Modeling and mapping suitability for six vegetation-based wildfire resistance strategies, on the South Coast of Santa Barbara County, California

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Conservation Biology Institute

sig nal Spatial Informatics Group Natural Assets Laboratory

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Executive Summary

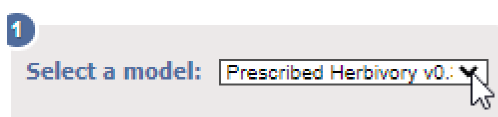
This report, and the associated decision support system, are part of the Regional Wildfire Mitigation Program's Landscape Domain. The Landscape Domain's goal is to protect and expand vegetated "greenbelts" that provide wildfire protection and ecosystem conservation co-benefits in the Santa Barbara County, CA region. Program outcomes are designed to also provide numerous co-benefits that support watershed and coastal ecological functions.

For this phase of the program, we focus on 6 types of proposed nature-based interventions (i.e. "treatments"):

- Shaded Oak Fuel Breaks
- Riparian Fuel Breaks
- Prescribed Herbivory
- Avocado Orchards
- Citrus Orchards
- Low-water Plantations (e.g. Agave)

This report summarizes and links to an Environmental Evaluation Modeling System (EEMS) designed to support these treatments. The EEMS presents pertinent spatial information and data in a logically structured and transparent format to guide landscape-scale planning and decision making. In this case, it maps the relative suitability of each reporting unit, a 196 ft X 194 ft (60 m X 60 m) square area, for implementing each treatment, irrespective of fire hazard or asset vulnerability. These suitability maps can be used as stand-alone decision support, and are to be combined with hazard and asset maps in a later part of the program's analytic workflow.

The **Suitability Map and Interface for each Treatment is here,** after clicking on the "Select a model" menu:



Here is a brief tutorial video for using this EEMS graphical user interface (GUI). This is highly recommended for learning the GUI or getting a reminder of some tips and tricks.

The target audience for the report and EEMS are the RWMP partners listed on the first page of the report, as well as any other entities doing landscape project planning for any of these treatments. The "logic model" diagrams for each analysis are in the sections below, followed by a brief written summary.

The south coast of Santa Barbara County was the focal area for this analysis. A map of this area and the results for one of the treatments is below (Figure 1), and explorable online.

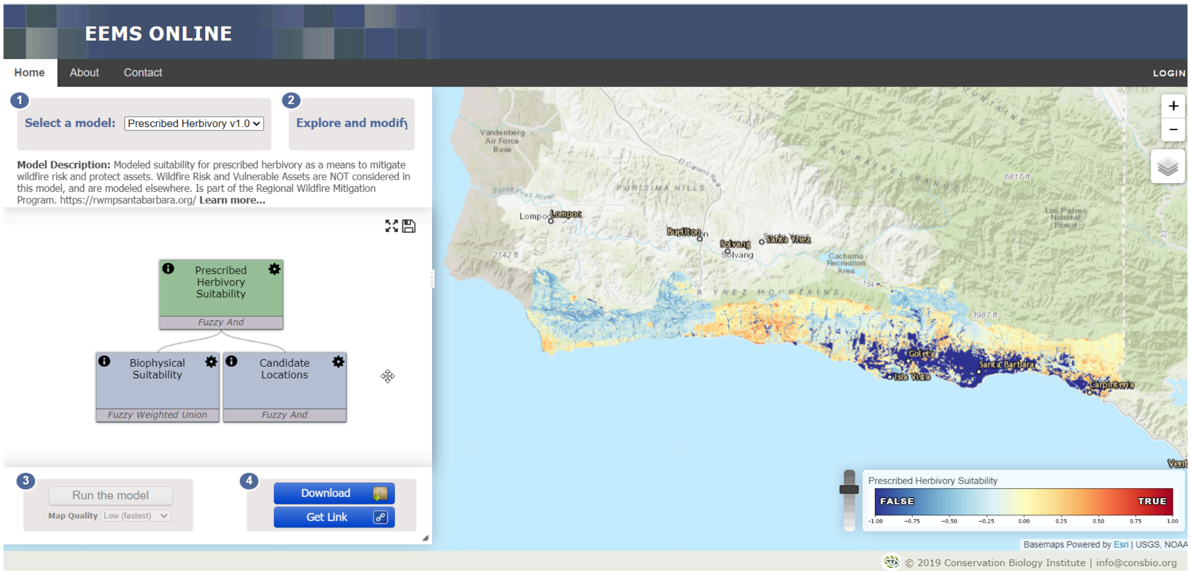


Figure 1. Project Study Area. The South Coast of Santa Barbara County, CA, and results from one of the six models.

Data used for the analysis can be found through the links in the GUI (click the lower boxes of the logic model to expand them all the way down to the inputs, then click the "i" button in the input's box) and in Appendix 1: Glossary of Input Criteria. An input criterion is a spatial data layer that gets transformed into a new layer with values ranging between -1 and 1, and then combined with other criteria.

The "flat files" in Appendix 2 provide technical details of the hierarchy for each treatment. They describe a logic model from the top down, and provide the details that are present in the graphical user interface via many mouse clicks, all in one "flatfile" doc, that you can scroll through with no mouse clicks.

More details on how to use the eemsonline.org GUI are in Appendix 3. Thank you to all the Experts and Advisors that supported this project, detailed later in the report.

