on regeneration rate determined based on the relative proportion of resprouting and facultative seeding post-fire reproductive strategies: R = resprouter species, FS = facultative seeder species

Regeneration rate			
High (≥40% R or FS)	*Moderate (10-40% R or FS)*	*Low (<10% R or FS)*	*No data*
High (5 points)	Moderate (3 points)	Low (1 point)	No data

STEP 2. MODIFY REGENERATION RATE BASED ON FIRE HISTORY

Task A. Specify number of fires in previous 40 years

Fire frequency is a key determinant on how well chaparral shrubland species recover post-fire. The natural fire return interval of shrublands in southern California is 30-130 years (Keeley and Syphard 2018), however experiencing shorter return intervals can impact the regeneration potential and reproductive ability of native shrubland species. Although resprouters are more resilient to frequent fire than obligate seeders, studies show that obligate seeders can be reduced after multiple short-interval fires (Zedler et al. 1983, Haidinger and Keeley 1993; Keeley and Brennan 2012). As a consequence, seeders can become eliminated from the community resulting in increasing dominance of grasses and forbs (Syphard et al. 2018).

For the PReP Tool we use a threshold of three or more fires in any given pixel in the 40 years prior to the fire date as the number after which species regeneration will be effected. This is based on the estimated 15 years necessary for seeder species to accumulate sufficient seed for post-fire regeneration (Zedler 1995). Note that while 15 years might an adequate interval in interior chaparral sites, it is likely to take less years in moister, coastal sites. Incidentally, a recent study by Syphard et al. (2018) found fire intervals of ≤10 years represented a critical threshold determining shrubland decline and replacement in the Santa Monica Mountains of southern California. From fires occurring in 2018 onwards, the calculation of the 'number of fires last 40 years' is included as an attribute in the USDA Forest Service Fire Return Interval Departure (FRID) (https://www.fs.usda.gov/detail/r5/landmanagement/gis/?cid=STELPRDB5327836; Safford and Van de Water 2014).

For running the PReP Tool on fires earlier than 2018 the user will need to generate this number by analysis of the fire perimeter dataset available from FRAP (http://frap.fire.ca.gov/data/frapgisdata-sw-fireperimeters_download). One technique for generating this value is by creating binary rasters stating whether a fire occurred (value of 1) or not (value of 0) for each of the 40 years prior to the fire date, and summing this raster stack to get the count of fires (i.e., 1, 2, 3, or ≥3 fires) that occurred. The regeneration rate score of each pixel is modified if 3 or ≥3 fires occurred in the 40 years prior to the start date of the target fire (Table 2).

In future developments of the tool, if applying the PReP Tool to areas of the landscape that are not burning with the high severity or intensity of chaparral-dominated fires, then data on fire intensity or severity could also be integrated into the tool, e.g., high fire intensity could kill resprouters leaving open spaces for seeders to recruit.

Table 2. Modification of regeneration rate score based on number of fires in last 40 years in each pixel

	Number of fires last 40 years			
	1	*2*	*3*	*>3*
All regen. rates	no change	no change	reduce 1 class	reduce 2 classes

Task B. Specify time since last fire

We use information on Time Since Last Fire (TSLF) to provide another indication of fire frequency and occurrence of short-interval fires at the site. This data is available as an attribute in the FRID dataset since 2011. The PReP Tool summarizes this information into a three class map: 0-5 years, 5-10 years, and 10-15 years (again, these breaks are most representative of interior versus coastal chaparral). Information on TSLF is combined with the proportion of resprouters and facultative seeders on a pixel by pixel basis.

We focus on modifying scores of those pixels with a low regeneration rate (<10% R or FS, i.e., where obligate seeders represent 10-90% of shrub cover) and moderate regeneration rate (10-50% R or FS). Where these pixels have 0-5 years TSLF the score is reduced by 2 classes, and for 5-10 years post-fire, scores are reduced by 1 class (Table 3). Obligate seeders are particularly susceptible as they regenerate entirely from long-lived, fire-cued soil seed banks that require one to two decades to replenish (Zedler 1995). Furthermore, multiple field studies have documented obligate seeder decline or elimination after repeated fire (Haidinger and Keeley 1993; Zedler et al. 1983). In the future, this component of the analysis (Task B) could be further informed by integrating data on the number of years between the last fire and the one before, or integrate high resolution, remotely-sensed data which captures the recovery of biomass with time since last fire.

Table 3. Modification of regeneration rate score based on time since last fire. This modification is only applied to pixels with low regeneration (<10% resprouters or facultative seeders, i.e., 10-90% obligate seeders) and moderate regeneration rates (10-40% resprouters or facultative seeders, i.e., 60-90% obligate seeders)

	Time since last fire		
	0-5 years	*5-10 years*	*≥10 years*
Low regen. rate (<10% R or FS)	reduce 2 classes	reduce 1 class	no change
Mod. regen. rate (10-40% R or FS)	reduce 2 classes	reduce 1 class	no change

STEP 3. MODIFY REGENERATION RATE BASED ON DROUGHT

Task A. Specify drought or non-drought conditions pre-fire

Step 3 and 4 of the tool include two novel components compared to the original tool: the inclusion of drought and non-native grasses, given the importance of these factors to shrublands in southern California (Pratt et al. 2007, Syphard et al. 2019). In contrast, drought was found to have little effect on resprouters in Spain (Parra and Moreno 2018).

We first consider the existence of drought in the growing season (November to May) in the year before the fire as this can affect the regeneration of resprouter species. Note that we are less concerned with the non-growing season summer months (June to October) as these often experience drought in southern California. Pre-fire drought can affect resprouters through sub-optimal production and depleting carbon stores (Pratt et al. 2014). This becomes critical during post-fire regeneration, when resprouters draw extensively on carbon reserves to fuel resprouting and to maintain a large root system. Since this situation is limited to resprouting species, only the ranking of pixels categorized as having ≥40% R or FS species (with high regeneration rate) are affected by this decision rule.

To inform the existence of pre-fire drought conditions, the PReP Tool provides a link to access a National Oceanographic and Atmospheric Administration (NOAA) website which calculates the Palmer Drought Severity Index (PDSI) by ecoregion: https://www.ncdc.noaa.gov/temp-and-precip/drought/historical-palmers/. On the NOAA site the user specifies the year before the target fire occurred and the months November to May. The NOAA site classifies ecoregions by month based on the degree of drought: moderate, severe, or extreme, or non-drought. Using the NOAA site, the user needs to count the number of months out of the seven months of the growing season that are classified as 'severe' or 'extreme' drought (PDSI < -3) and enter this figure into the PReP Tool. In situations where the preceding growing season has ≥4 months classified as severe or extreme drought, the ranking of pixels with ≥40% R or FS species is reduced by one class (Table 4). There is no change made where there is moderate drought.

