REGENMAPPER post-fire reforestation assessment tool user documentation

Version 1.2 – September 30th, 2023

Summary

Regenmappper is a web-based tool for assessing potential for post-fire conifer regeneration. It enables users to upload a classified burn severity map and returns spatial information on the probability of natural forest recovery. This document is intended as a guide for Regenmapper users planning post-fire reforestation work. New users should begin by going to Regenmapper (https://orthanc.dbs.umt.edu/regenmapper) to create an account and log in. In the "About" tab in the upper right corner of the site you will find a short video that illustrates how to run a job. For most users, this will provide enough information on how to get started. A quick start guide below briefly describes the steps shown in the video tutorial. The rest of the document describes in more detail the files required to run a job, how to upload data, and the user-defined choices that must be made before launching a job. Section IV provides more detail on use and interpretation of the raster grid and polygon shapefile outputs. We use the 2017 Lolo Peak fire, Montana as a case study.

Contents

I. Introduction

The last decade has seen a rapid increase in wildfire activity, with several record-breaking western United States (U.S.) wildfire seasons. Reforestation needs, driven largely by stand-replacing wildfires now outpace the resources available for replanting. Resource managers across state and federal agencies could benefit from tools designed to assist in identifying and prioritizing sites for planting. Regenmapper was designed primarily to address this need.

Regenmapper will take a burn severity raster map that the user provides and estimates the probability of natural regeneration within severely burned areas within the burned area. Users can also run jobs for historical (1984-2021) wildfires with the Monitoring Trends in Burn Severity (MTBS) dataset without uploading any data. Figure 1 shows a schematic outline of the workflow that is executed when a job is run. Areas identified as stand replacing in burn severity maps are used to calculate distance to the nearest seed source for each pixel. Then, a regression model trained using historical recruitment data from across 32 western U.S. wildfires is used to predict the probability of natural regeneration, based on historical climate factors, time since fire and distance to a seed source. The outputs also include a set of ancillary grids that may be useful for additional planning in GIS. For U.S. Forest Service (USFS) users, the tool will return spatial and tabular information retrieved from the FACTS database, detailing areas burned by the fire that may, because of past activities, require planting under federal law. It also includes suitability layers or suitability layer surrogates, depending on the USFS Region. The model will also query a database containing all publicly available road features and calculate the distance to the nearest road for each severely burned pixel. Road distance is then used to calculate a simple cost-benefit index, designed to identify areas that are close to roads and that have a lower probability of natural recruitment because they are far from live, adult trees. A full list of outputs produced by the model and their description is provided in Table 1. Finally, various GIS operations are used to summarize the outputs in order to simplify them for the user.

The Regenmapper tool is relatively easy to run. The only requirement aside from a computer with access to the internet, is a classified burn severity map (e.g., a classified differenced Normalized Burn Ratio, a BARC/SBS, BAER or MTBS map). This input file should be in GeoTIFF format with projection information, and it needs to be classified (e.g., low, moderate, high severity). The spatial resolution of the input file can vary, and the projection can vary as well. The number of classes in the map can vary from 2-10. The only other requirements from the user are to specify the height at which the user thinks the trees in the fire area are likely to begin producing seeds and selecting tree species of interest. The former is a somewhat subjective decision, and we will explain later why it is important and how to decide if the user doesn’t really know. The interface is relatively simple, and the quick start guide will help you go run the tool without having to this entire document.

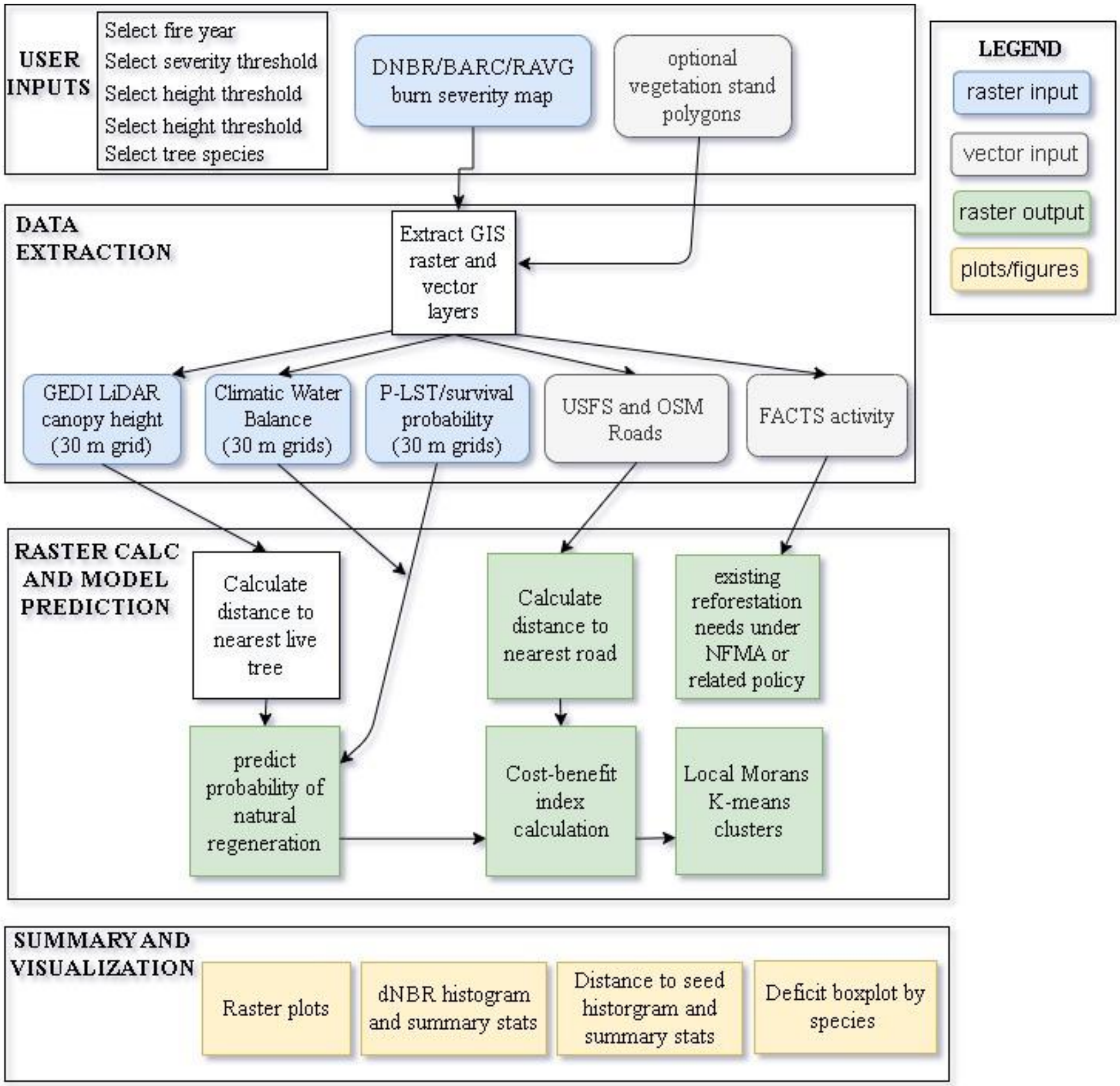


Figure 1. Schematic outline of the Regenmapper workflow.

II. Quick start guide

1. In a web browser go to the Regenmapper site: https://orthanc.dbs.umt.edu/regenmapper

If this is your first time using the tool, you will need to use a valid email address to log in. Select: "**Sign up**", then enter your email address, create a password, select continue. This will take you to the front page of the Regenmapper tool. You can also sign up using your google account.

NOTE: hovering over selectors in the job submission page will bring up additional text description.

2. The only file required to run Regenmapper is a user-specified classified burn severity map, in GeoTIFF format (.tif file extension). It is assumed that you have this and can locate it on your computer. Place your burn severity map in a zipped folder (.ZIP extension). The WinZip and 7Zip programs are free and available to USFS employees.

3. Next, go to the **"Upload file"** button in the upper left corner of the Regenmapper interface and select it. Then, select "**Choose file**" and navigate to the location of your zipped burn severity file, select your file and the select 'open' in your file browser.

4. Go to the "**Select fire year**" drop down and select the year in which your fire burned. For example, if it is November of 2021, and your fire occurred earlier that summer, choose 2021 for the fire year.

5. You will see a set of radio buttons allowing you to **select individual conifer species**. Select the radio button for each species you would like outputs for. Note that western larch (LAOC) is not available.

6. You may choose to use the **slope threshold** slider bar. You can adjust the slope (%) to specify a threshold value beyond which no planting work will be done. If you do, a classified slope raster grid will be returned to you, with values greater than your selected threshold set to "101". This may or may not be useful for you and is optional.

7. Use the **Tree Height Threshold** slider to select the height at which trees in your study area are likely to begin producing seeds. This value defines the threshold for what is considered a live adult tree and will determine the distance to nearest seed source. It is important. If you don't have any idea, choose a relatively small value (e.g., 5 meters/16 feet). Note if you don't enter anything the program will use 8 meters as the default value. NOTE: Units are in meters. 1 meter=3.28 feet.

