



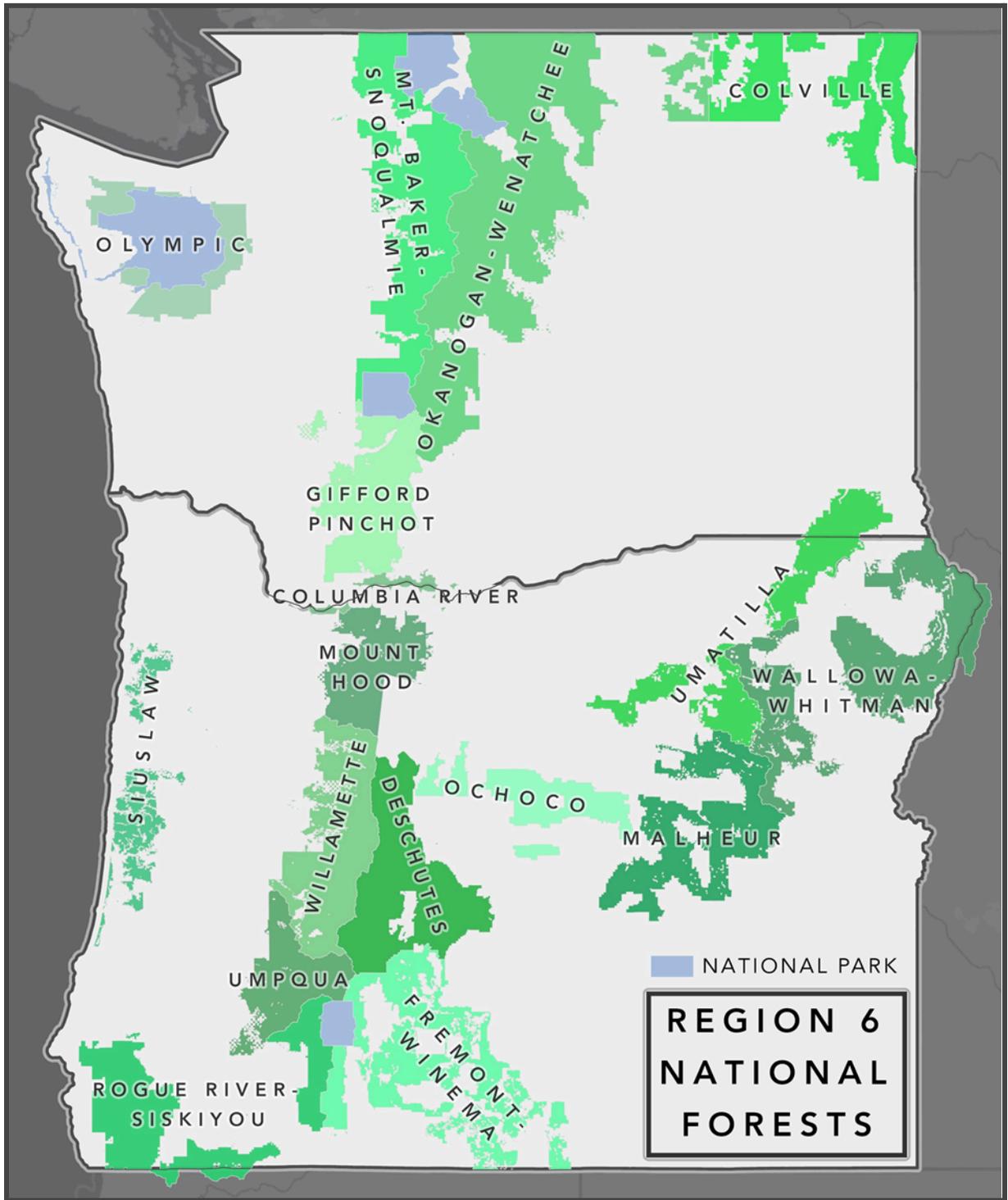
# Data-Driven Decision Support for Sustainable Trail Management Across PNW National Forests