Table 4. Modification of regeneration rate score in pixels with ≥40% resprouter or facultative seeders, based on occurrence of severe or extreme drought in 4 of the seven months of the growing season (November to May) before the fire

	Regeneration rate
	High (≥40% R or FS)
Year pre-fire	reduce by 1 class

Task B. Specify drought or non-drought conditions post-fire

In addition to screening for drought conditions during the pre-fire growing season, we also assess drought conditions in the growing seasons (November to May) for each of the three years following the fire. Modification of the scores of each pixel are made on a *cumulative* basis, so scores will be modified based on year 1 drought conditions first, followed by year 2. We assess these conditions for pixels with the following regeneration rates:

1. Moderate or low: <10% R or FS or 10-40% R or FS, i.e., dominated by seeder species: although research has shown seeder species are likely to resist droughts of low to moderate intensity, and over a long period (Pausas et al. 2015) and , the ability of seeders to germinate and the survival of seedlings can be negatively impacted by drought.

2. High: ≥40% R or FS, i.e., dominated by resprouting species: extreme drought (particularly when combined with drought conditions pre-fire) can cause high mortality of resprouters. Limited water availability restricts the ability of resprouters to build a canopy and photosynthesize sufficiently to meet carbon needs, which results in part of the root system being pruned, which in turn, can reduce access to water (Table 5) (Pratt et al. 2014). If drought continues for multiple years, then it can cause the loss of hydraulic function due to drought-induced cavitation and complications arising from prolonged stomata closure and declining carbohydrate reserves (Anderegg et al. 2012; Pratt et al. 2014).

In the modification of regeneration rate scores with post-fire drought in the growing season, the reduction in the score for pixels with <10% and 10-40% R or FS (Table 5a) is relative less than those which are dominated resprouter species (Table 5b).

To apply the scoring system for drought conditions post-fire the user first enters the number of years (1 or 2) for which post-fire drought information is available. Depending on this response, the interface will display one or two boxes for the user to complete using the NOAA PDSI website (as described under Step 3, Task A). This task can still be undertaken if there are only data for year 1, i.e., it is not necessary to have 2 years of post-fire drought information before running the PReP Tool.

Based on the proportion of resprouter and facultative seeder species in each pixel, the PReP Tool applies a decision tree: for pixels with 10-40% and <10% R or FS we use Figure 5a and for pixels with <10% R or FS species we use Figure 5b.

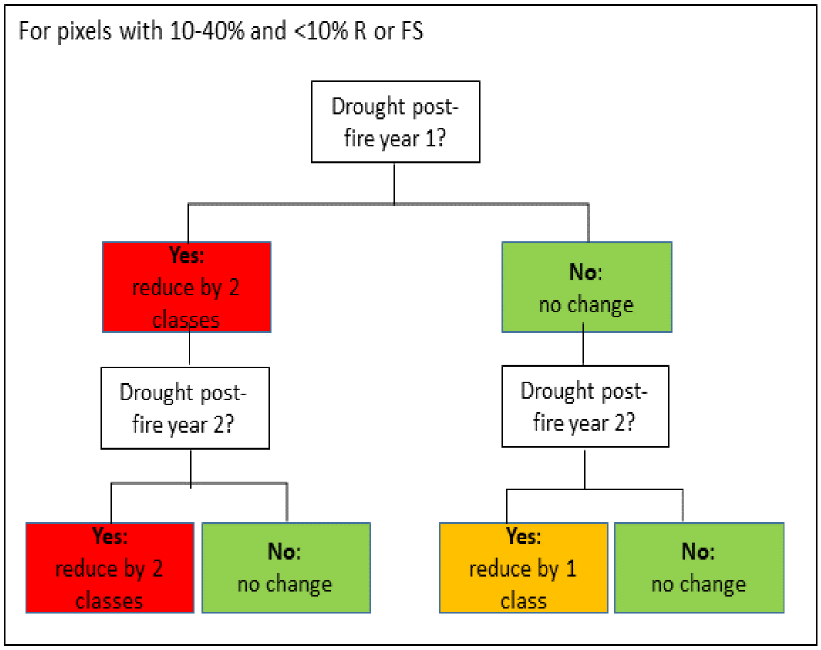

Figure 5a. Modification of regeneration rate score in pixels with 10-40% and <10% resprouter or facultative seeders based on occurrence of severe or extreme drought in ≥ 4 of the growing season months (November to May) in years 1 and 2 post-fire

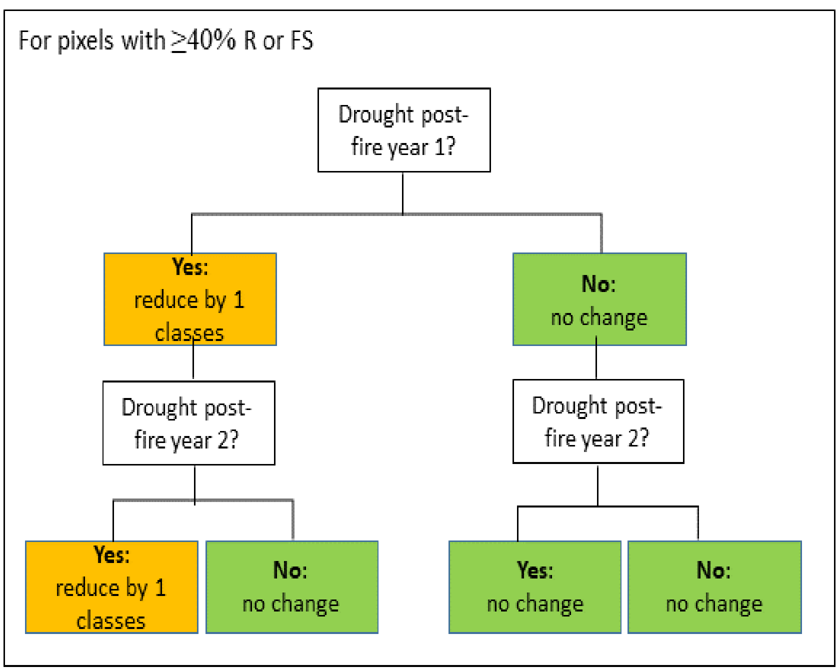

Figure 5b. Modification of regeneration rate score in pixels with ≥40% resprouter or facultative seeders based on occurrence of severe or extreme drought in ≥ 4 of the growing season months (November to May) in years 1 and 2 post-fire

Task C. Specify if fire occurs in wet season or dry season

The season in which the fire occurs relative to the growing season is a necessary factor to consider. Studies have shown that wet season (winter) fires can lead to the failure of seeds to recruit, as they have only just germinated when the summer drought occurs. In comparison, fires occurring in the dry season (spring), occur when seeds are in the seedbank waiting for the wet season for germination.

In Step 3, Task C of the PReP Tool the user is asked to select if the fire occurred in the wet season (June-October) or the dry season (November–May). If it occurred in the wet season, then the score of pixels in the moderate (10-40% R or FS) or low (<10% R or FS) regenerating classes are reduced by one class (Table 6).