Decision Support System Overview

The spatial models for mapping the suitability for each vegetation management type for each reporting unit on the landscape are based on GIS Layer overlays. Each GIS Layer is a criterion, and they are combined in algebraic and logical ways, such as taking the mean of the values from all the layers for a particular location.

We use a type of nuanced, common-sense multicriteria overlay known in academia as fuzzy logic. This logic is based on the premise that this is not a black and white world. Rather than saying a particular place is either good or bad for a particular criterion, like the slope, this logic gives relative truth values. For example, how good is the slope for a particular treatment, like planting avocados. A 20% slope is not as good as a 5% slope, but is still feasible, and should still be considered, just less so. Fuzzy logic also allows for weighted means, and also taking the min or max value among all the criteria for a particular location.

We use the environmental evaluation modeling system (EEMS) to implement this logic. Fuzzy logic and EEMS are overviewed in the associated journal article (Sheehan and Gough 2016) and user manual (Sheehan, Strittholt, and Gough 2016). Here, if a criterion is considered “true” for a particular location it is mapped as a 1, if it is considered false, it is mapped as a -1, and all values in between represent the fuzzy values. Hence a 0 is neither true nor false, and a 0.5 is somewhat true. Fuzzy logic has an associated vocabulary (Table 1), and the user manual (Sheehan, Strittholt, and Gough 2016) provides the quickest primer.

One of the reasons we use EEMS is because the associated graphical user interfaces (GUI) are transparent and can communicate all of the model methodology. Further, they link to the input data which are described and viewable as interactive maps (as per the tutorial video).

Fuzzy Logic Term	*Definition*
Convert to Fuzzy	Converting a range of numbers into the -1 to 1 range, using a linear transformation with the min and max values identified.
Convert to Fuzzy Category	A process for categorical variables, giving each category a value between -1 and 1.
Convert to Fuzzy Curve	Converting a range of numbers into the -1 to 1 range, using a non-linear transformation with the min and max values identified as well as inflection points on the curve.
EEMS Read	Collect input data
Fuzzy And	The minimum value of the inputs for each cell is the one carried forward. (It needs to be true for variable 1 AND 2 to be true.)
Fuzzy Or	The maximum value of the inputs for each cell is the one carried forward. (It needs to be true for variable 1 OR 2 to be true.)
Fuzzy Union	Mean
Fuzzy Weighted Union	Weighted Mean

Table 1: Brief glossary of EEMS terms. Formal Fuzzy Logic has a specific vocabulary for combining criteria, which is shown in the graphical user interface, and is translated in brief here.

In designing the logic models, the project team relied on two principles in addition to the best practices of multicriteria modeling and scientific practice more generally:

Parsimony: The models attempt to come close to modeling the complexity of any given situation, yet simple enough to be understood by stakeholders and decision makers. In this pursuit of parsimony, not every conceivable variable or nuance is included.

Area Inclusivity: In many cases of data processing, analysis, and logic model design, or weighting, a judgment call needs to be made about if the amount of suitable lands mapped for a mitigation strategy should be a slight overestimate or slight underestimate. Because the EEMS model is meant to support decisions that are then verified via ground-truthing and expert judgment, the team decided to make slight overestimates.

Context

These analyses are not meant to be viewed in isolation when determining where to do fire mitigation projects. End users are expected to be also considering wildfire hazard risks and asset vulnerabilities via their expert knowledge, maps, and/or further analyses. The same goes for project feasibility, as we made no attempt to map or model landowner willingness to perform the various treatments. Non-governmental conservation areas are considered private land in this issue. The maps associated with this report are intended to prioritize areas at the landscape-scale, followed by ground surveys, implementation, and monitoring. The 6 treatments discussed in this report are components of the action priorities (Figure 2, box #2) in the RWMP Landscape Domain workflow illustrated below.