8. Select the **burn severity threshold** you wish to use for your analysis. Your options are Moderate and High. If you choose high severity, only the areas classified as high severity (usually class 4 in a burn severity map, but it may vary depending on the burn severity map used) will be used to calculate distance to live trees. If you choose moderate, the moderate and high severity classes will be grouped together into the high severity class. The result will usually be larger high severity patches, with longer distances to live seed sources and more area requiring planting.

9. Finally, use **the Select moderate severity class** and **select high severity class** drop down buttons to tell the program what values in your burn severity raster map correspond to moderate and high severity. For example, if you are using a standard MTBS type dNBR map, you would enter "3" for the moderate class and "4" for the high severity class.

11. When you're finished, hit the "**upload**" button at the bottom left corner of the screen. You will receive an email with a link to download your results when your job is complete.

III. Running a job using a custom burn severity map -detailed instructions

This section provides detailed step-by-step instructions and screen captures for running a Regenmapper job using your own burn severity input map. This is most common use and is designed for rapid post-fire assessments when BARC/SBS or RAVG burn severity assessments have been done for wildfires in the current year.

A. Input file preparation

The only input file **required** to run a Regenmapper job is a single, classified burn severity map. This file must be in GeoTIFF format (.tif file extension) and contain information about the projection of the grid (e.g., Albers Equal Area, World Geodetic System). Any projection can be used. Figure 2 shows an example for the 2017 Lolo Peak Fire, Montana. Please note how many severity classes are in your severity map, and what classes correspond to moderate and high severity as this information will be needed by Regenmapper to run your job correctly. **NOTE: When uploading your geoTIFF file, DO NOT include any files with extensions like .aux, .xml. Only a single .tif file is allowed.**

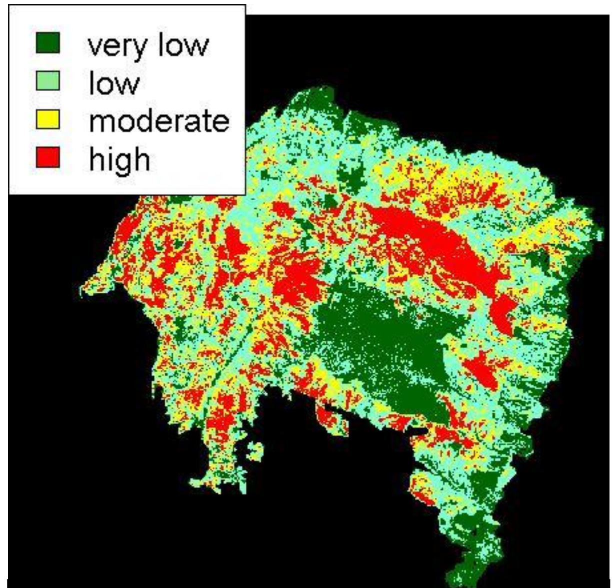


Figure 2. Classified differenced Normalized Burn Ratio (dNBR) for the 2017 Lolo Peak fire. This layer was provided by the Monitoring Trends in Burn Severity project (MTBS). You must specify what values correspond to moderate and high severity in the burn severity raster grid you upload to correctly run your job.

Optionally, you can also upload a spatial polygon shapefile. This file must be in shapefile format (.shp) and contain projection information in the form of a .PRJ file. This file should represent some type of vegetation management unit (e.g., stands). We recommend working directly with the gridded raster outputs in your assessment. However, uploading a stand or vegetation polygon will result in each polygon in the file being attributed with values from the raster outputs.

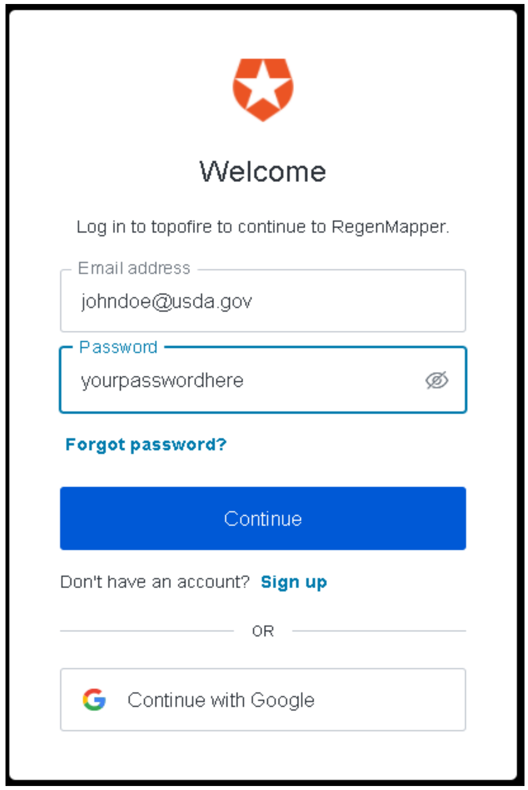
Your classified burn severity raster geoTIFF (and optionally a polygon shapefile) should be placed in a single folder and converted to Zip file (.ZIP extension). Various programs can be used to create a .ZIP file. WinZip or 7Zip are free software programs available to USFS employees that create ZIP files.

B. Starting a job and uploading files

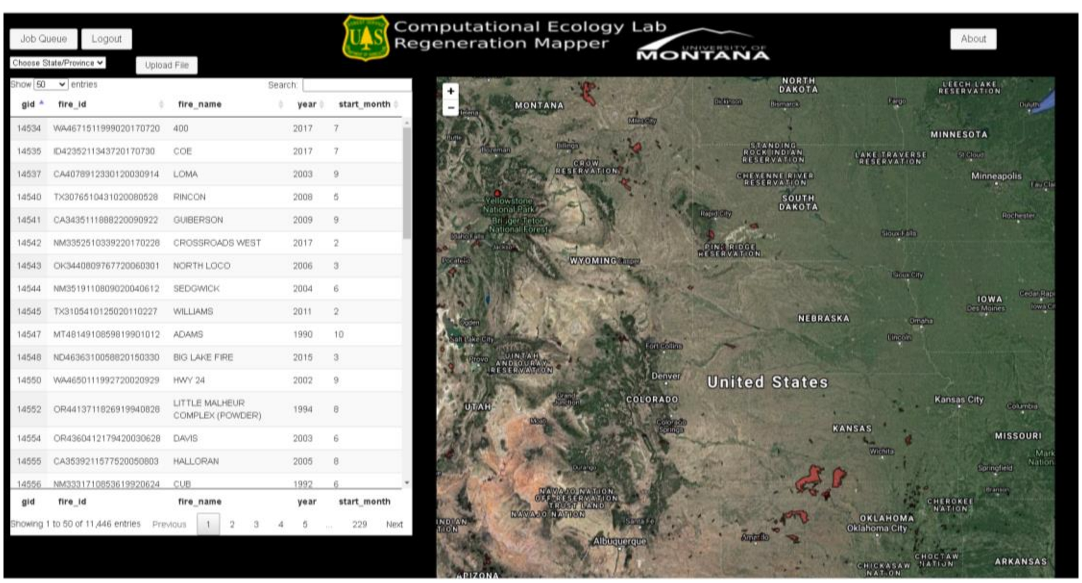
1. In a web browser (Chrome, Microsoft Edge, Firefox) go to the regenmapper site:

https://orthanc.dbs.umt.edu/regenmapper

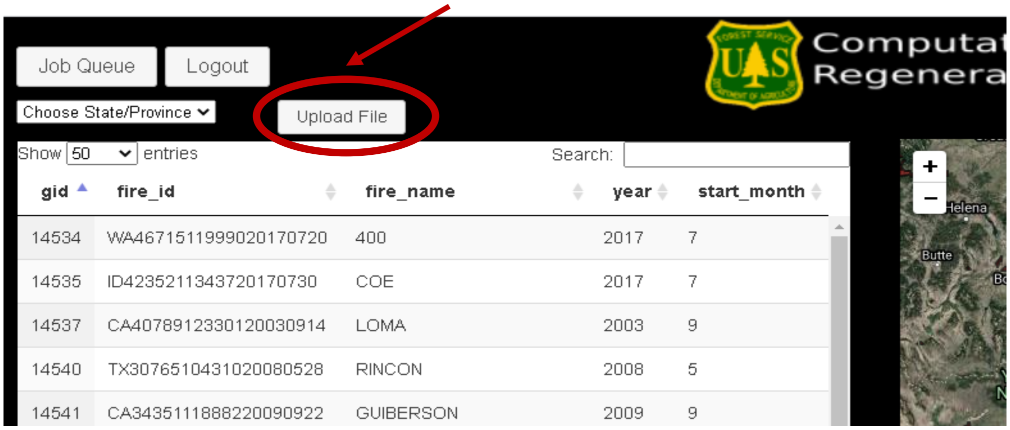
If this is your first time using the tool, you will need to use a valid email address to log in. Select: "**Sign up**", then enter your email address, create a password, select continue. This will take you to the front page of the Regenmapper tool. You can also sign up using your google account. Once you have created your account, you can return to the site at any point and sign in.



Once you've logged in you will be taken to the Regenmapper front screen.