Table 6. Modification of regeneration rate score in pixels with 10-40% and <10% resprouter or facultative seeders, based on occurrence of fire in the wet season

	Regeneration rate
	Moderate (10-40% R or FS) or Low (<10% R or FS)
Wet season fire	reduce by 1 class

There are a number of other considerations that are important relating to the impacts of drought but are not included in the PReP Tool. For example, the PReP Tool only considers the impacts of pre-fire and post-fire drought on native chaparral shrubland species, it does not consider the effect of drought on non-native grasses: if these are more sensitive than native species it could mean a less competitive environment for native seeders to germinate and establish which would benefit the recovery of native species. In addition, we do not consider the impact of soil depth on drought tolerance: shallow soils restrict the root depth of resprouting species, which is likely to cause a more detrimental impact of severe drought than when resprouting species occur on deeper soils.

STEP 4. MODIFY REGENERATION RATE BASED ON NON-NATIVE GRASSES

Specify abundance of non-native grasses pre-fire

The perennial grasslands adjacent to chaparral shrublands have been largely replaced by non-native grasses which now make up the majority of herbaceous cover (D'Antonio 2007). Despite the resilience of native shrublands to occasional disturbance, the close proximity of non-native grasses, occurrence of drought, anthropogenic disturbance, and altered fire regimes means chaparral has been invaded, and sometimes completely replaced, by non-native grasses (Syphard et al. 2013; Syphard et al. 2018) . Non-native grasses are a particular threat to seeding (versus resprouting) species and can ultimately lead to type conversion and alteration of fire regimes.

We recognize two components relating to the effect of invasive species on post-fire regeneration capacity. The first is the *susceptibility* to non-native grass invasion which is indicated by the proportion of resprouting and facultative seeding species present in each landscape unit. In Step 1 we assign a score for the regeneration rate of landscape units based on their proportion of resprouting or facultative seeding species: high (≥40% R or FS), moderate (10-40% R or FS), or low (<10% R or FS, i.e., dominated by seeding species). We assume that the scores assigned to these classes indicate the unit's vulnerability to a number of factors, including invasion.

The second component relates to the *abundance* of non-native species pre-fire. Data on the percent herbaceous cover for each of the years 1984-2010 for southern California are developed from Landsat TM imagery using intra-annual phenological differences in NDVI between herbaceous forbs and grasses and evergreen shrublands (Park et al. 2018). These data can be downloaded from: https://ucdavis.box.com/s/b3fiisbusof9tr0wa5zrhxum655vqgsi). Each pixel in the dataset has a value 0-1 to indicate the percent cover of non-natives (with 1 representing 100%). The percent herbaceous data for the year before the target fire will be integrated automatically into the tool, providing the raster has the standardized name as described in the 'Setting up the tool' section. If the fire occurred after 2012, then the latest date of data available (2010) need to be used, with the associated caveats that it pre-dates the target fire. Further processing by the USFS Remote Sensing Lab of recent Landsat data using the same methodology is anticipated to occur.

The user then specifies a threshold at which they assume the presence of invasive species will affect the regeneration capacity of the different functional groups. As a default, the tool uses a threshold of 20% non-natives cover in a pixel: below this threshold there is assumed to be a low risk from non-natives and there is no change in the score of the pixel (Table 7) and above this threshold, non-native species are considered a high risk to the maintenance of desired conditions in that pixel. For the moderate (10-40% R or FS) and low (<10% R or FS) regeneration rate classes, where seeding species dominate) the scores are reduced by one class (Table 7). A future modification to this component of the tool would be to consider the cover of non-natives in surrounding pixels as well.

Table 7. Modification of regeneration rate score based on % cover of non-native grasses in each pixel

		Non-native grasses threshold (%)	
		below	*above*
Regen. rate	*≥40% R or FS*	no change	no change
	10-40% R or FS	no change	reduce 1 class
	<10% R or FS	no change	reduce 1 class

STEP 5. INTEGRATE EROSION RISK

The erosion risk associated with the removal of vegetation post-fire is an important consideration for the regeneration of native shrubland species (Alloza et al. 2016). The geology, topography, and soils in southern California combine to produce a naturally very erosive landscape which is exacerbated by wildfire (Wohlgemuth and Lilley 2018; Wohlgemuth et al. 2009). Fire causes the combustion of vegetation canopy and surface litter layer, as well as fire-induced changes in soil properties, which result in increased erosion on hillslopes.

Here we integrate erosion risk data generated from the USDA Forest Service BAER (Burned Area Emergency Response) assessment which models the risk of erosion immediately post-fire (note, however, that erosion risk modeling conducted for BAER is not necessarily standardized across fires). The user will need to acquire this for the target fire from the relevant national forest. The BAER post-fire erosion risk data for the Copper fire were developed using the USDA Forest Service ERMIT tool (Erosion Risk Management Tool; https://forest.moscowfsl.wsu.edu/cgi-bin/fswepp/ermit/ermit.pl) which is based on the Water Erosion Prediction Program (WEPP). The tool predicts erosion associated with storm events, rather than an annual erosion rate. The erosion rate (tons/ha) are relative to an unburned landscape and associated (in this case) with a one in five year erosion event (i.e., an exceedance value based on 20% probability). Note that these values should be interpreted as a distribution of *erosion risk* and not a magnitude of erosion, as the number of variables involved prevents the accurate prediction of the true magnitude of erosion. In applying ERMIT, we used a one in five year erosion event as this captures variation across the landscape compared to a two year event, or a 10 year event that can be dominated by different types of erosion rather than the sheet erosion that WEPP is predicting (BAER coordinator soil scientist pers. comm). In the PReP Tool, data on erosion risk is categorized into four classes based on those used in the original tool: <25 tons/ha per year, 25-50 tons/ha, 50-100 tons/ha, and >100 tons/ha per year.

These two sources of information on degradation: one on the risk of erosion of sediment and topsoil and the other on the regeneration potential of the pre-fire vegetation are integrated and assigned to four categories: very high, high, moderate, and low (Table 8). The outcome of this integration (Output Map 5, see Figure A2) identifies areas within the fire perimeter that are potentially the most vulnerable to fire, i.e., areas with lower regeneration capacity and with more risk of soil erosion and, at the other extreme, areas which have a low risk of erosion and are likely to regenerate well without management intervention.

Table 8. Integration of the regeneration rate (based on post-fire reproductive strategy, fire history, pre- and post-fire drought, and non-native grass cover) and the BAER erosion risk data

		Erosion risk (units are t/ha/yr)			
		Low (<=25)	*Moderate (25-50)*	*High (50-100)*	*Very high (>100)*
Regeneration rate	*High*	Low	Moderate	High	High
	Moderate-high	Low	Moderate	High	High
	Moderate	Moderate	Moderate	High	Very high
	Moderate-low	Moderate	Moderate	High	Very high
	Low	High	High	Very high	Very high

This is spatially represented in the summary map of ecosystem degradation risk (Output Map 5, Figure A2). Pixels within the fire perimeter in the 'very high' class can be considered priorities for management actions to restore vegetation, as they have moderate to low regeneration rates (owing to factors such as high fire frequency, pre- and post-fire drought, and non-native species presence) and also have a high risk of erosion post-fire. This can be compared to areas in the 'low' class, which have low erosion risk and are likely to regenerate naturally very well as they are dominated by resprouting or facultative seeding species.

In using these output data and maps for guiding management activities and decisions, we strongly recommend a field survey is undertaken 2-3 years post-fire to improve the reliability of the vegetation regeneration map and to improve the assessment of drought and non-native species impacts with field data.