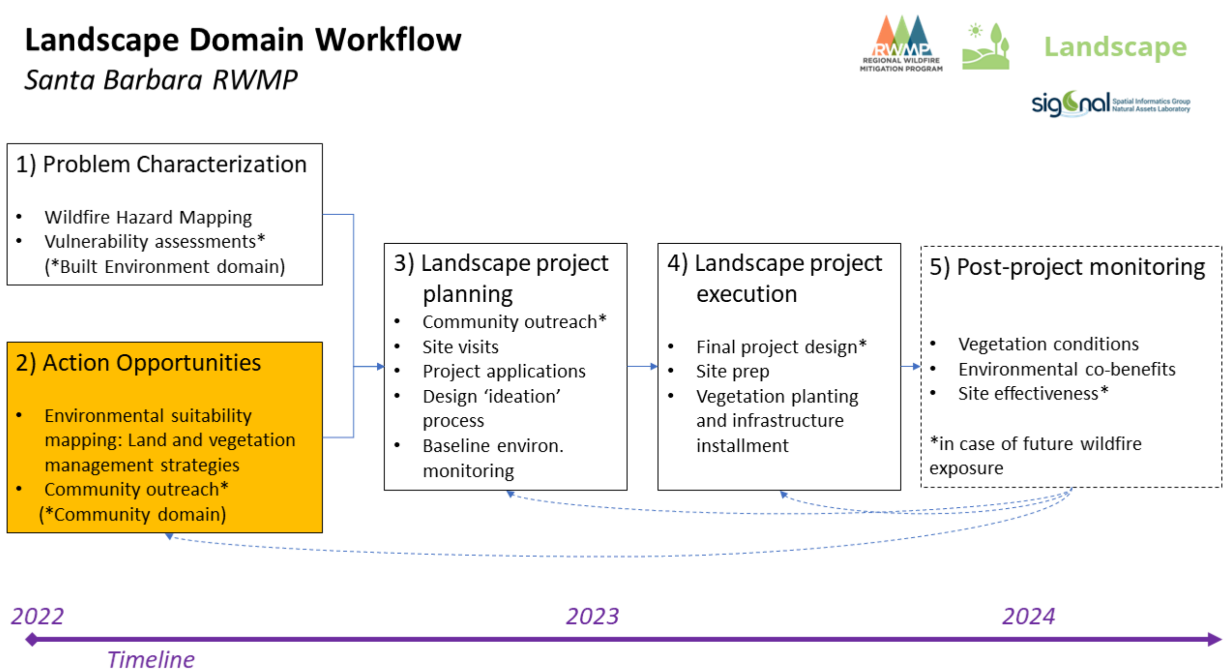


Figure 2. The above diagram summarizes the overall conceptual workflow. More details can be seen here, https://rwmpsantabarbara.org/ .

Shaded Oak Fuel Breaks

When a wildfire is moving towards important assets, such as a city, it has been known to be dampened or even halted when it encounters a shaded fuel break. These are timbered areas where the trees have low density and low ladder fuels, yet retain enough crown canopy to make a less favorable microclimate for surface fires (nwcg 2022). Here we focus on wild oak woodlands.

This EEMS model helps with the question, **what areas are especially suitable for planting oaks?** (In future years, another EEMS model can be made that asks where existing oak stands can be thinned to make shaded oak fuel breaks.)

The EEMS model answers the question about where to plant without considering where the vulnerable assets are, nor where fire is most likely to be moving, as these are considered later in the RWMP modeling process. So this analysis is not a complete prioritization of where to make shaded-oak fuel breaks. Instead, we focus here on where oak planting is most suitable based on a variety of criteria defined from geospatial data inputs.

We interviewed local experts at the Santa Barbara Botanic Garden and referred to the literature, especially to the USFS Fire Effects Information System (USFS 2022) in developing the logic model of the Oak Planting Feasibility EEMS model.

The modeled results for all six models are mapped and provided in a user interface for exploring the data (See Appendix 3 for a user guide), here: **EEMS Interface for the Whole Project** and scroll down to the latest version of this model in “Select a Model”.

The logic model is diagrammed in the following page (Figure 3), and is summarized after that in narrative bullets. See also the “i” information icon in each box of the user interface.

For the model addressing the suitability of areas for oak planting we chose 4 key criteria which are the 4 primary branches to the Oaks model. These key criteria are: habitat adjacency, terrain, soil water, and habitat type. Below we explain the reasoning for the choice of variables in the EEMS model that affect these 4 key criteria in the model.

- Regarding habitat adjacency:
    - We recognize that the new plantings are more successful if near existing oaks, due especially to the benefits of oak associated mycorrhizae.
    - Being close to orchards or vineyards is also beneficial because it makes it easier and more feasible to water the plantings using existing water infrastructure.
    - Being close to riparian areas is beneficial due to an assumed higher access to natural groundwater.
    - Rodents eating oak seedlings is a problem in such efforts, and these rodents are especially plentiful in shrub ecosystems, so proximity is a negative factor.