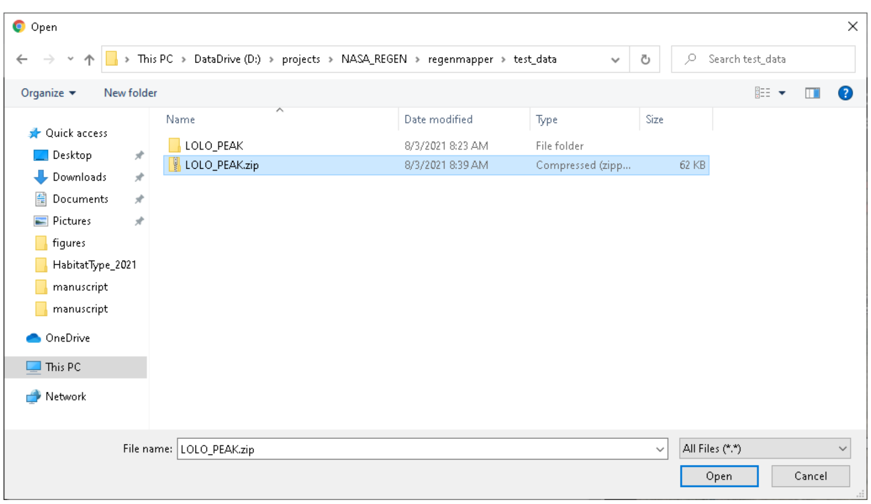


2. Next, go to the **“Upload file”** button in the upper left corner of the Regenmapper interface



3. Select “**Choose file**” and navigate to the location of your zipped burn severity file select your file and the select ‘open’ in your file browser.

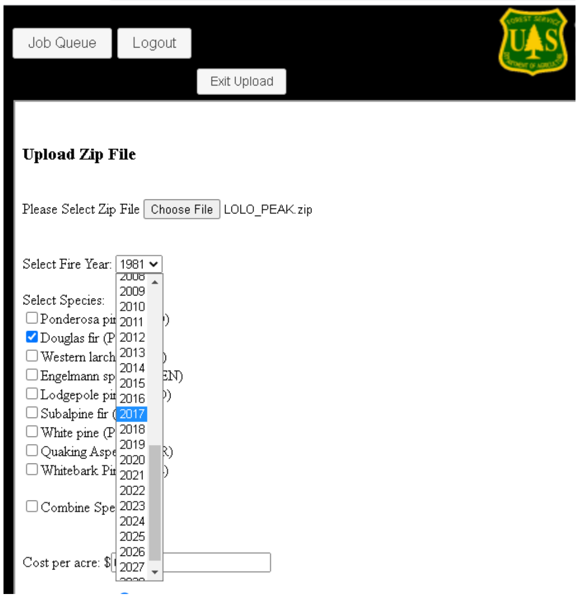
4. Select your file and the select ‘open’ in your file browser.



C. User defined input selection

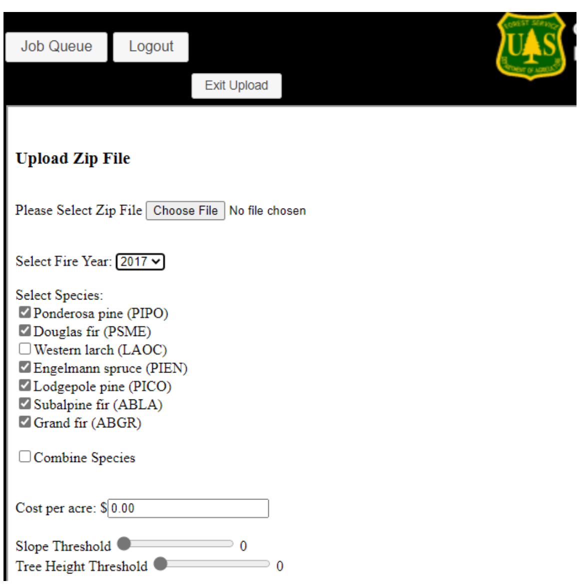
There are five critical pieces of information Regenmapper requires in order to provide you with useful outputs. These are: 1. Selecting the year in which your fire occurred; 2. Selecting the tree species of interest; 3. Selecting the moderate versus high burn severity class threshold; 4. Selecting the height of nearby trees that could provide a potential live seed source for severely burned areas; and 5. Specifying the burn severity classes in the severity map you upload the correspond to moderate and high severity. Each of these selection options is described in detail below.

1. Selecting year of fire



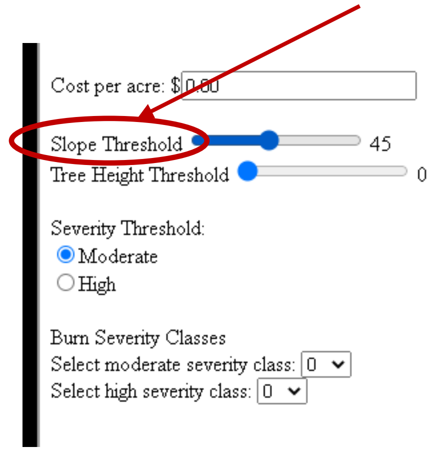
The probability of natural regeneration decreases over time after a fire. Grass and shrubs can establish and limit seedling establishment. Years since fire is a variable in the regression model used to predict natural regeneration so inputting the correct fire year is important. Go to the "**Select fire year**" drop down bottom and select the year in which your fire burned. For example, if it is currently November of 2021, and your fire occurred earlier that summer, choose 2021 for the fire year.

2. Selecting seedling species of interest

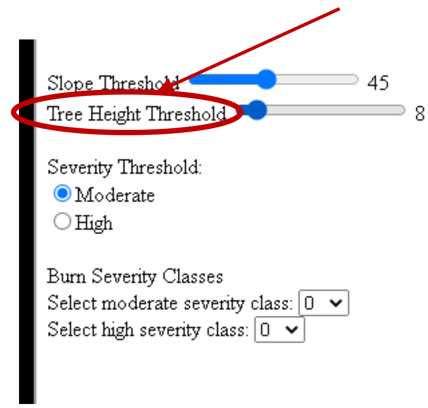


You will see a set of radio buttons allowing you to select individual conifer species. Select the radio buttons for species you would like outputs for. Selecting nothing will return outputs based on a model fit using data for all conifer species combined. Note that the western larch model is not currently available. Selecting the LAOC radio button will not disrupt the program.

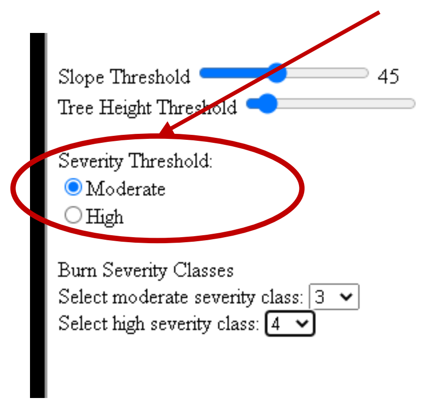
3. You may choose to use the optional **slope threshold** slider bar. You can adjust the slope (%) to specify a threshold value beyond which no planting work will be done. If you do, a classified slope raster grid will be returned to you, with values greater than your selected threshold set to “101”. This may or may not be useful for you and is optional. Here, I have set the slope threshold to 45% because I consider slopes this steep too difficult to plant on.



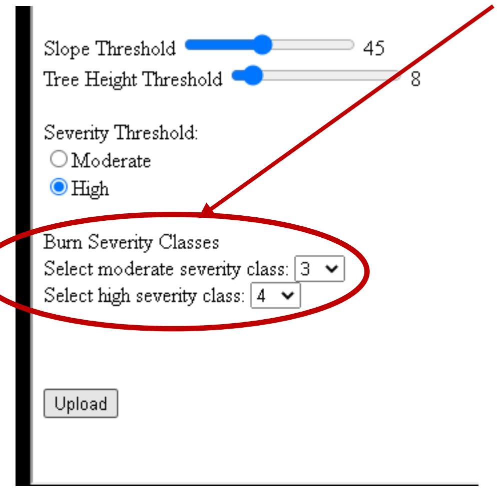
4. Use the **Tree Height Threshold** slider to select the height at which trees in your study area are likely to begin producing seeds. This value defines the threshold for what is considered a live adult tree and will determine the distance to nearest seed source. It is important. If you don’t have any idea, choose a relatively small value (e.g. 5 meters/16 feet). Note if you don’t enter anything the program will use 5 meters as the default value. **NOTE: Units are in meters**. 1 meter=3.28 feet.



5. Select the **burn severity threshold** you wish to use for your analysis. Your options are Moderate and High. If you choose high severity, only the areas classified as high severity will be considered potential reforestation targets and used to calculate distance to live trees. on the burn severity map used) will be If you choose moderate, the moderate and high severity classes will be grouped together into the high severity class. The result usually be larger high severity patches, with longer distances to live seed sources and more area requiring planting. Please consider this choice carefully. If you are evaluating a fire that occurred this year, the post-fire satellite image used will be from the year of the fire and substantial additional adult tree mortality could occur in the following year. **We recommend choosing the moderate severity threshold** in this situation. You can always refine your decisions about planting after visiting these sites in the field but grouping moderately burned areas will ensure that they are at least included in your initial evaluation.



6. Finally, use **the select moderate severity class** and **select high severity class** drop down buttons to tell the program what values in your burn severity raster map correspond to moderate and high severity. For example, if you are using a standard MTBS type dNBR map, you would enter "3" for the moderate class and "4" for the high severity class. This choice is very important, particularly if you are using a burn severity raster grid where the high severity class is not 4. Some RAVG maps for example are produced with 7 classes, where class 5=moderate and classes 6 and 7 are high severity. Be sure you know what number in your burn severity map corresponds to high severity. In the case of a 7 class RAVG map, if you selected a moderate severity threshold (above) and wanted all moderate and high severity classes included in your assessment, you would select 5 for the moderate severity class and 6 for the high severity class. Classes 5, 6 and 7 would all be grouped into high severity and considered in the model assessment.