Conclusions

The PReP Tool for Chaparral Shrublands is a dynamic tool to help identify priority areas for resource managers based on the regeneration capacity of pixels within the fire perimeter, and the modification of this capacity based on fire history, drought tolerance pre- and post-fire, and presence of non-native grasses. The final step integrates this modified regeneration capacity with soil erosion risk data to identify areas at risk of ecosystem degradation.

The summary map of ecosystem degradation risk can be downloaded and analyzed in relation to other spatial data, such as other areas with high value for ecosystem services, or distance to roads and trails to assess the accessibility of sites for restoration. This, along with the inclusion of expert input, can further refine areas for management action.

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APPENDIX

Copper Fire Case Study using the Post-fire Restoration Prioritization Tool

To demonstrate the inputs and outputs of the Post-Fire Restoration Prioritization (PReP) Tool and provide interpretation of output maps for users, we created the Copper Fire Case Study.pdf. This document should be used in conjunction with the Technical Guide to fully understand the rationale, decision rules, and scoring system implemented by the PReP Tool. In addition, the user can run the PReP Tool for the Copper fire using the spatial data accompanying the tool in PReP_Tool.zip file (uploaded on: https://github.com/adhollander/postfire).

The Copper fire burned 7,284 ha (18,000 acres) of chaparral in 2002, Four WHR vegetation types dominate the Copper perimeter pre-fire: mixed chaparral, chamise redshank chaparral, coastal scrub (although this is likely misclassified given this is an interior site), and annual grassland. Other vegetation types present were either too small in spatial area or classified as a non-shrub lifeform to be included in the PReP Tool. Landscape units were developed which divided each dominant vegetation type into a warmer, more exposed 'south facing slope, summit and ridges' class and a cooler, less exposed 'north facing slope, valleys, and depressions' class. Below we describe relevant information at each step of the tool:

Step 1: Based on the review of Gordon and White (1994), analysis of the 14 FIA shrubland plots within five miles of the Copper perimeter, and discussion with botanists familiar with the Angeles National Forest we assigned the following proportion of resprouting and facultative seeding species (Table A1):

Table A1. Proportion of R and FS in each landscape unit

Landscape unit	Prop of R and FS species present
Mixed Chaparral; south-facing slopes, summits, ridges	>40%
Mixed Chaparral; north-facing slopes, valleys, depressions	>40%
Coastal Scrub*; south-facing slopes, summits, ridges	>40%
Coastal Scrub*; north-facing slopes, valleys, depressions	>40%
Chamise-Redshank Chaparral; south-facing slopes, summits, ridges	10-40%
Chamise-Redshank Chaparral; north-facing slopes, valleys, depressions	10-40%
Annual Grassland; south-facing slopes, summits, ridges	<10%
Annual Grassland; north-facing slopes, valleys, depressions	<10%
Valley foothill; south-facing slopes, summits, ridges	omit
Valley foothill; riparian north-facing slopes, valleys, depressions	omit
Other; south-facing slopes, summits, ridges	omit
Other; north-facing slopes, valleys, depressions	omit
* unlikely to be coastal scrub, assigned mixed chaparral proportions	

Based on these R and FS proportions, the PReP Tool awarded the highest number of points (5 points) to the mixed chaparral and coastal scrub warmer and cooler landscape units based on their regeneration capacity, and annual grasslands the least (1 point) (see Output Map 1 in Copper Fire Case Study.pdf)

Step 2: In terms of fire history, most of the Copper fire (61%) had experienced one fire in the last 40 years (prior to 2002), however, a small portion (1%) had experienced three fires in 40 years. The scores for pixels with three fires were reduced by one class. For 'time since last fire' the majority of the fire (96%) had burned more than 5 years ago, but 4% had burned within 0-5 years. The PReP Tool reduced the scores for these pixels by two classes (see Output Map 2 in Copper Fire Case Study. pdf).

Step 3: The analysis of drought in the growing season pre-fire (2001) and the growing seasons for two years after the fire resulted in no change as none were categorized as extreme or severe drought.

Step 4: To assess the impact of non-native species on regeneration capacity, we used a threshold value of 0.2 for the herbaceous data (Park et al. 2018), i.e., where pixels had more than 20% non-native grasses this was assumed to be detrimental to the recovery of native shrubs, particularly obligate seeding species. The majority of the Copper fire was above this threshold (see Copper Fire Case Study.pdf), so scores for pixels dominated by obligate seeders (10-40% and <10% R and FS) were reduced by one class.

The pixel values associated with implementing steps 1 to 4, are depicted in Output Map 4 (Figure A1).

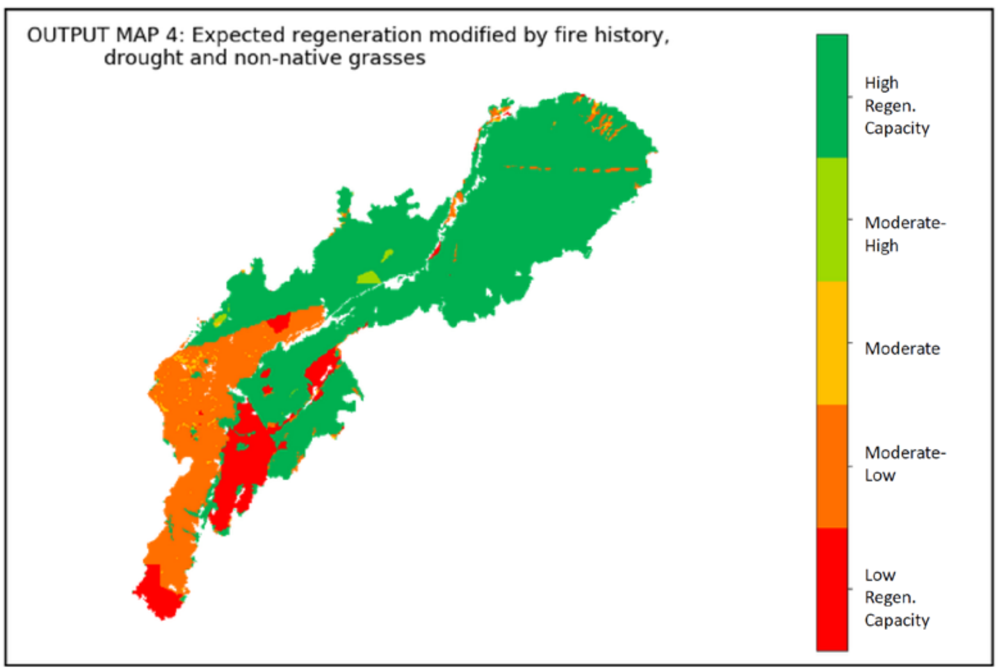

Figure A1. Map (Output Map 4) depicting the regeneration potential of the pre-fire vegetation based on the regeneration capacity of the species present (determined by its reproductive strategy) and modified by its fire history, drought tolerance pre- and post-fire, and presence of non-native grasses in each pixel

Step 5: The soil erosion risk data from the BAER assessment showed most of the Copper fire had <50 tons/ha of erosion relative to an unburned landscape (associated with a one in five year erosion event). The northern part of the fire harbored areas of higher soil erosion risk. The final map of the Copper Fire Case Study.pdf (Output Map 5, Figure A2) shows the integration of two data layers: (a) soil erosion risk and (b) the regeneration capacity of pixels based on their proportion of resprouting and facultative seeding species, fire history, drought, and non-native species.