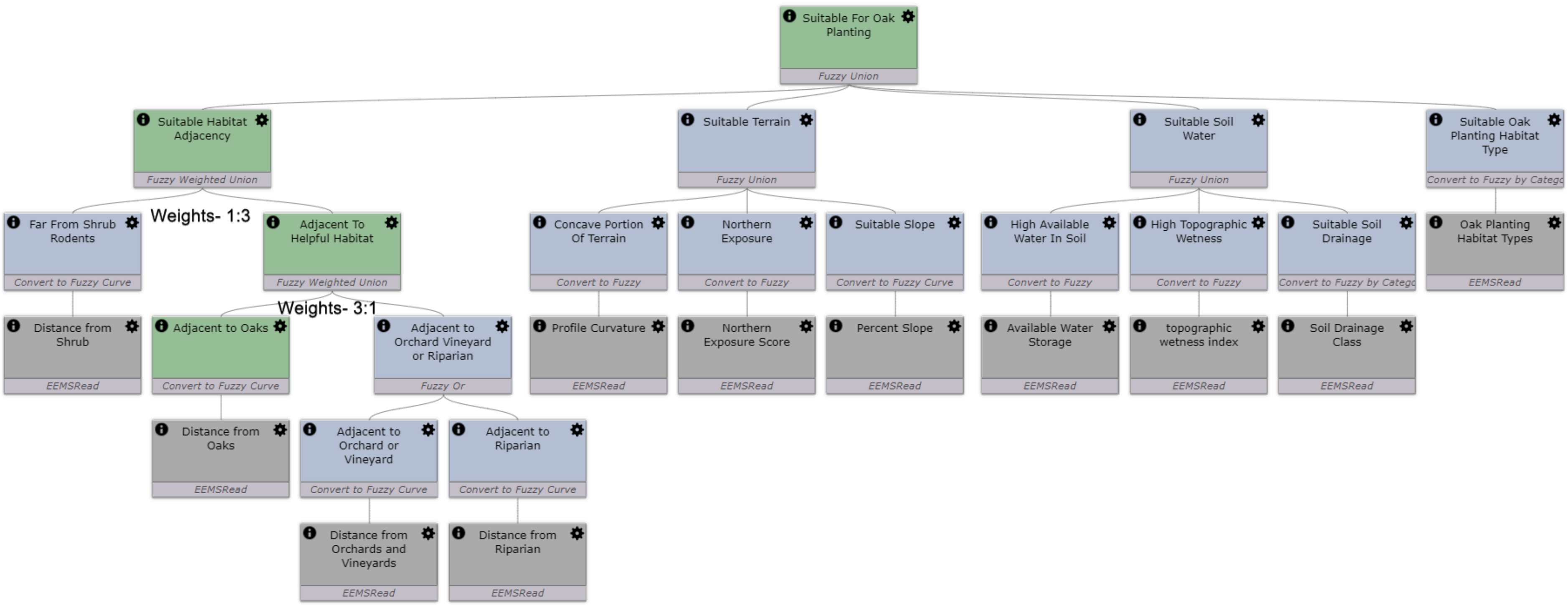


Figure 3: Oak Planting Suitability Logic Model. The relative weights and values for the criteria are documented in the information details on that criterium's box in the graphical user interface. Some information about each criterion is also provided in the description box, accessed via the "i" button. All recent models for the project are here. The entire model has been fit on a single page to give the reader a complete structural overview. To sharpen text in boxes, zoom to 150 or 200% on your browser window.

- Regarding terrain:
  - oaks grow better on north facing slopes, all else being equal.
  - small portions of the landscape that have a concave profile curvature catch and retain more water, so are also modeled and mapped
  - further, oaks can be planted on steeper slopes than all other mitigation measures in this project
- Regarding soil water (aka edaphic water):
  - oaks grow best in places where the water drains at a medium rate, not too fast or too slow,
  - they grow best where the soil is modeled to have a high amount of available water storage under the surface, and
  - they grow best where the landscape is modeled to have high topographic wetness.
- We assumed that for now, we want to focus only on planting oaks in what is currently annual grassland, pasture, oak woodland, or riparian areas.

A description of each input data layer and how it is normalized is detailed in Appendix 1. The top-down details of the logic models (i.e. how these input criteria become results) are provided in Appendix 2, and summary of how to use the online user interface is provided in this brief tutorial video and Appendix 3.

Riparian Fuel Breaks

When a wildfire is moving towards important assets, such as a city, it can be dampened or even halted when it encounters a riparian corridor fire break. These are areas along streams with a high density of lush trees like willows and cottonwoods.

This EEMS model helps with the question, **what areas are especially suitable for doing riparian restoration?** The EEMS model answers the question about where to restore without considering where the vulnerable assets are, nor where fire is most likely to be moving, as these are considered later in the RWMP modeling process. So this analysis is not a complete prioritization of where to make shaded-oak fuel breaks. Instead, we focus here on where riparian restoration is most suitable based on a variety of criteria defined from geospatial data inputs.

We interviewed local experts at the Santa Barbara Botanic Garden and referred to the literature, especially to the USFS Fire Effects Information System (USFS 2022) in developing the logic model of the Riparian Restoration Suitability EEMS model, which is diagrammed below, and is summarized in the below bullets.

The modeled results for all six models are mapped and provided in a user interface for exploring the data (See Appendix 3 for a user guide), here: **EEMS Interface for the Whole Project** and scroll down to the latest version of this model in “Select a Model”.

The logic model is diagrammed in the following page (Figure 4), and is summarized after that in narrative bullets. see also the “i” information icon in each box of the user interface.

For the riparian analysis, we did a majority of the geoprocessing outside of EEMS at high resolution, then we summarized these into the EEMS environment:

- We first mapped all areas in the region assumed to be riparian. These were given a value of 1 if we were more certain about this, 0.5 for the other areas less certain but still likely to be riparian.
- We then assumed that the lower the canopy height of the riparian area, the higher the priority for restoration, all else being equal.
- Those two data layers were multiplied together, so areas mapped as riparian with higher certainty, but very low canopy height, got a value of 1.
- Those data were at high resolution (~33 X 33 feet), and then needed to be generalized to the EEMS reporting unit (194 X 194 feet).
- This is problematic for reporting units that are partially outside of the riparian area, as they then have some null values (i.e. no value).
- An argument could be made to summarize using a mean value, or a summed value
- So we did both, and combined them using a mean.

A description of each input data layer and how it is normalized is detailed in Appendix 1. The top-down details of the logic models (i.e. how these input criteria become results) are provided in Appendix 2, and summary of how to use the online user interface is provided in this brief tutorial video and Appendix 3.