## Introduction

The United States Forest Service (USFS) administers over 24,000 miles of trails in the Pacific Northwest (Region 6), providing expansive access, connectivity, and recreation experiences for the public's benefit (USFS Region 6 2020; Bash et al. 2019). Trails support public health and local rural economies (Ciabotti et al. 2023), and well-constructed trail systems offer widespread benefits such as increases in fire resilience, improvements in stormwater management, and movement corridors for wildlife (Davis et al. 2023). National Forest trail systems also provide critical linkages to Tribes for hunting and collection under treaty rights and to agencies for land management activities such as logging, trail maintenance, and wildfire control and response (Bash et al. 2019).

There is increasing demand for trails to serve agencies, visitors, and local communities in a wide variety of ways, and they must be maintained to meet mixed uses of recreation, transportation, and land management. As the Forest Service shifts to a shared stewardship model of trail maintenance, it is crucial that trails are managed in a transparent, sustainable way that meets these cross-cutting needs and supports a diverse public user base (USFS Region 6 2020). With over 14.7 million visitors to the Pacific Northwest region's federal lands and waterways in 2023, the Forest Service is identifying strategic, data-driven approaches to evaluating and managing their trail network in an effort to increase organizational efficiency, maximize taxpayer return on investment, and provide access to public assets that are ecologically, economically, and socially sustainable (United States Forest Service, 2017).

To meet this need, the Conservation Biology Institute (CBI) is working in partnership with USFS to create a web-based decision support tool to facilitate collaborative management and quantitative assessment of trail sustainability (considering ecological, economic, and social factors) for Region 6 National Forests in Oregon and Washington (Figure 1). This work can readily be leveraged and adapted to cover additional geographies and/or to meet other use case needs for trail planning and management, relevant to various administrative, NGO, industry, and partner needs.