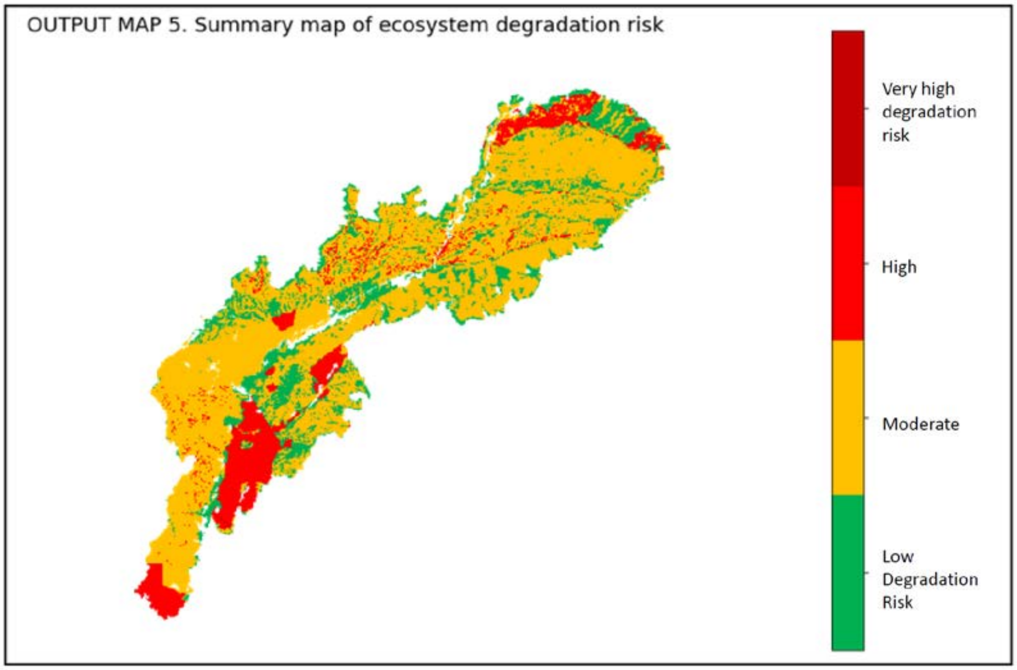

Figure A2. Map (Output Map 5) depicting the integration of the regeneration capacity of pixels (Figure A1) and soil erosion risk

However, given that soil erosion risk is likely to be minimal 17 years after the fire (2002), we focus the remainder of the case study on the results depicted in Output Map 4 (Figure A1) depicting five levels of regeneration capacity (high, moderate-high, moderate, moderate-low, and low) (Table A2).

Table A2. Area (and proportion) in each regeneration class based on post-fire reproductive strategy modified by fire history, drought and non-native species

Regeneration capacity	Area (acres)	Proportion of Copper fire
Low	1,642	9%
Moderate-Low	13,030	70%
Moderate	98	1%
Moderate-High	138	1%
High	3,618	20%

Informing Resource Management of Copper Fire

with Outputs from the Post-fire Restoration Prioritization Tool

In the Copper Fire Case Study.pdf, and below, we provide two examples of how the map of regeneration capacity (modified by fire history, drought, and non-natives species, Output Map 4) can be used for resource management. We also describe how data compiled from the literature as part of developing the Post-fire Restoration Prioritization (PReP) Tool can be used for identifying candidate species for chaparral restoration.

1. Identifying new restoration sites based on low regeneration and accessibility

The Angeles National Forest has identified a number of sites as important and practical for restoration and some of these have been actively restored (see map in Copper Fire Case Study.pdf). Important considerations in selecting these sites included:

- Areas where native shrubs have been converted to non-native grasses (or high percent cover of non-natives)
- Accessible (close to roads, non-steep slopes for ease of watering)
- Avoid Off-Highway Vehicle (OHV) trails
- Avoid powerlines
- Flatter terrain (versus ridgelines) as wind protected

Using Output Map 4 (Figure A1), and overlaying roads to indicate accessibility it is possible to identify a number of additional candidate areas for restoration in the southern portion of the Copper fire, characterized by low regeneration capacity and close to roads for access for planting (Figure A3). The next step is to ground-truth these candidate areas to assess whether the projections of regeneration capacity post-fire from the tool are correct.

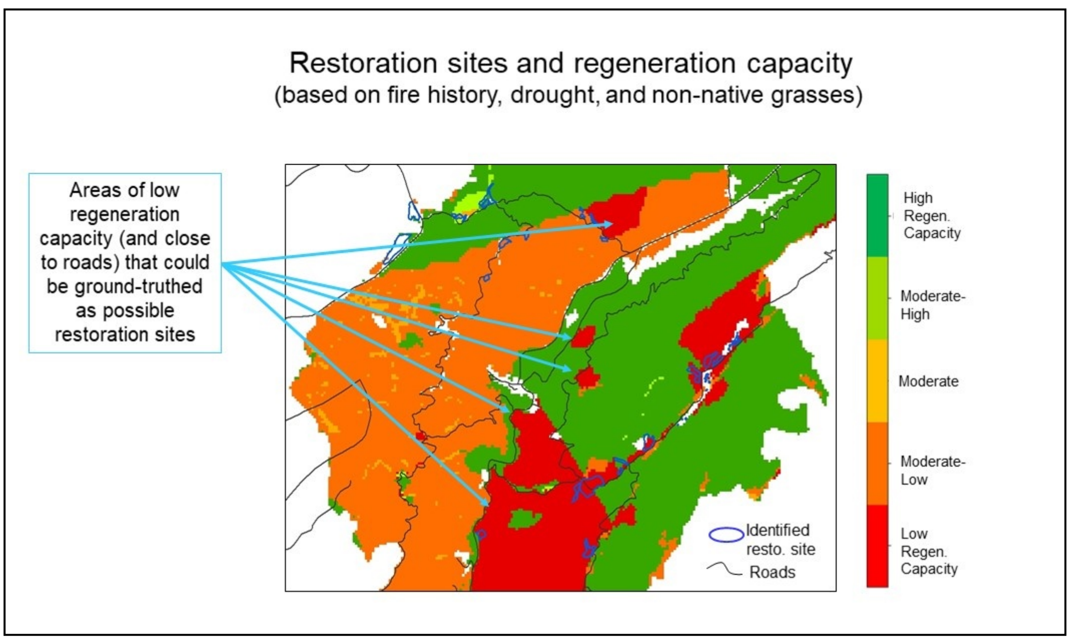

Figure A3. Overlay of Output Map 4 (Figure A1) from the PReP Tool showing areas of low regeneration capacity (red) with roads, to identify possible restoration sites to complement the existing ones (blue)

2. Identifying new restoration sites based on areas of ecosystem services

Using the Output Map 4 (Figure A1) from the PReP Tool we assessed the overlap between the areas mapped with low regeneration capacity (based on post-fire reproductive strategy, fire history, drought, and non-native species) and areas of high value for ecosystem services. As an example, we used spatial data on four ecosystem services (water runoff, groundwater provision, carbon storage, and biodiversity) developed as part of a broader ecosystem services project funded by the USFS Pacific Southwest region (Underwood et al. 2018) (Figure A4).