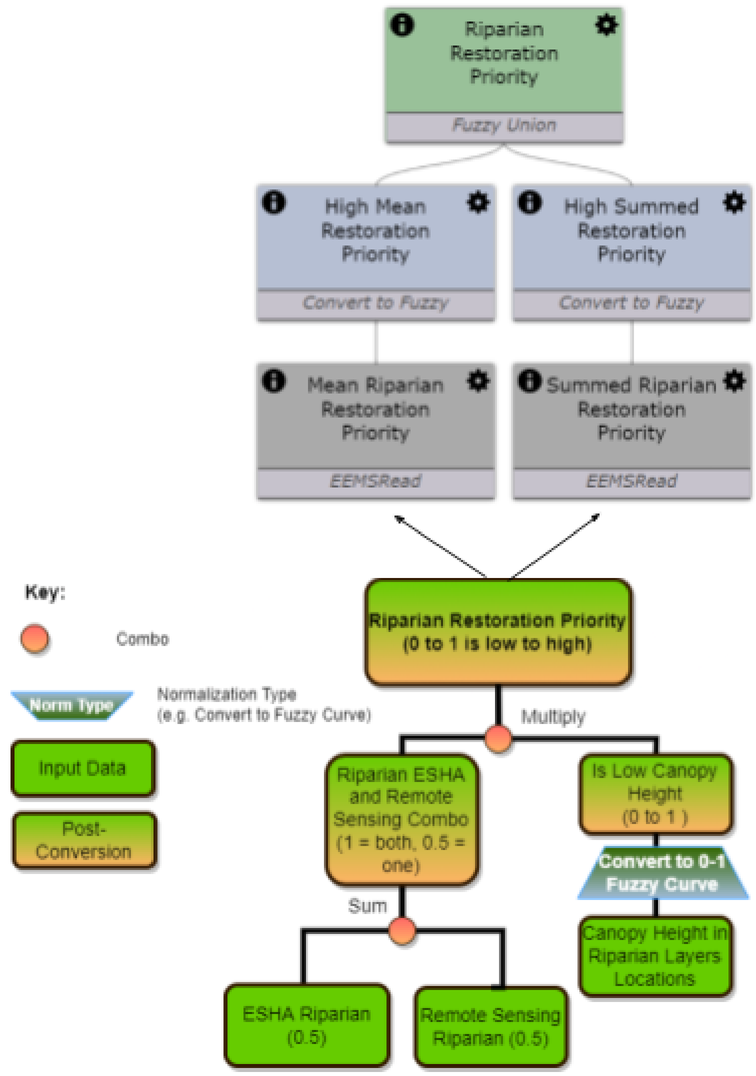


Figure 4: Riparian Restoration Suitability Logic Model. The relative weights and values for the criteria are documented in the information details on that criterium's box in the graphical user interface. Some information about each criteria is also provided in the description box, accessed via the "i" button. All recent models for the project are here.

Prescribed Herbivory

When a wildfire is moving towards important assets, such as a city, it can be dampened or even halted when it encounters an area that has had much of the surface fuel removed via prescribed herbivory. This management technique is usually performed by setting up a temporary electric fence and grazing sheep or goats in an area for a limited time.

This EEMS model helps with the question**, what areas are especially suitable for prescribed herbivory?** The EEMS model answers the question about where to prescribe herbivory without considering where the vulnerable assets are, nor where fire is most likely to be moving, as these are considered later in the RWMP modeling process. So this analysis is not a complete prioritization of where to make prescribed herbivory fuel breaks. Instead, we focus here on where riparian restoration is most suitable based on a variety of criteria defined from geospatial data inputs.

In developing the logic model of the Prescribed Herbivory Suitability EEMS model, we drew from our previous work in EEMS modeling for fire risk in the region via the Regional Priority Planning Project (Gallo, Canter, and Spencer 2021). We also interviewed local experts at Cuyama Lamb and referred to the literature (Lovreglio and Meddour-Sahar 2014; Ingram, Doran, and Nader 2013; Taylor 2006). The logic model is diagrammed below, and is summarized in the below bullets.

The modeled results for all six models are mapped and provided in a user interface for exploring the data (See Appendix 3 for a user guide), here: **EEMS Interface for the Whole Project** and scroll down to the latest version of this model in "Select a Model".

The logic model is diagrammed in the following page (Figure 5), and is summarized after that in narrative bullets. see also the "i" information icon in each box of the user interface.

There are two primary branches to the model that both need to be met for a place to be considered suitable:

- Candidate Locations:
  This is essentially a map of all the areas that are not excluded for other reasons, namely:
    - areas that are not Urban, Water (i.e. lakes), Golf Course, or Agricultural Land between development and wildland (i.e. Ag Greenbelt),
        - (we assume that it is unlikely that the landowners in these places will want prescribed herbivory)
    - and, we also map areas that are not environmentally sensitive habitat (ESHA), since the assumption is that prescribed herbivory cannot be permitted in these areas.
- Biophysical Suitability, in which we consider four major branches:
    - As the slope gets steeper, it gets increasingly difficult to do prescribed herbivory, especially making a well-constraining fence
    - Areas of high ecological value should be avoided, since goats or sheep can impact the ecological processes of wild ecosystems
        - these are mapped using a previous analysis that considers many factors, but is more coarse
        - as well as special emphasis on avoiding wetlands
    - areas of recent fire are especially suitable since prescribed herbivory can be completed faster per acre than in non-burned areas,
    - And vegetation suitability is an importance consideration, and is comprised of 2 minor branches:

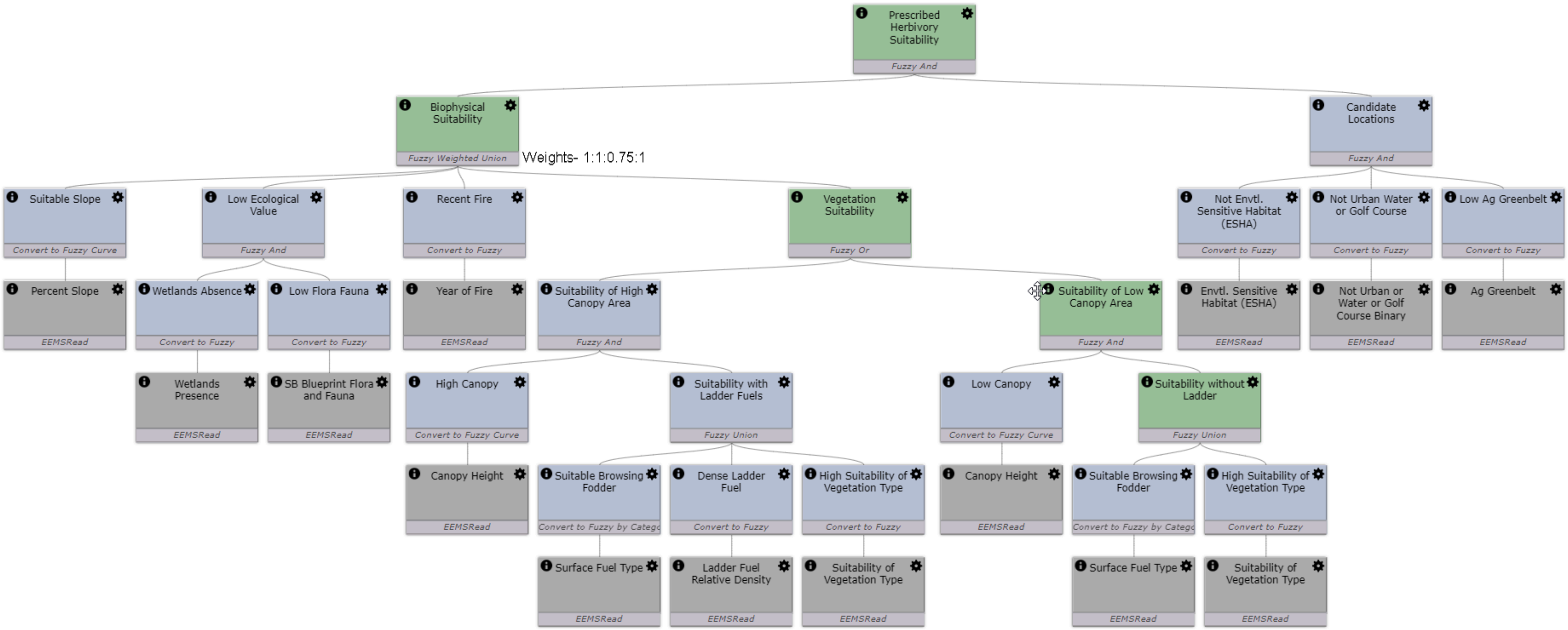


Figure 5: Prescribed Herbivory Suitability Logic Model. The relative weights and values for the criteria are documented in the information details on that criterium's box in the graphical user interface. Some information about each criteria is also provided in the description box, accessed via the "i" button. All recent models for the project are here. The entire model has been fit on a single page to give the reader a complete structural overview. To sharpen text in boxes, zoom to 150 or 200% on your browser window.

        - Locations with high canopy (>4 m) are especially suitable if they have:
            - a high relative density of ladder fuel (<4 m high),
            - high suitability of browsing fodder, based on expert opinion,
            - and high suitability of vegetation type, based on expert opinion.
        - and, locations with low canopy (<4 m) are especially suitable,
            - using the same criteria as above except ignoring the ladder fuel data.

A description of each input data layer and how it is normalized is detailed in Appendix 1. The top-down details of the logic models (i.e. how these input criteria become results) are provided in Appendix 2, and summary of how to use the online user interface is provided in this brief tutorial video and Appendix 3.

Avocado Orchards

When a wildfire is moving towards important assets, such as a city, it has been known to be dampened or even halted when it encounters an orchard. This is because orchards are well watered, and often have very little ground cover or ladder fuels. Here we focus on avocado orchards.

This EEMS model helps with the question, **what areas are especially suitable for putting new avocado trees, stands, or orchards?** The EEMS model answers the question about where to plant without considering where the vulnerable assets are, nor where fire is most likely to be moving, as these are considered later in the RWMP modeling process. So this analysis is not a complete prioritization of where to plant avocado to become a fuel breaks. Instead, we focus here on where avocado planting is most suitable based on a variety of criteria defined from geospatial data inputs.

We interviewed local experts and observed existing avocado orchard attributes in developing the logic model of the Avocado Suitability EEMS model.

The modeled results for all six models are mapped and provided in a user interface for exploring the data (See Appendix 3 for a user guide), here: **EEMS Interface for the Whole Project** and scroll down to the latest version of this model in “Select a Model”.

The logic model is diagrammed in the following page (Figure 6), and is summarized after that in narrative bullets. See also the “i” information icon in each box of the user interface. There are two primary branches to the model that both need to be met for a place to be considered suitable:

- Candidate Locations:
  This is essentially a map of all the areas that are not excluded for other reasons, namely:
    - Available Space, i.e. areas that are not Urban, Water (i.e. lakes), Golf Course, USFS Land, or land zoned as Recreation,
        - (we assume that it is unlikely that the landowners in these places will want avocado orchards)