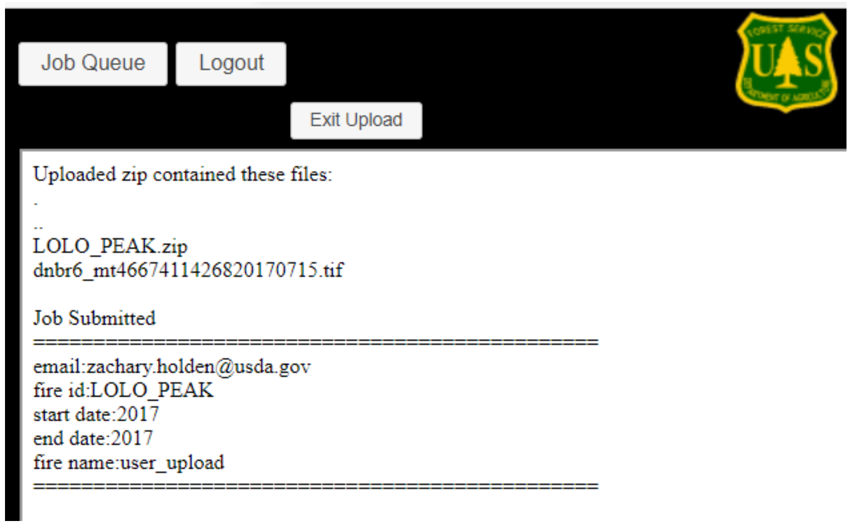
More information on BAER and RAVG burn severity data can be found at the following links:

BAER: https://burnseverity.cr.usgs.gov/baer/

RAVG: https://burnseverity.cr.usgs.gov/ravg/

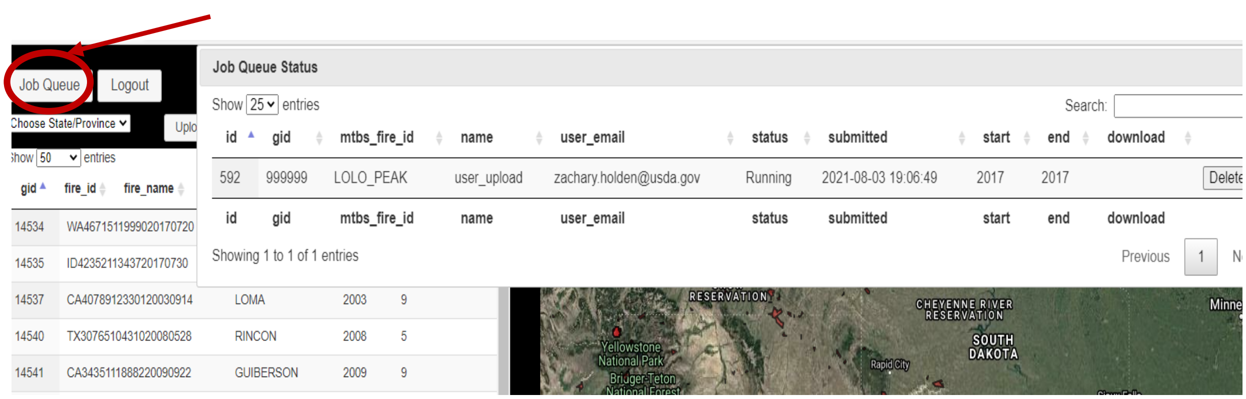
D. Submitting a job

11. When you're finished selecting the inputs for your job, you are now ready to submit your job. Simply hit the "**upload**" button at the bottom left corner of the screen. This will send your data to a server. You will see a screen like this indicating that your job has been submitted. You can select the "Exit upload" button to leave this screen. Check the Job Queue tab after a few minutes. Most jobs finish in around 15 minutes.



E. Troubleshooting

You can use the Job Queue to check on the status of your submitted job. It will take the program several minutes to find and start running your job. Initially your just status will show "Pending" and will change to "Running" once the job has begun. Some basic checks are run on the burn severity map you upload. If errors are found in that file, you will see an error message within several minutes of starting your job. The status will show as "finished" once the job is complete. For the largest fires, a job should take no more than 25 minutes to run. If after 20-25 minutes you check the job status and the status says "Running" or you see an error message, please delete your job and then try submitting the job again. If your job still fails to finish, you should examine your burn severity map to make sure you input the correct classes for moderate and high severity, and that it contains projection information. If you don't see anything obviously wrong with your files, please contact regional office staff for assistance.



IV. Interpreting job results

This section will provide information about the files contained in your job outputs and some basic guidance on how to begin using them. Some of the outputs are specific to USFS users and therefore some of this discussion is focused on agency users. In particular, the vector/shapefile outputs are primarily designed for their use. However, the continuous raster outputs should generally be useful for any forested area in the western US.

A. Getting started-unzipping files and inspecting outputs

You should have received an email with a link to download your job results. The results are contained in a compressed zip file (.ZIP extension). Various programs like WinZip and 7Zip are available for unzipping your files. Use your preferred software to unzip the folder to a directory where you will be working.

Once you've unzipped your output folder you will see several files. Table 1 provides a list of these files and a brief description. Most of these are 30-meter resolution raster grid files in a GeoTIFF format. All geotiff files are in WGS84 projection and are usable in any GIS software program. You may choose to reproject these to a projection matching other data layers. The remaining files are vector data in Shapefile format. These also contain projection information and are compatible with GIS programs like ArcGIS. If you upload a vegetation polygon shapefile, data that are added to this layer will be returned in the original projection of the file you uploaded.

You will see one PDF file in your outputs called **regenmapper_plots.pdf**. This file contains image plots visualizing each of the raster grid results in your folder. You can use this to quickly inspect the results for your fire. You should be able to get a general sense from these outputs whether the results are sensible, and some of the spatial patterns in your burned area.

Table 1. Spatial outputs provided by Regenmapper with a brief description of each file.

Layer Name	Description
Primary raster grid outputs	
distance_to_seed.tif	Distance to nearest potential live seed source (meters)
USFS_admin_priority_30m.tif	10-class raster identifying Intermountain West Decision Matrix outputs.
Distance_to_road_30m.tif	Distance to nearest road for all severely burned pixels (meters)
Cost_index.tif	Continuous cost-benefit index raster based on distance to roads and probability of natural recruitment. Larger values indicate lower cost and higher relative benefit.
Cost_cluster_5class.tif	5 class version of the continuous cost index above
Conifer seedling climatic suitability and regen probability prediction grids	
regen_probability_9221.tif	Predicted probability of natural recruitment for any conifer species (0 to 1). This and other all species outputs are used for derived outputs (cost index, polygon summaries).
regen_probability_9221_climate.tif	All species probability of natural recruitment with seed distance effects removed (climate only).
regen_probability_2050.tif	Predicted probability of natural recruitment for any conifer species for projected 2050 climatic conditions (0 to 1).
PIPO_regen_prob_1981-2010.tif	Predicted probability of natural recruitment for PIPO (0 to 1). This is the only individual species model that includes effects of distance to live tree.
PICO, PIEN, ABGR, ABLA_regen_prob_climate.tif	Optional recruitment probability predictions for selected species. The models show only climatic suitability for those species and do not include distance to a potential seed source.
Ancillary raster grid outputs	
deficit_mm_9221_mean.tif	Climatic water deficit 30-year average (millimeters)
PSST_1982-2018_q95.tif	35-year average potential land surface temperature (degrees C) showing areas that are potentially lethal for seedlings.
GEDI_canopy_height	GEDI lidar canopy height (meters) with severely burned areas masked as NoData
Slope_30m.tif	Slope (%) from 30-meter Landfire DEM
Elevation_30m.tif	Elevation (meters) from 30-meter Landfire DEM
Aspect_30m.tif	Aspect (degrees) from 30-meter Landfire DEM
Shapefile/vector outputs	
Admin_priority_polygons.shp	USFS_admin_priority_30m raster grid converted to vector polygons (outputs from the Intermountain West Decision Matrix).
FACTS_regen_poly.shp	FACTS polygons meeting criteria for existing or imminent reforestation needs as defined in the Intermountain West Decision Matrix and its appendix.
Stand_poly_regen.shp	Optional output if user uploads a vegetation polygon shapefile with raster outputs attributed to the vegetation polygons

B. Distance to potential seed source

The primary factor that determines whether natural regeneration will occur at a site is proximity to live, adult trees. Many studies have shown that the probability of tree recruitment after a fire decrease with increasing distance from live trees, and natural recovery becomes unlikely beyond distances of 100 meters (330 feet). Regenmapper uses spaceborne light detection and ranging (LiDAR) data from the Global Ecosystem Dynamics Investigation (GEDI). For every severely burned pixel in your burned area, the distance to a non-severely burned pixel that meets a user-defined height threshold is calculated. Figure 3 shows the full LiDAR image (left panel) with severely burned pixels shown in white, and the distance to seed source shown on the right. The distance to seed source grid is used as a predictor in the model prediction of probability of natural regeneration. Both raster grids in Figure 3 are provided as GeoTIFF outputs for you to use in planning your project.