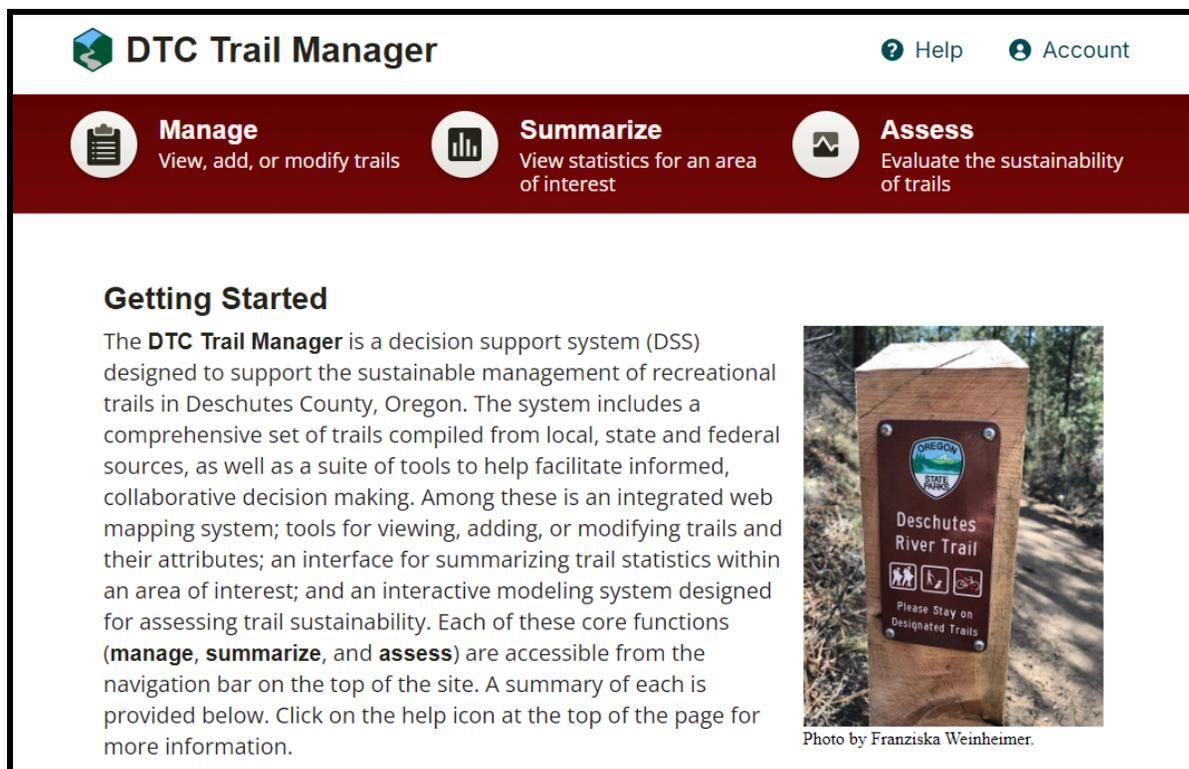


**Figure 1:** United States Forest Service Region 6 National Forests across the Pacific Northwest.

## Project Background

In 2020, the US Forest Service partnered with the Conservation Biology Institute and the Deschutes Trails Coalition (DTC) to develop a web-based decision support system to help foster sustainable management of recreational trails in Deschutes County, Oregon. The result of that effort is the DTC Trail Manager — a powerful application that combines a trail sustainability assessment with a suite of data management, exploration, and visualization tools to help facilitate informed, collaborative decision making. The application’s trail sustainability assessment component is powered by CBI’s Environmental Evaluation and Modeling System (EEMS) (Sheehan and Gough 2016). It uses over one hundred spatial data layers to create a transparent, location-based model incorporating environmental, physical, social and economic sustainability drivers, based on the “four sustainability pillars” laid out in the DTC’s Strategic Plan. CBI worked closely with USFS staff, DTC members, subject matter experts, and other stakeholders to determine how trail sustainability was captured in the model and to define core functionality of the information management system, resulting in an accessible, data-rich, online platform to inform local decision-making.

The DTC Trail Manager provides users with the ability to track and evaluate existing trail characteristics and sustainability scores, as well as access a landscape-level assessment to quantify multi-criteria sustainability of proposed new trails. This web application also allows users to investigate sustainability attributes and explore the outputs through interactive maps, providing an opportunity to understand the drivers of different sustainability factors and augmenting on-the-ground knowledge of field crews, local coalitions, and agency managers (Figure 2).