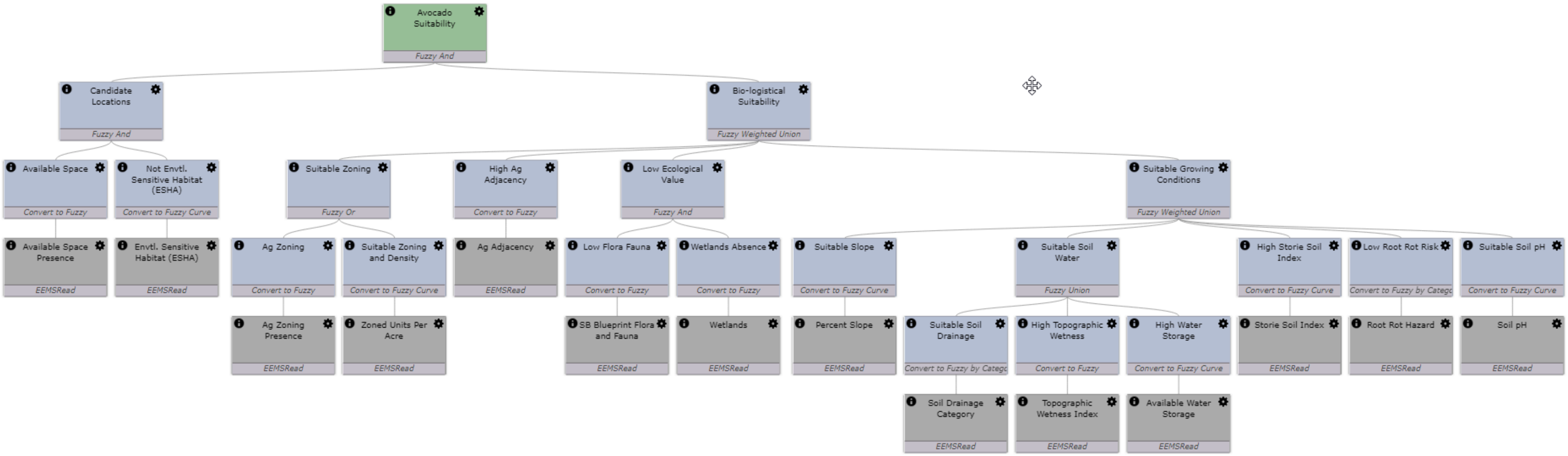


Figure 6: Avocado Orchard Suitability Logic Model. The relative weights and values for the criteria are documented in the "gear-icon" details on that criterium's box in the graphical user interface. Some information about each criteria is also provided in the description box, accessed via the "i" button. All recent models for the project are here. The entire model has been fit on a single page to give the reader a complete structural overview. To sharpen text in boxes, zoom to 150 or 200% on your browser window or document reader. Or click on the icon when viewing the logic model online.

    - and, we also map areas that are not environmentally sensitive habitat (ESHA), since the assumption is that prescribed herbivory cannot be permitted in these areas.
- Bio-logistical Suitability, which is comprised of four major branches:
    - Suitable zoning, which is not only agricultural zoning, but also residential zoning, with a lower density of houses (i.e. estates) being more feasible for avocado grove fire breaks.
    - Being adjacent to current agricultural parcels, as this usually more palatable to neighborhoods and planners, and also links to existing infrastructure;
    - Being in an area of low ecological value, as this is a better place to convert to an avocado orchard compared to an area of high ecological value; and
    - a large branch called suitable growing conditions which considers several criteria:
        - As the slope gets steeper, it gets increasingly difficult and then infeasible to grow avocados. Slope needs to be less than 30% (Bender 2004).
        - and if there is a lot of water in the soil, that makes things more suitable. This is modeled in three ways:
            - having good soil drainage,
            - having a lot of expected, water based on the topography,
            - and having a lot of water stored in the soil, based on soil type.
        - another analysis for estimating soil productivity, known as the Storie Index,
        - suitable soil pH (acidic soils are better, and local farmers often make their soils more acidic).
        - and low root rot hazard

A description of each input data layer and how it is normalized is detailed in Appendix 1. The top-down details of the logic models (i.e. how these input criteria become results) are provided in Appendix 2, and summary of how to use the online user interface is provided in this brief tutorial video and Appendix 3.

Citrus Orchards

For an introduction about how orchards act as a greenbelt, and the objective of this citrus orchards tool, see the avocado section. For citrus orchards, we interviewed local experts and observed existing citrus orchard attributes in developing the logic model of the Citrus Suitability EEMS model.

The modeled results are mapped and provided in a user interface for exploring the data (See Appendix 3 for a user guide), here: **EEMS Models Link** and scroll down to the latest Citrus Orchard Model in “Select a Model”.

The citrus orchards model is the same as avocado except for several key parameters, including the slope criterion. It is not feasible to harvest citrus at commercial production scales on slopes as steep as those cultivated for avocado due to a few factors, including that the citrus trucks get heavier than the avocado trucks and can tip easier. Slope needs to be less than 25% (Orhan 2021). See Appendix 1 for details on the relative values. Secondly, citrus is more hardy than avocado with regards to tolerating sub-optimal soil pH. This is reflected in the Appendix 1 details. Thirdly, citrus is susceptible to avocado root rot but not as much as avocado.

Low-water Plantations

For an initial introduction about how agricultural operations act as a greenbelt, and the objective of this tool, see the avocado section. For low-water plantations specifically (e.g. Agave), we interviewed local experts and observed existing low-water plantations attributes in developing the logic model of the Low-water Plantations Suitability EEMS model.