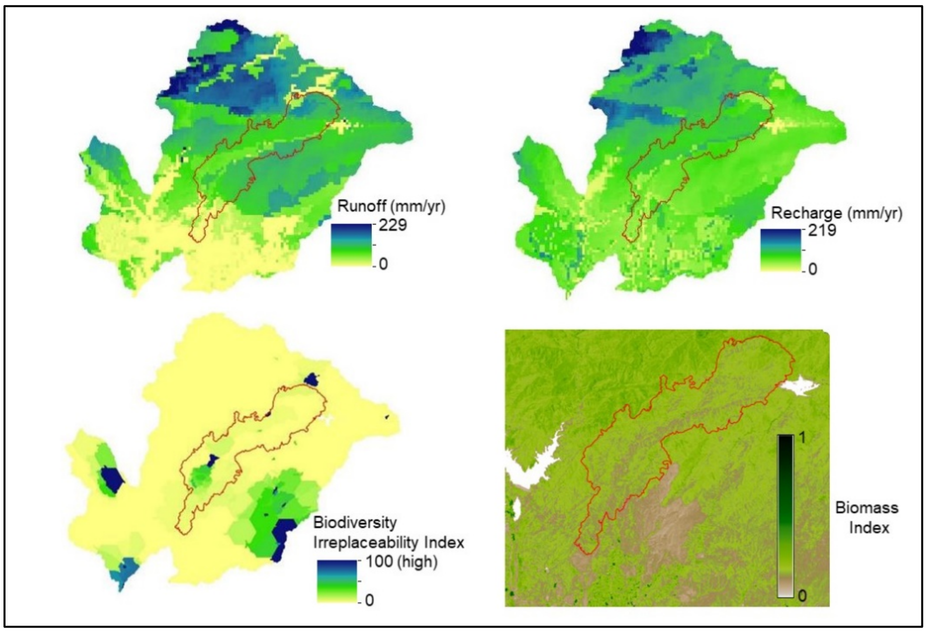

Figure A4. Spatial data on four ecosystem services for the Copper fire (red perimeter) developed as part of a broader ecosystem services project (Underwood et al. 2018)

We used these four layers to identify areas of ecosystem services hotspots in the Copper fire, by dividing the data for each service into deciles and summing the four different layers to give four categories of ecosystem services value (Figure A5). We overlaid areas of highest value (4) with the maps of regeneration capacity and suggest that areas with low regeneration capacity and high value ecosystem services provision pre-fire could be useful candidate areas to ground-truth (Figure A5).

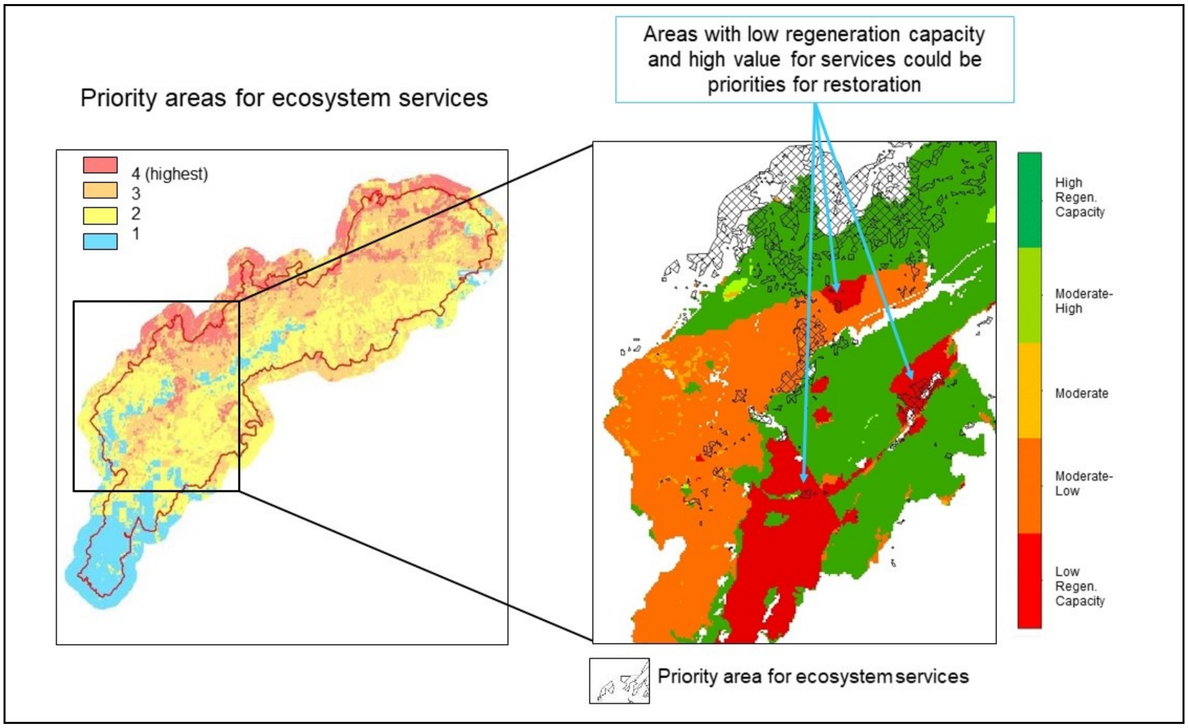

Figure A5. Map on left shows spatial data on four ecosystem services for the Copper fire (red perimeter) developed as part of a broader ecosystem services project (Underwood et al. 2018). Map on right shows Output Map 4 (Figure A1) from the PReP Tool with priority areas for services overlain

3. Determining plant species for restoration

The development of the Post-fire Restoration Prioritization Tool has resulted in a number of different outputs that can be useful to help determine species for post-fire restoration in chaparral shrublands:

(a) Characteristic species within the Copper fire. To develop the proportion of R, FS, and S species in each landscape unit, we queried FIA shrubland plots in and 5 miles around the Copper fire, and analyzed the percent cover by each landscape unit. Although there are a limited number of FIA plots in each landscape unit (ranging from 5 in mixed chaparral south facing slopes, summits, and ridges to 1 in coastal scrub north facing slopes, valleys, and depressions), this list gives a preliminary indication of which species grow well in each vegetation by aspect by topographic units in the Copper fire which can help inform planting lists for chaparral restoration (see Table A3).