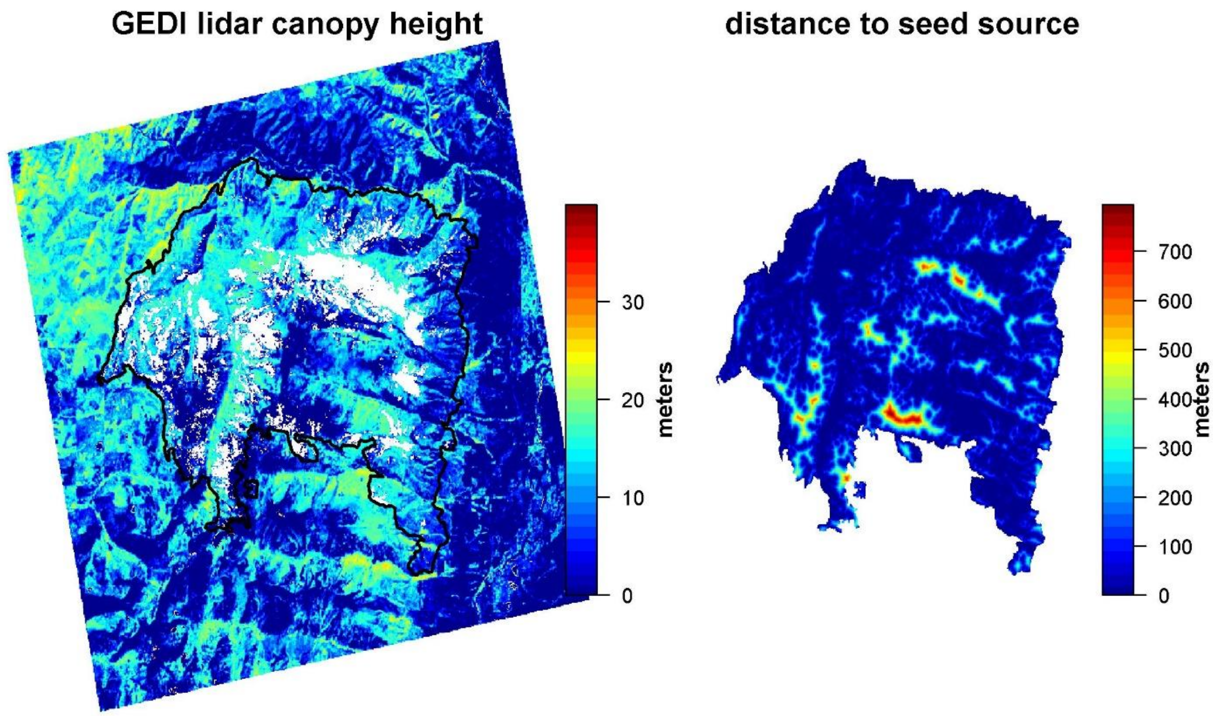


Figure 3. GEDI LiDAR canopy height and distance to seed source outputs for the Lolo Peak fire.

C. Natural regeneration predictions

The primary outputs provided by Regenmapper are 30-meter maps predicting the probability of natural regeneration for all grid cells in your burned area map. This section describes how the layers were produced and how to interpret and use them. Figure 4 below shows example outputs for the 2017 Lolo Peak Fire.

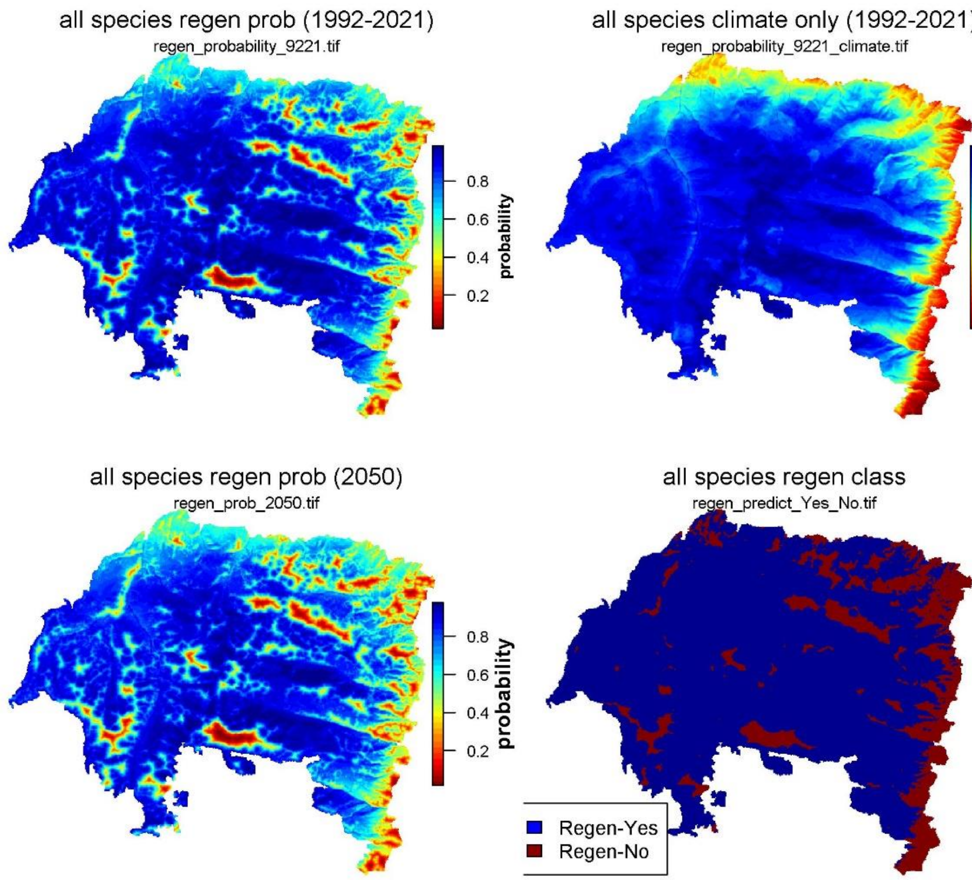


Figure 4. Prediction maps showing probability of natural regeneration for a model fit for all species. Left two panels show predictions for the full regression model that includes distance to potential seed source for historical and projected 2050 climate. Upper right panel shows the climatic effects from the regression, with the distance to seed source effect removed. The lower right panel shows the full model prediction classified into a binary (Yes-No) prediction map.

Post-fire regeneration maps are created using logistic regression models fit using a database of more than 10,000 field observations described in Davis et al. (2023). A generic model that includes all conifer species in that dataset is used to make the primary prediction maps. This means that plots where any ponderosa pine, Douglas-fir, Jeffrey pine, lodgepole pine, grand fir, subalpine fir or Engelmann spruce were found post-fire were labeled present and plots where no regeneration occurred were labeled absent. Predictors from models described in Davis et al. 2023 include distance to nearest live tree, fire severity, and the density of surrounding tree within 300 meters of each plot. Two additional predictors, maximum potential soil surface temperature from 1982-2018 and mean annual climatic water balance deficit from 1992-2021 were added to each plot as spatial predictors of post-fire regeneration. These 30-meter raster layers are provided as outputs for fire extent and are discussed in more detail below. Derived outputs, including the binary (regen yes/no) raster and USFS administrative priorities are made using the model for all species.

Example predictions from the 2017 Lolo Peak fire are shown in Figure 4. When examining these outputs, you will notice that in the upper two panels, the probability of natural regeneration is lowest in larger severely burned patches where the distance to a potential seed source is highest. Even in relatively wet sites that may be climatically suitable for seedling survival, the lack of proximity to a nearby seed source will be limited**. Species like lodgepole pine, with serotinous cones, or aspen which can resprout clonally may be exceptions and will not be accurately represented by the model output.** However, for other conifers which reproduce via dispersed seeds, distance to seed source will still limit recovery.

In addition to the full model prediction, a "climate only" prediction with the effect of distance to seed removed is also provided as an output. Here the effect of distance to seed source is set to less than 30 meters for every grid cell in the study area and the model prediction is made using only historical climate variables and years since fire. This layer is provided as an output and can be used to visualize the climatic suitability for planting, independent of the size of high severity patches that strongly determine natural recruitment probability. You will notice that for the Lolo Peak fire, lower elevation sites on the east side of the fire have lower survival probabilities while the wetter high elevation areas toward the center of the fire have higher probabilities.

In addition to outputs showing the continuous probability (0 to 1 scale) a binary "Yes-No" layer is provided. Here, the all-species model predictions are combined, and any place where the probability exceeds an empirically optimized threshold of0.60 a 1 is assigned (Yes, natural regen could occur). Grid cells where the regeneration probabilities are less than 0.60 are assigned a 0 (No-natural regeneration unlikely). For many users, this is likely the only prediction map you will need to use. This layer can be used to guide initial assessments about where to begin planning planting activities. Again, for serotinous lodgepole pine or aspen, where distance to live trees may not be a limiting factor, these predictions will have little utility for predicting natural recovery.

For users interested in species specific information, separate models trained using only data for those species are used to make raster predictions for each species selected by the user. Here, only the climatic suitability for each of those species is provided. Example outputs for lodgepole pine, grand fir, subalpine fir and Engelmann spruce are shown in Figure 5.