The modeled results are mapped and provided in a user interface for exploring the data (See Appendix 3 for a user guide), here: **EEMS Models Link** and scroll down to the latest Low Water Plantations Model in "Select a Model".

The low-water plantations model is the same as avocado except for the slope criterion, and residential density, as of now. Low water plantations can be planted on steeper slopes than avocado. Hence, slope is modeled as highly suitable to 25% slope, then decreasing in suitability until being modeled as highly unsuitable atl 40% slope. For residential density, the assumption is that people can have a low water plantation in residential areas easier than avocado and citrus, and that they are effective even in higher densities of housing. A residential zoning housing density of 0 has a suitability of 1, which decreases linearly in suitability until 2 units per acre, when the model gives this a suitability value of 0.5. This then decreases more sharply and ends with being highly unsuitable value at 4 units per acre and denser. See Appendix 1 under "Percent Slope" for a diagram of this suitability curve.

The logic model is diagrammed in the following page (Figure 7), and is summarized after that in narrative bullets. See also the "i" information icon in each box of the user interface.

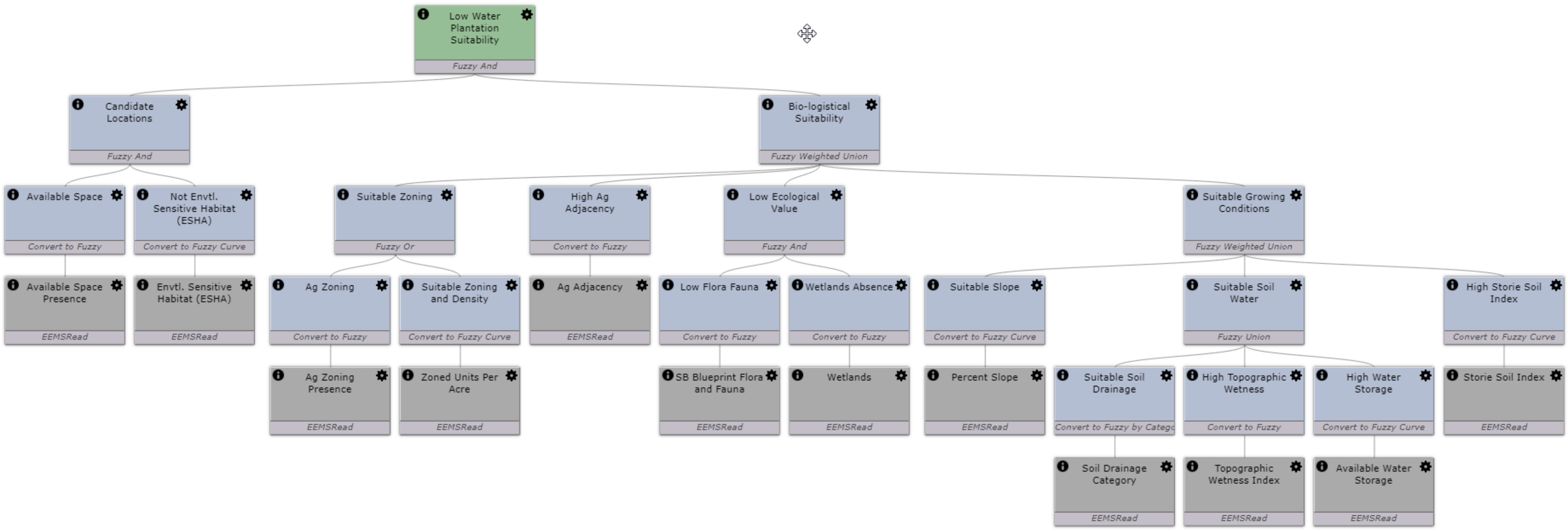


Figure 7: Low-water Plantation Suitability Logic Model. The relative weights and values for the criteria are documented in the "gear-icon" details on that criterium's box in the graphical user interface. Some information about each criteria is also provided in the description box, accessed via the "i" button. All recent models for the project are here. The entire model has been fit on a single page to give the reader a complete structural overview. To sharpen text in boxes, zoom to 150 or 200% on your browser window or document reader. Or click on the  icon when viewing the logic model online.

Advisors and Experts

Thank you to the advisors and experts that took time to advise us in developing the model, review the draft report, view the models, provide comments, and/or show us their on-the-ground operations:

- Frank Davis, Professor, Bren School of Environmental Science and Management, UCSB
- Elihu Gevirtz, Senior Plant Ecologist, BayWa r.e. Wind
- Riley Kriebel, founder/owner, Grounded Land Works
- Jessica Peak, Senior Biologist and Owner, Storrer Environmental
- Jorge Renteria, Applied Ecologist, Santa Barbara Botanic Garden
- Matthew Shapero, Livestock and Range Advisor, UCANR Cooperative Extension and now Conservation Grazing Program Manager, Midpeninsula Regional Open Space District
- Paul Van Leer, President, Santa Barbara Firesafe Council President; Manager, Las Varas Ranch, Santa Barbara County Agricultural Advisory Committee

Photo Credits

Cover Photo: Marc Mayes, A Santa Barbara Mountain Community, 15 April 2022 (part of the "RWMP cycling for ground truthing" photo series).

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Appendices

Hotlink to Appendix 1: Glossary of Input Criteria Details

Hotlink to Appendix 2: Logic Model Technical Detail "Flatfile" for Treatments

Hotlink to Appendix 3: EEMSOnline.org Graphical User Interface Brief Tutorial