(b) Native shrub species across southern California. We developed a list of 47 native shrubs species that occur in the vegetation series of the Angeles, San Bernardino, and Cleveland national forests based on Gordon and White (1994) (see Table A4). For each shrub we assigned a functional group according to its post-fire reproduction strategy based on the literature and databases including: USDA Forest Service Fire Effects Information System (FEIS) (https://www.feiscrs.org/feis/faces/index.xhtml;jsessionid=6320AAA06E2C403C7B192DC

E08A0DD03), California Native Plant Society's California Manual of Vegetation (http://vegetation.cnps.org/), and the plant profiles produced by the Riverside-Corona Resource Conservation District (RCRCD) (https://www.rcrcd.com/#Plant_Materials).

With the caveat that some of these species might be too distant from the area being restored, it does provide a list of native shrubs with their associated reproductive strategies from which users can select additional species to complement the key chaparral species (i.e., those listed based on the analysis of FIA plots by landscape units).

This Appendix aims to describe summary data and interpretation of the outputs of the Post-fire Restoration Prioritization Tool for the Copper fire (2002). Users of the tool are able to explore these data and run the tool using the spatial information provided at: https://github.com/adhollander/postfire. We also show examples of how these outputs could be used by resource managers to identify other candiate areas to restore based on accessibility and proximity to areas of high ecosystem services provision. Finally, we describe data compiled on native shrubs in the Copper area, as well as southern California, in terms of their reproductive strategy, growth, and ability to provide erosion control and wildlife habitat. When using the PReP Tool it is extremely valuable to have input from botanists or ecologists familiar with the target fire (e.g., verifying the proprotion of resprouting, facultative seeding, or obligate seeding species). In additoin, it is essential to include a field work component to running the tool, both to inform the proportion of shrubs with different reproductive strategies and also to ground-truth the outputs from the PReP Tool before being used for planning.

Table A3. Characteristic native species within the Copper fire

Reproductive Strategy: **R** = Resprouter; **FS** = Facultative Seeder; **S** = Obligate Seeder

Landscape Units in Copper Fire	Species	Reprod. Strategy
Chamise redshank chaparral south facing slopes, summits, ridges	Adenostoma fasciculatum	FS
Chamise redshank chaparral south facing slopes, summits, ridges	Ceanothus perplexans (greggii)	S
Chamise redshank chaparral south facing slopes, summits, ridges	Eriogonum fasciculatum	FS
Chamise redshank chaparral south facing slopes, summits, ridges	Hesperoyucca whipplei	FS
Chamise redshank chaparral south facing slopes, summits, ridges	Salvia mellifera	FS
Coastal scrub north facing slopes, falleys, depressions	Adenostoma fasciculatum	FS
Coastal scrub north facing slopes, falleys, depressions	Ceanothus perplexans (greggii)	S
Coastal scrub north facing slopes, falleys, depressions	Eriodictyon crassifolium	FS
Coastal scrub north facing slopes, falleys, depressions	Salvia mellifera	FS
Coastal scrub south facing slopes, summits, ridges	Artemisia cana	FS
Coastal scrub south facing slopes, summits, ridges	Encelia farinosa	R
Coastal scrub south facing slopes, summits, ridges	Hesperoyucca whipplei	FS
Coastal scrub south facing slopes, summits, ridges	Acmispon glaber (Lotus scoparius)	S
Coastal scrub south facing slopes, summits, ridges	Salvia mellifera	FS
Coastal scrub south facing slopes, summits, ridges	Sambucus nigra	FS
mixed chaparral north facing slopes, valleys, depressions	Adenostoma fasciculatum	FS
mixed chaparral north facing slopes, valleys, depressions	Arctostaphylos glandulosa	FS
mixed chaparral north facing slopes, valleys, depressions	Ceanothus perplexans (greggii)	S
mixed chaparral north facing slopes, valleys, depressions	Ceanothus cordulatus	S
mixed chaparral north facing slopes, valleys, depressions	Ceanothus perplexans (greggii)	S
mixed chaparral north facing slopes, valleys, depressions	Eriodictyon traskiae	FS
mixed chaparral north facing slopes, valleys, depressions	Eriogonum fasciculatum	FS
mixed chaparral north facing slopes, valleys, depressions	Prunus ilicifolia	R
mixed chaparral north facing slopes, valleys, depressions	Quercus dumosa	R
mixed chaparral north facing slopes, valleys, depressions	Salvia mellifera	FS
mixed chaparral south facing slopes, summits, ridges	Adenostoma fasciculatum	FS
mixed chaparral south facing slopes, summits, ridges	Arctostaphylos glandulosa	FS
mixed chaparral south facing slopes, summits, ridges	Ceanothus cuneatus	S
mixed chaparral south facing slopes, summits, ridges	Ceanothus perplexans (greggii)	S
mixed chaparral south facing slopes, summits, ridges	Ceanothus leucodermis	FS
mixed chaparral south facing slopes, summits, ridges	Cercocarpus montanus	R
mixed chaparral south facing slopes, summits, ridges	Eriodictyon crassifolium	FS
mixed chaparral south facing slopes, summits, ridges	Eriogonum fasciculatum	FS
mixed chaparral south facing slopes, summits, ridges	Hesperoyucca whipplei	FS
mixed chaparral south facing slopes, summits, ridges	Keckiella ternata	UNK
mixed chaparral south facing slopes, summits, ridges	Acmispon glaber (Lotus scoparius)	S
mixed chaparral south facing slopes, summits, ridges	Quercus wislizeni	R
mixed chaparral south facing slopes, summits, ridges	Quercus chrysolepis	R
mixed chaparral south facing slopes, summits, ridges	Quercus dumosa	R
mixed chaparral south facing slopes, summits, ridges	Quercus john-tuckeri	R
mixed chaparral south facing slopes, summits, ridges	Rhamnus crocea	UNK
mixed chaparral south facing slopes, summits, ridges	Rhamnus ilicifolia	FS
mixed chaparral south facing slopes, summits, ridges	Rhus trilobata	FS

mixed chaparral south facing slopes, summits, ridges	Salvia mellifera	FS
mixed chaparral south facing slopes, summits, ridges	Toxicodendron Mill.	R
Annual grasslands south facing slopes, summits, ridges	Adenostoma fasciculatum	FS
Annual grasslands south facing slopes, summits, ridges	Eriogonum fasciculatum	FS
Annual grasslands south facing slopes, summits, ridges	Hesperoyucca whipplei	FS
Annual grasslands south facing slopes, summits, ridges	Salvia mellifera	FS

Notes:

1. These are the species from FIA shrubland plots in and 5 miles around the Copper fire within each landscape unit (species with only a single occurrence in the shrubland plots have been omitted)

2. The number of FIA plots in each landscape unit ranged from 5 in mixed chaparral south facing slopes, summits, ridges to 1 in coastal scrub north facing slopes, valleys, depressions

3. The coastal shrub vegetation type is likely misclassified in the WHR vegetation map

4. See Technical Guide for more details.

Table A4. Functional groups of native shrubs in southern California

Reproductive Strategy: **R** = Resprouter; **FS** = Facultative Seeder; **S** = Obligate Seeder