The probability of seedling recruitment for ponderosa pine was developed using a different dataset and model. Here, we used data from Davis et al. 2019, which contains data collected on multiple sites from 32 wildfires across the western U.S. Sampling in these data includes the year of establishment, which enables more detailed characterization of climate-recruitment relationships. The regression model used for ponderosa pine was fit using five spatial predictors: climatic water balance deficit (Holden et al. 2019) representing dryness, growing degree days (temperature), years since fire, potential land surface temperature, and distance to seed source. Each of these variables is calculated for your burned area and the fitted regression model is used to predict the probability of natural recruitment for each grid cell in your project area.

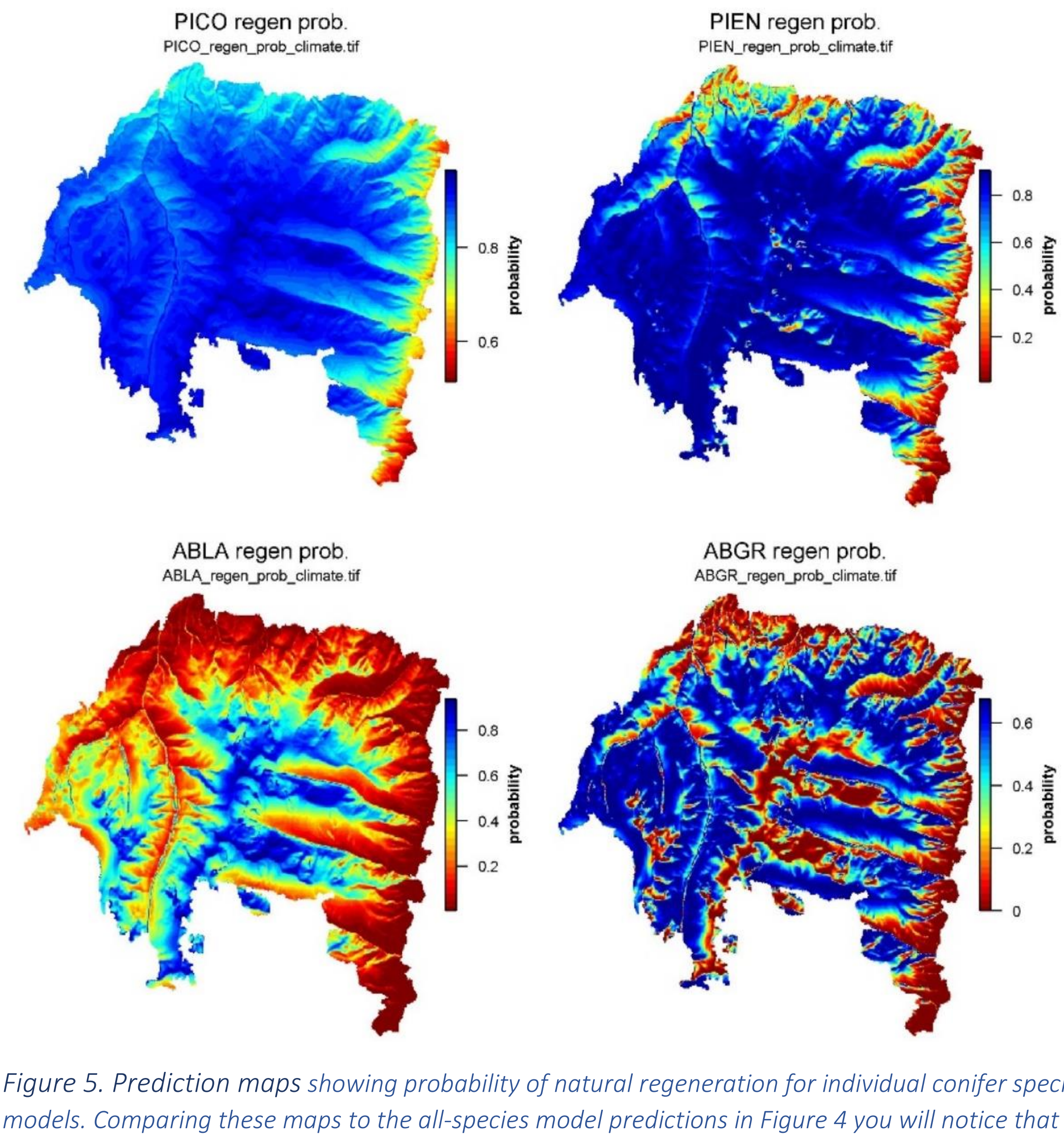


Figure 5. Prediction maps showing probability of natural regeneration for individual conifer species models. Comparing these maps to the all-species model predictions in Figure 4 you will notice that distance to seed source effects from large high severity patches are absent in these predictions. For these species, we make only climatic suitability predictions.

D. Potential soil surface temperature

Regenmapper provides one additional 30-meter resolution raster map designed to provide information on the vulnerability of seedlings at potential planting sites to heat-induced mortality. Stand replacing wildfires alter the biophysical. Removal of the overstory canopy increases incoming radiation reaching the ground, increasing temperatures at the ground surface. Temperatures at the soil surface can exceed 2-meter air temperatures by 10-15 °C. We provide maps of climatological average maximum surface temperature (1982-2018), simulated for a bed of 2-inch ponderosa pine seedlings (Holden et al. in preparation). Because the simulations are done in the absence of any overstory canopy, we call this product "potential" soil surface temperature (PLST), to better represent what the near surface temperatures might be like after overstory canopy loss. Figure 6 shows an example map of PLST for the 2017 Lolo Peak fire. This layer could be helpful for evaluating the potential thermal stress on seedlings planted at marginal, low-elevation, south-facing sites.

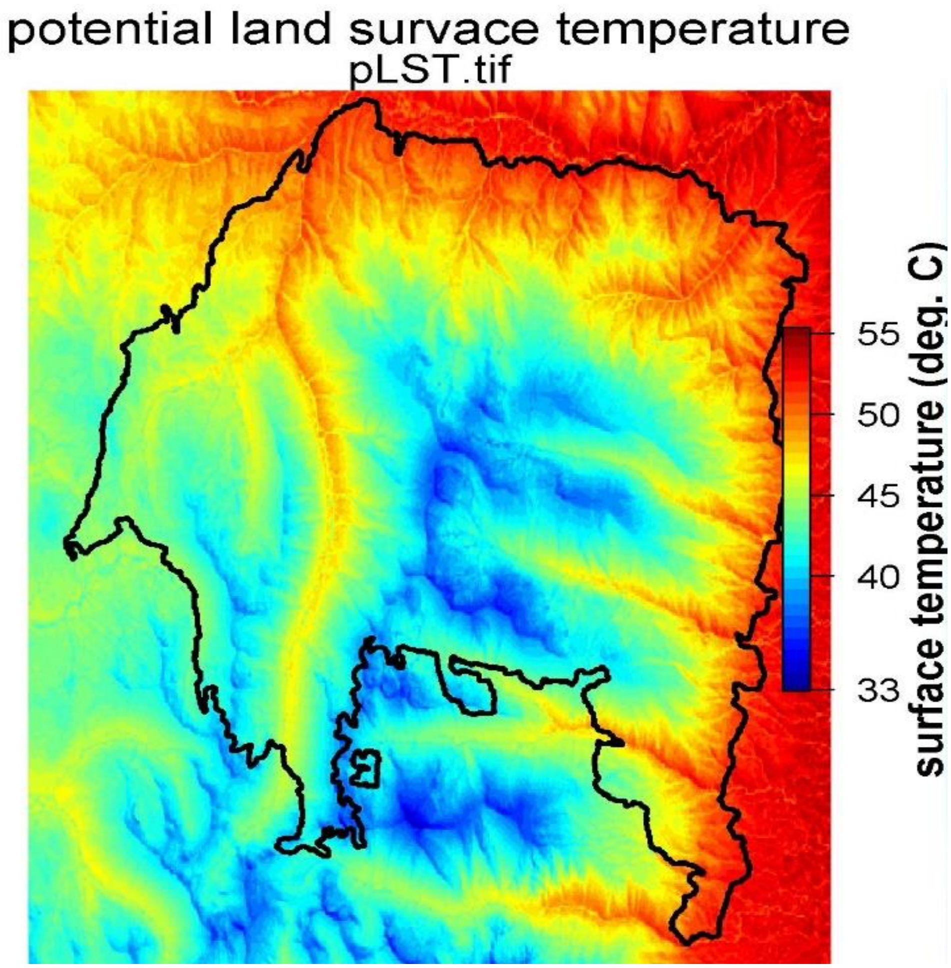


Figure 6. Potential land surface temperature (PLST) and probability of survival for the Lolo Peak fire in Montana.