**DTC Trail Manager** Help Account

**Manage**  
View, add, or modify trails

**Summarize**  
View statistics for an area of interest

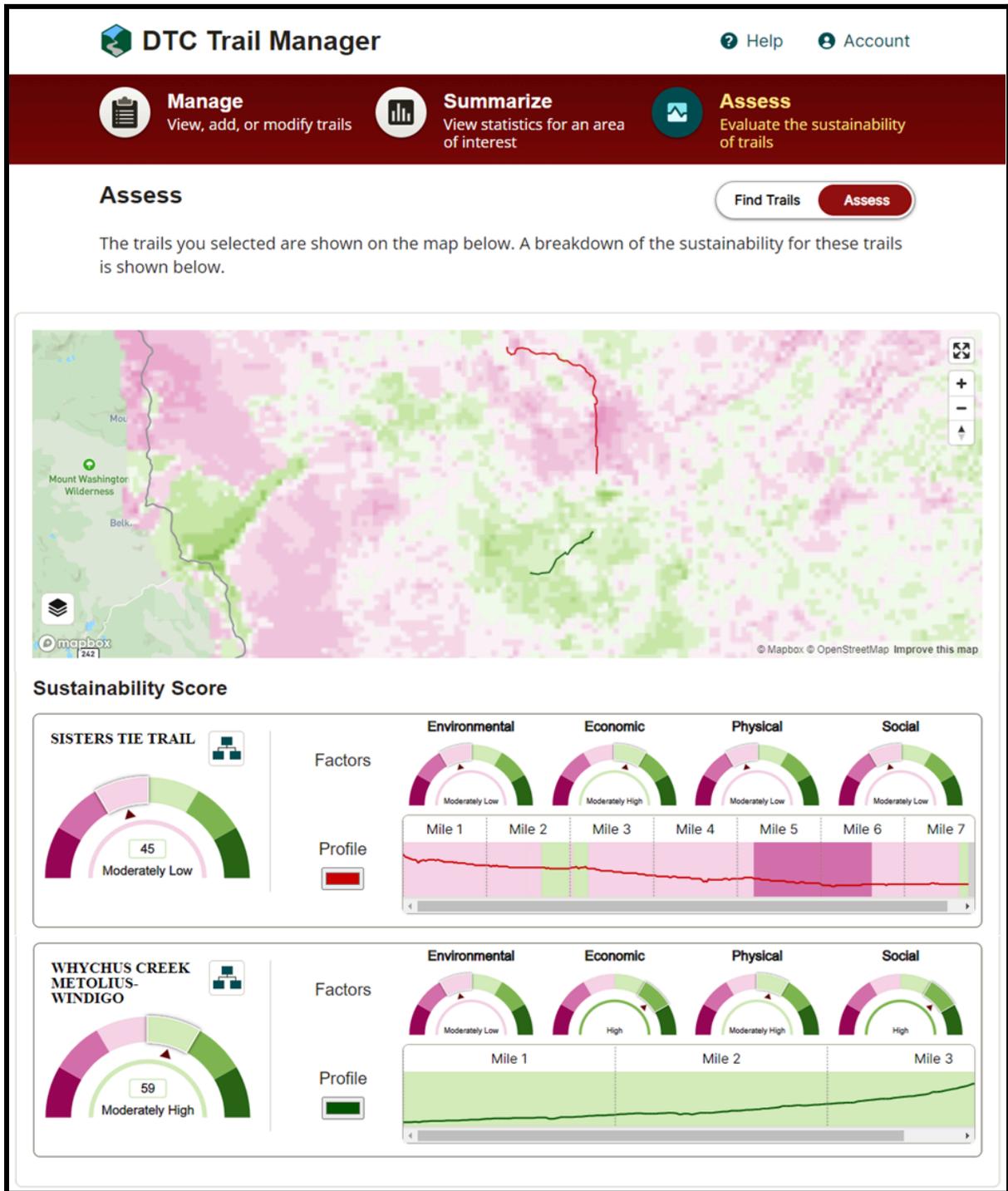
**Assess**  
Evaluate the sustainability of trails

### Getting Started

The **DTC Trail Manager** is a decision support system (DSS) designed to support the sustainable management of recreational trails in Deschutes County, Oregon. The system includes a comprehensive set of trails compiled from local, state and federal sources, as well as a suite of tools to help facilitate informed, collaborative decision making. Among these is an integrated web mapping system; tools for viewing, adding, or modifying trails and their attributes; an interface for summarizing trail statistics within an area of interest; and an interactive modeling system designed for assessing trail sustainability. Each of these core functions (**manage**, **summarize**, and **assess**) are accessible from the navigation bar on the top of the site. A summary of each is provided below. Click on the help icon at the top of the page for more information.



Photo by Franziska Weinheimer.