Species	Sp. Code	Common Name	Reprod. Strategy	Description
Acmispon glaber (L. scoparius)	LOSC52	Deerweed	S	Obligate seeder
Adenostoma fasciculatum	ADFA	Chamise	FS	Facultative resprouter from lignotuber; most seeds (~80%) need fire (low to mod heat) to germinate
Adenostoma sparsifolium	ADSP	Redshank	FS	Facultative resprouter from lignotuber; seeds also germinate following fire w' lower survival rates
Arbutus menziesii	ARME	Madrone	R	Fire-stimulated sprouting (Sugihara et al. Table 11.4)
Arctostaphylos glandulosa	ARGL4	Eastwood manzanita	FS	Obligate resprouter, from subsurface burl; seeds have some resistance to heat.
Arctostaphylos glauca	ARGL5	Bigberry manzanita	S	Obligate seeder, fire stimulated; seeds need heat and charate to break dormancy
Arctostaphylos hooveri	ARHO7	Hoover's manzanita	S	Obligate seeder (no info on post-fire demography)
Artemisia californica	ARCA11	California sagebrush	FS	resprouts from root crown after fire and from basal buds in intervals btw fires
Baccharis pilularis	BAPI	Coyotebrush	FS	Reprouts after mild (not severe) fire; wind-dispersed seeds colonize bare ground after fire
Ceanothus crassifolius	CECR	Hoaryleaf ceanothus	S	Obligate seeder, fire stimulated; seeds need heat to break dormancy
Ceanothus cuneatus	CECU2	Wedgeleaf ceanothous	S	Obligate seeder, fire stimulated; seeds need heat to break dormancy
Ceanothus perplexans (greggii)	CEGRP	Cupleaf ceanothus	S	Obligate seeder, fire stimulated; seeds need heat to break dormancy
Ceanothus integerrimus	CEIN3	Deerbrush	FS	Facultative seeder; facultative sprouter from crown
Ceanothus leucodermis	CELE2	Chaparral whitethorn	FS	Facultative resprouter with seeds stimulated by fire
Ceanothus megacarpus	CEME	Bigpod ceanothus	S	Obligate seeder, fire stimulated; seeds need heat to break dormancy
Ceanothus oliganthus	CEOL	Hairyleaf ceanothus	S	Obligate seeder, fire stimulated; seeds need heat to break dormancy
Ceanothus papillosus	CEPA2	Wartleaf ceanothus	S	Obligate seeder (no info on post-fire demography)
Ceanothus spinosus	CESP	Greenbark ceanothus	FS	Facultative resprouter from stump and seedlings
Ceanothus tomentosus	CETO	Wollyleaf ceanothus	FS	Facultative seeder, facultative sprouter (see Gordon and White 1994, pg. 160)
Cercocarpus betuloides	CEBE2	Mountain mahogany	R	Obligate resprouters, from stumps and root crowns
Diplacus aurantiacus	DIAU	Orange-bush monkeyflower	FS	Facultative seeder, resprout from rhizomes
Eriodictyon crassifolium	ERCR2	Yerba Santa	FS	Facultative sprouter; facultative seeder. Mostly resprouts
Eriodictyon trichocalyx	ERTR6	Hairy Yerba Santa	FS	Facultative seeder, resprout from rhizomes
Eriogonum fasiculatum	ERFA2	California buckwheat	FS	Partial resprout (coastal sites more than inland sites); from seedlings
Fraxinus dipetala	FRDI2	Chaparral ash	R	Fire-stimulated sprouting (Sugihara et al. Table 9.5)
Garrya flavescens	GAFL2	Pallid silktassel	R	Fire-stimulated sprouting from basal burl or lignotuber (Sugihara et al. pg. 112)
Garrya veatchii	GAVE2	Canyon silktassel	R	Obligate resprouter; seeds do not survive fire well.
Heteromeles arbutifolia	HEAR5	Toyon	R	Obligate resprouter; seeds germinate readily but are short-lived and heat sensitive
Malacothamnus fasciculatus	MAFA	Bush mallow scrub	FS	Facultative seeder, facultative sprouter
Malosma laurina	MALA6	Laurel sumac	FS	Facultative seeder, facultative sprouter
Pinus coulteri	PICO3	Coulter pine	S	Serotinous cone seeder; cone production begins at around 10 years of age
Prunus ilicifolia	PRIL	Hollyleaf cherry	R	Obligate resprouter from root crown
Quercus berberidifolia	QUBE5	Scrub oak	R	Obligate resprouter from root crown, from stumps, crowns and roots
Quercus chrysolepis	QUCH2	Canyon live oak	R	Obligate resprouter, from rootcrown and stump; thin, flaky bark results in trees easily killed by fire
Quercus john-tuckeri	QUJO3	Tucker's oak	R	Obligate resprouter; not studied (per R5-TP-019), but likely similar to scrub oak (QUBE5)
Quercus wislizenii	QUWI	Interior live oak	R	Obligate resprouter from stumps and rootcrowns; acorns sprout readily but sensitive to heat
Rhamnus californica (now Frangul	RHCA2	California buckthorn	R	reprouts after fire; wind-dispersed seeds recolonize after fire
Rhamnus ilicifolia	RHIL	Holly-leaf redberry	FS	Facultative seeder, facultative sprouter
Rhus ovata	RHOV	Sugar bush	FS	Facultative seeder, facultative sprouter (Montalvo et al. 2017)
Rhus trilobata	RHTR	Basket or 3-leaf sumac	FS	Facultative seeder, facultative sprouter
Salvia leucophylla	SALE3	Purple sage	FS	Resprouts from basal burl; some recruitment from soil-stored seeds
Salvia apiana	SAAP1	White sage	FS	Facultative resprouter with seeds stimulated by fire (see Gordon and White 1994, pg. 159)
Salvia mellifera	SAME4	Black sage	FS	Facultative resprouter from root crown mostly after low-intensity fires; also from seedlings
Toxicodendron diversilobum	TODI	Poison oak	R	Fire-stimulated sprouting (Sugihara et al. Table 11.3)
Umbellularia californica	UMCA	California bay	R	Obligate resprouter, from crown, bole or stump
Xylococcus bicolor	XYBI	Mission manzanita	FS	Facultative seeder, facultative sprouter but seedlings rarely establish (see Gordon & White, p. 152)
Yucca whippleii	YUWH	Chaparral yucca	FS	Sprouts from rhizomes, rarely from seeds; reproduces after fire from thick underground rhizomes

Majority of descriptions are from:

1. Gordon, H., and T. C. White. 1994. Ecological Guide to Southern California Chaparral Plant series. Transverse and Peninsular Ranges: Angeles, Cleveland, and San Bernardino National Forests. USDA Forest Service Pacific Southwest Region R5-ECOL-TF-005.
2. Borchert, M. 2004. Field Guide to Coastal Sage Scrub and Chaparral Alliances of Los Padres National Forest R5-TP-019

Other cited references are:

3. Sugihara, N.G., Van Wagtendonk, J.W., Shaffer, K.E., Fites-Kaufman, J. and A.E. Thode. 2006. Fire in California ecosystems. Univiversity of California Press, Los Angeles, CA. 596 pp
4. Montalvo et al. 2017. Profile for R. ovata. Native Plant Recommendations for SoCal Ecoregions. Riverside-Corona RCD & USDA FS, PSW Research Station, Riverside, CA.