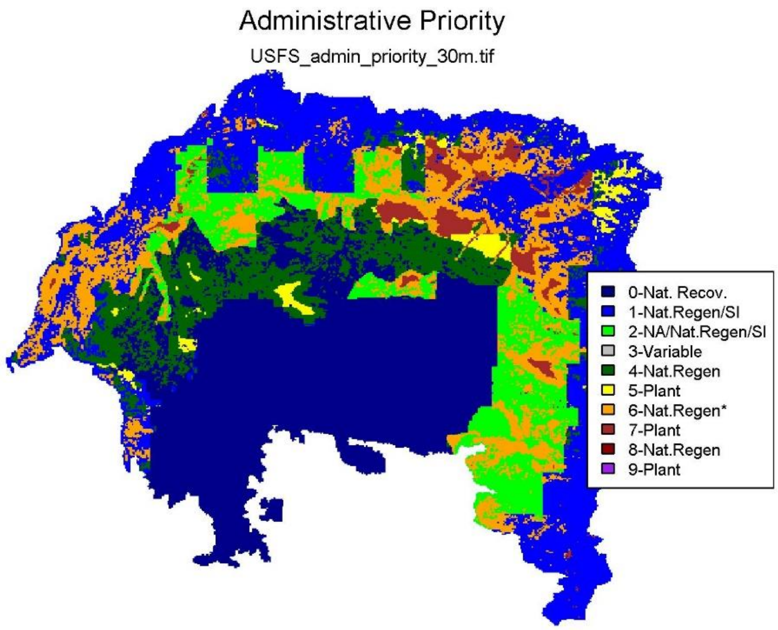
E. USFS Administrative priority classification

This section describes Regenmapper outputs that integrate data from regional timber suitability layers, suitability surrogates, and the USFS Forest Activity Tracking System (FACTS) database. It is intended for USFS users. If you are not a USFS employee or are working on a post-fire assessment for a wildfire that occurred outside of Forest Service land, these outputs may not be relevant for your project.

The USFS uses a spatial and tabular database called FACTS to track management activities on USFS lands. When wildfires burn through areas where recent reforestation harvests have occurred or are currently underway, high priority is placed on post-fire reforestation. Any other planned reforestation actions that were burned through are also triggered as high priority. The 1976 National Forest Management Act (NFMA), the Repairing Public Lands by Planting Necessary Trees (REPLANT) Act and related policy drives this priority. USFS Regions 1-4 have developed a decision matrix to identify and prioritize reforestation actions based on outstanding reforestation needs in FACTS, the severity of the fire and whether the area burned is inside the forest's suitable timber base (Table 2). The decision matrix specifies ten categories from 0-9 which determine the potential reforestation action and its level of urgency. For example, severely burned areas with a fire that intersect with an existing reforestation need identified in FACTS, that are within the suitable timber base for that forest, and that have a low probability of natural regeneration are a assigned a value of 9, with 9 being the highest priority, indicating that planting is likely required.

This decision matrix logic is automated in Regenmapper. A query is sent to the FACTS database, and all spatial polygons meeting the required FACTS codes are returned. These polygons are then intersected with either an actual regional or a provisional suitable timber base map, the burn severity map, and the probability of natural regeneration map. Then the decision matrix logic is applied and returned as a 30-meter resolution raster grid called "USFS_admin_priority_30m.tif". To facilitate ease of use, this 30-meter raster is converted to a spatial polygon shapefile called "USFS_admin_priority_polygon.shp". An example output for the Lolo Peak fire is shown in figure 7.

Where regional suitability layers (compiled from individual forest plans) are not available, a surrogate, provisional suitable base layer is used based on wilderness and roadless areas along with climatic suitability for tree occurrence. Thus, USFS users will want to verify outputs against their local suitable timber base layer where a regional layer is not incorporated.



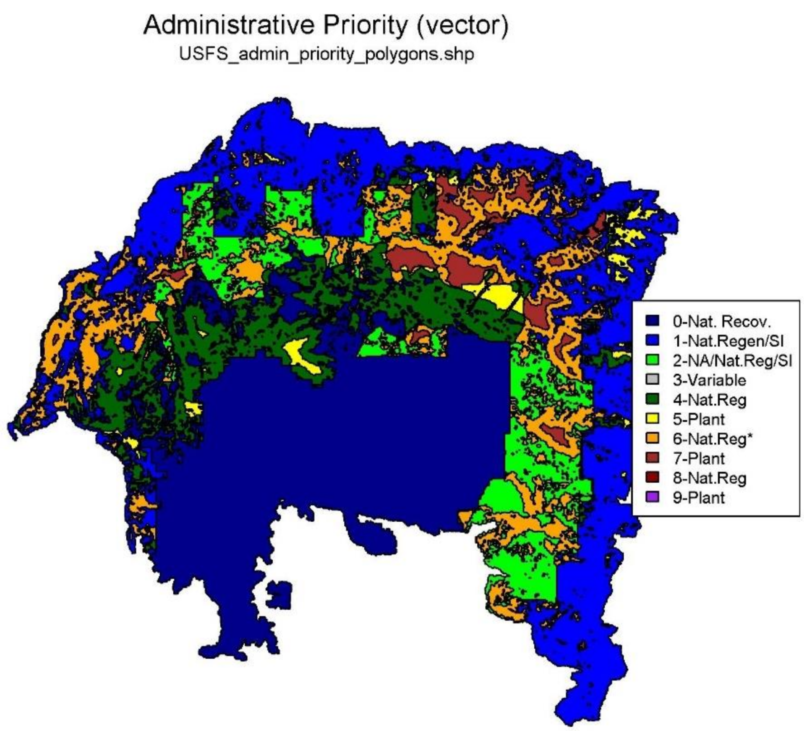


Figure 7. USFS Administrative priority raster layer (top) and shapefile layer (bottom). Values in the raster and shapefile outputs reflect the Decision Matrix logic in Table 2 above. Values of 8 and 9 have the highest priority, indicating sites having an outstanding reforestation need from FACTS, moderate or high severity fire, and that likely fall within the suitable timber base.

Table 2. Intermountain west decision matrix for regions 1 through 4 which defines the administrative priorities for post-fire planting.

Fire Severity	**Suitable Base**[1]	**Existing Reforestation Need, Incomplete Regeneration Harvest, or Incomplete Treatments Where Causal Agent is Not Null**[2]	**Priority**[3]	**Natural Regeneration Probability**	***Regen mapper* Cell Value**	**Diagnoses**	**Potential FACTS Activity Sequence**[4]
High or Moderate	N/A	Yes	Very High	N	9	Plant	Plan planting in Year 3 entering appropriate causal agent, pre-plant survey year 1
High or Moderate	N/A	Yes	Very High	Y	8	Natural Regeneration	Initiate Natural Regeneration (NRG) and planned certification of natural regen without site prep entering appropriate causal agent, plan stocking survey year 1
High or Moderate	Yes	No	High	N	7	Plant	Plan planting in Year 3 entering appropriate causal agent, pre-plant survey year 1
High or Moderate	Yes	No	High	Y	6	Natural Regeneration	Initiate Natural Regeneration (NRG) and planned certification of natural regen without site prep entering appropriate causal agent, plan stocking survey year 1
High or Moderate	No	No	Medium	N	5	Plant	Plan planting in Year 3 entering appropriate causal agent, pre-plant survey year 1
High or Moderate	No	No	Medium	Y	4	Natural Regeneration	Initiate NRG and planned certification of natural regen without site prep entering appropriate causal agent, plan stocking survey Year 1 or 2.
Any	No or N/A. This category includes all specially designated areas, excluding inventoried roadless areas, wilderness, potential wilderness areas, or wilderness study areas.	N/A	Variable[5]	Y or N	3	Natural Recovery, **OR**	Enter Natural Recovery with the appropriate causal agent; plan follow-up monitoring in 20 years; **OR**
						Natural Regeneration or Plant depending on management objectives	Plan natural regeneration or planting depending on management objectives, including considerations for municipal watershed recovery, landslide/soil stabilization, etc.
Low	N/A	Yes	Medium	Y	2	Natural Regeneration	Initiate NRG and planned certification of natural regen without site prep entering appropriate causal agent, focusing on desired species mixes, plan stocking survey year 3 for conifers, year 1 for hardwoods.
Low	Yes	No	N/A	Y	1	No Reforestation Action/ Stand Improvement (SI) Need, **OR**	Site may be adequately stocked; assess and plan SI activities to achieve appropriate species composition if adequately stocked. If not adequately stocked, consider natural regeneration entering appropriate causal agent, **OR**
			Low	Y	1	Natural Regeneration	Initiate NRG and planned certification of natural regen without site prep entering appropriate causal agent, plan stocking survey year 3 for conifers, year 1 for hardwoods.
Any	No. This category includes wilderness, intended or potential wilderness areas, and wilderness study areas.	N/A	N/A	N/A	0	Natural Recovery	Enter Natural Recovery with the appropriate causal agent; plan follow-up monitoring in 20 years

[1] *Regenmapper* currently uses a surrogate suitability layer that removes Congressionally withdrawn areas, except for USFS Regions 1 and 2. For these two regions, regional Forest Plan suitability layers have been built into the decision matrix within *Regenmapper*. For Region 1, suitable base includes lands suitable for timber production or lands where harvest is allowed for purposes other than timber production. In Region 2, the suitable base layer includes lands suitable for timber production. Outside of Regions 1 and 2, existing forest suitability layers can be overlain onto *Regenmapper* results to refine decision space.

[2] See Decision Matrix Appendix 1.

[3] All reforestation needs as well as natural recovery areas need to be entered in the FACTS database, regardless of priority. FACTS data entry can incorporate priority through a variety of methods (i.e., planned dates, local qualifiers, Activity Unit or SubUnit naming conventions, implementation projects, etc.).