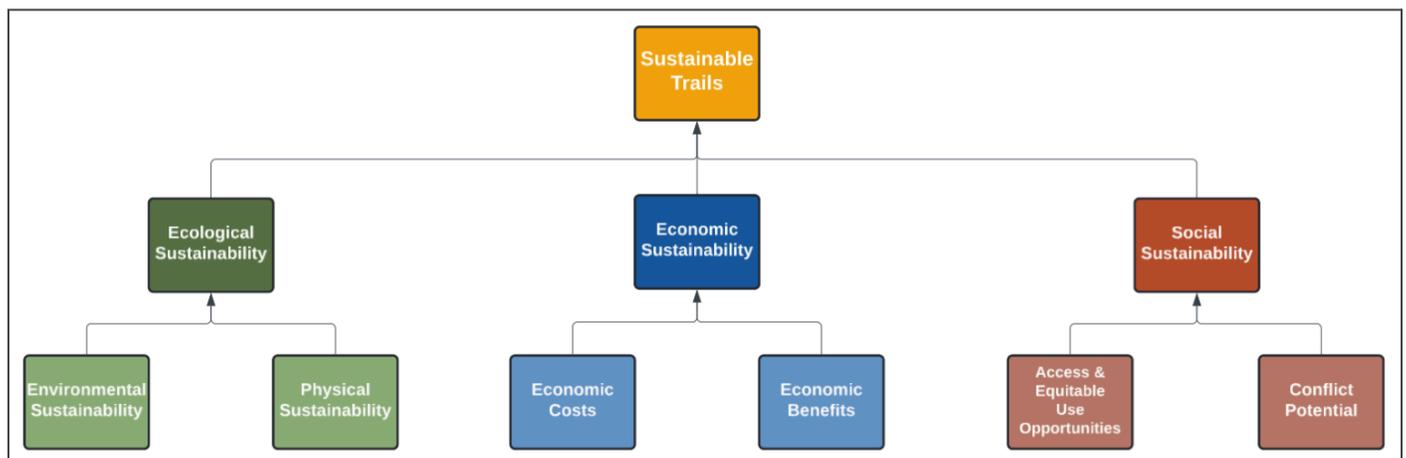
**Figure 2:** The DTC Trail Manager offers a suite of data management, exploration, and visualization tools, allowing users to explore data-driven sustainability scores related to environmental, physical, social and economic sustainability criteria for trails in Deschutes County.

In the future, the Trail Manager will be adapted to meet broader Forest Service agency and partner needs, creating a version for the USFS that covers PNW National Forest land (Region 6). A significant advancement towards creating a USFS Trail Manger system is the creation of a preliminary model to power the landscape-level sustainability assessment in the online decision support application.

## USFS Trail Sustainability Model

In the current phase of this project, CBI is working with the US Forest Service to adapt and expand the Trail Sustainability Model to the USFS Pacific Northwest region covering over one million acres of National Forest land in Oregon and Washington. Landscape-level sustainability metrics have been updated and customized to represent the agency’s three spheres of trail sustainability: ecological, economic, and social sustainability, as laid out in the USFS National Strategy for a Sustainable Trail System (United States Forest Service, 2017).

The preliminary USFS Trail Sustainability Model’s ecological component addresses environmental and physical trail sustainability, incorporating data on potential impacts to species and their habitat, and the physical stability of terrain surfaces, among other inputs. The economic element factors in both the potential costs of maintaining trails and access, as well as the economic benefits of trail systems to nearby communities through recreation-based tourism, desirable user experiences, and synergy with surrounding recreation opportunities. The social sustainability side focuses on trail access and support of multi-use recreation experiences geared towards a diverse user base, in addition to the potential for conflict across different types of user groups and between recreationists and vehicles. The draft USFS Trail Sustainability Model’s analytical structure and factors driving preliminary trail sustainability metrics are shown in Figure 3.



**Figure 3:** The draft model framework developed to assess ecological, economic, and social dimensions of trail sustainability across Oregon and Washington National Forest lands, in alignment with USFS and agency partner needs.

## USFS Trail Sustainability Modeling Methodology

The USFS Trail Sustainability Model metrics were generated using a hierarchical fuzzy logic modeling approach, executed with CBI's Environmental Evaluation Modeling System (EEMS). EEMS is particularly well suited to enable data-driven decision making to answer complex questions. This modeling approach can integrate key themes and numerous types of input data, as well as represent relationships across model components, synthesizing complex information into more easily digestible formats. Figure 4 provides an overview of major workflow steps in the modeling process.