[4] This is not incorporated in model output; this field provides recommended activity sequences (based on policy) for FACTS data entry once additional local analysis is performed from model output. Considerations need to be made for existing FACTS SUIDS that were modified by disturbance that need to be adjusted; others SUIDS may need to be created in their entirety. Tablet applications are in development for field verification of needs for refinement over time.

[5] This would typically be a diagnosis of natural recovery, but local decisions can include areas for reforestation actions where management objectives dictate (i.e., municipal watersheds, Wild and Scenic Rivers, etc.). These areas may need to be emphasized for reforestation where suitable base may be irrelevant. Local decisions should refine reforestation action and priority decision space accordingly.

F. Cost-benefit index calculation

A simple cost-benefit index equation is implemented in Regenmapper to assist in identifying areas in need of replanting, have a higher probability of survival if trees are planted there, and that are near roads, which results in less expense to treat. The basic logic of this calculation is that all else being equal, if we can't plant every severely burned area within a fire and we must prioritize one site over another, we would likely select areas that are easy to access (near roads) with a high need (unlikely to regenerate on their own) and where trees will survive if we plant there. The cost-benefit calculation is shown in Equation 1, where RoadDistance is the distance to the nearest road, SurvivalProb is the probability of survival based on climatic suitability, and RegenProb is the probability of natural regeneration taken from the maximum survival probability from either ponderosa pine or Douglas-fir in Figure 4 above.

Figure 8 shows the output from this calculation for the Lolo Peak fire. The continuous output (unitless) is shown in the left panel. A spatial clustering algorithm is applied to the continuous output to produce a classified version of the map, shown in the right panel. Values of 5 indicate with the highest need with close proximity to roads and should be considered high priority for potential reforestation action.

Equation 1

$$CostBenefit = \left(\frac{1}{RoadDistance * SurvivalProb * (1 - RegenProb}\right)$$

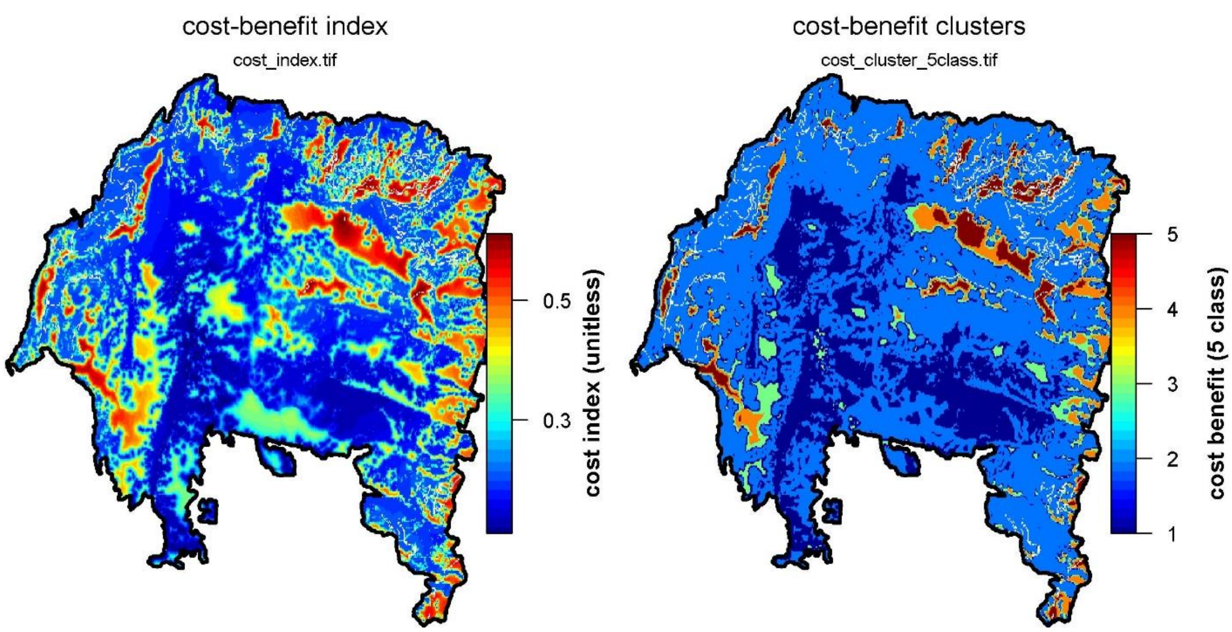


Figure 8. Cost-benefit index (left) and a classified version of the index based on spatial clustering (right). Larger values in the index and classified values indicate higher priority areas that are closer to roads and less likely reforest naturally in the absence of intervention.

G. Vegetation polygon shapefile attributes

Users have the option to upload a vector shapefile representing vegetation units or stands in addition to the burn severity map. If Regenmapper finds a polygon shapefile in the uploaded .ZIP file, some of the key raster grid ouputs described above with be extracted for each polgygon and those attributes will be added to to the polygons and returned to you in your results folder as the file: “stand_poly_regen.shp”. In USFS Region 1, the vegetation polygons are available in the VMAP product. These polygons can be clipped to the extent of the fire, added to your .ZIP file and uploaded with your burn severity map. Examples of two outputs for VMAP polygon results for the Lolo Peak fire are shown in Figure 9. The right panel shows distance to the nearest road for each polygon. The left panel shows the binary Regen-YesNo output (shown in raster grid format in Figure 4 above).

The use of existing vegetation or stand polygons that are already used and part of your corporate data is attractive. These datasets are likely familiar and contain attributes that may be useful for planning. However, it is important to note that stand replacing wildfires can fundamentally change the landscape, and will likely not align with stand delineations made before the fire. For example, a large, high severity patch may fully overlap multiple stand polygons but only partially overlap others. It may therefore be more practical to use the continous raster outputs when identifying areas to consider for reforestation activities.

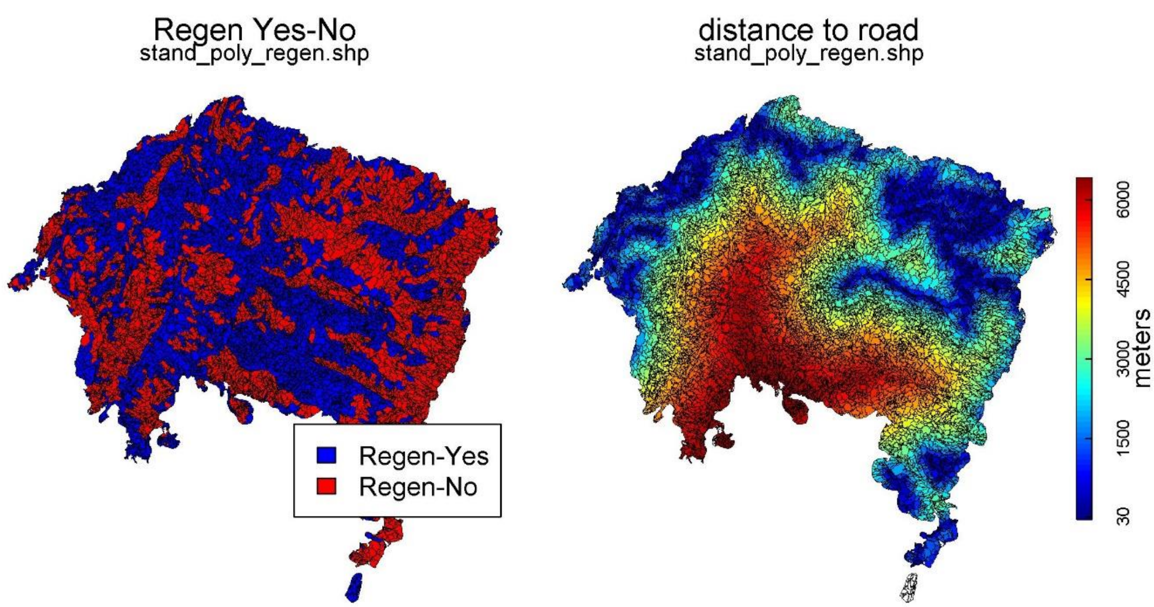


Figure 9. Example polygon attributes extracted for Region 1 VMAP polygons uploaded for the Lolo Peak fire. Each polygon is attributed with some of the raster grid outputs discussed in the sections above.

Literature Cited

Davis, K.T., S. Dobrowski, P. Higuera, Z.A. Holden, T.T. Veblen, M.T. Rother, S. Parks, A. Sala and M. Maneta (2019). Wildfires and climate change push low-elevation forests across a critical climate threshold for tree regeneration. Proc. Nat. Acad. Sci. 116:6193-6198.

Holden, Z.A. and J. Evans (2009). Using fuzzy C-means and local autocorrelation to cluster satellite-inferred burn severity classes. Int. J. Wild. Fire. 19:853-860.

Holden, Z.A., W. Jolly, A. Swanson, D. Warren, M. Maneta, M. Burgard, C. Gibson, Z. Hoylman, and E. Landguth (2019). TOPOFIRE: A topographically resolved wildfire danger and drought monitoring system for the conterminous United States. Bull. Amer. Met. Soc. 100, 1607-1613.

Holden, Z.A., S. Dobrowski and M. Maneta (in preparation). Potential land skin temperature limits forest recruitment at the low elevation tree line in the western United States.

Dixon, R., S. Dobrowski, P. Higuera, Z.A. Holden and M. Maneta (2020). Conifer seedling survival in response to high surface temperature events of varying intensity and duration. Frontiers.