Model performance and optimization were achieved in several ways. The values of every dataset used in the model are scaled from -1 (lowest trail sustainability score) to +1 (highest trail sustainability score) using thresholds, which determine how input data are normalized along this continuum. Thresholds can be set in multiple ways, including: 1. Using the full range of input data values; 2. Based on expert opinion/heuristics; 3. Guided by the statistical distribution of the input data; 4. Taken from previously published studies and literature. Relationships among the sustainability drivers are defined using various model operators. During the draft USFS Trail Sustainability Model development process, CBI relied on expert input provided during DTC model development, literature, and statistically driven approaches, to set thresholds and select model operators, thus ensuring display of informative gradients across the study area with nuanced representation of each model component. Execution of the USFS Trail Sustainability Model extensively leveraged previous work undertaken in collaboration with partners at USFS and key stakeholders. However, this draft model is expected to be substantially refined with additional agency input prior to integration into the Trail Manager application.

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<b>1. Acquire Data</b>	Acquire and preprocess all data for the analysis and study area.
<b>2. Prepare Inputs</b>	Prepare input data for integration into the model.
<b>3. Summarize Metrics</b>	Summarize metrics to 270 meter reporting units and integrate into the model.
<b>4. Model Execution</b>	Execute model within the Environmental Evaluation Modeling System platform. Calculate trail sustainability scores for each 270m x 270m reporting unit in the study area, based on input data, selected operators, thresholds, and weights.
<b>5. Model Review</b>	Review model outputs and architecture. Update input data and adjust model parameters to maximize performance.
<b>6. Model Reruns</b>	Additional model tuning, runs, and examination of results. Iterate steps 4-6 to achieve desired outcomes.

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**Figure 4:** *Workflow steps used in the USFS trail sustainability modeling process.*

## USFS Trail Sustainability Model Outputs

The Conservation Biology Institute's draft USFS Trail Sustainability Model synthesizes over 100 spatial data layers to act as a foundation for evaluation of the ecological, economic, and social dimensions of trail sustainability across National Forest Lands in Oregon and Washington. Input data was selected based on quality, access, and coverage of the study area. Model data sources include products from USGS, USFWS, WGA, USFS, NRCS, NPS, FCC, US Census Bureau, EOG, PRISM, and Strava Metro, with extents covering Oregon, Washington, the Pacific Northwest, Western US, and the contiguous United States.

The draft USFS Trail Sustainability Model outputs, created for eventual use in the Trail Manager application, can be accessed [via an online interface](#) that facilitates exploration of the analytical structure, components, and preliminary sustainability metrics via interactive maps. A user can select any element in the interface's model diagram to display the corresponding sustainability metric on the map and examine drivers contributing to a sustainability score for any given 270 meter reporting unit.

Map values show landscape-level sustainability scores across National Forest land in Oregon and Washington. Key model outputs for ecological, economic, and social trail sustainability metrics are shown in screen captures below (Figures 5 - 8) and described as follows:

Overall Trail Sustainability (shown in Figure 5) is an average of ecological, economic, and social sustainability metrics. Ecological Sustainability (shown in Figure 6) comprises: 1. Environmental Sustainability metrics (focal species impacts, habitat impacts, human modifications, wildfire hazard potential); 2. Physical Sustainability metrics (surface stability, landslide susceptibility, avoidance of flat terrain, fire and water impacts); and 3. Cultural/Historic Value metrics. Economic Sustainability (shown in Figure 7) comprises: 1. Economic cost metrics (access and maintenance costs, proximity of existing trail amenities) and 2. Economic benefits metrics (direct benefits to the local economy, synergistic effects, user experience benefits). Social Sustainability (shown in Figure 8) comprises: 1. User access metrics (proximity of existing access points), 2. Diverse use opportunities metrics (promotion of diverse user types), and 3. User conflict potential metrics.

Sustainability metrics range in value along a continuum from very low (-1), to moderate (0), to very high (+1). These can essentially be interpreted as composite sustainability scores for a given location, based on the select model component and its drivers. Green areas on the map have higher trail sustainability scores, red areas have lower sustainability scores, and yellow areas have intermediate trail sustainability scores. This information can inform the evaluation of both proposed and existing trail sustainability at any given location across USFS Region 6 Forests.

# Overall Trail Sustainability

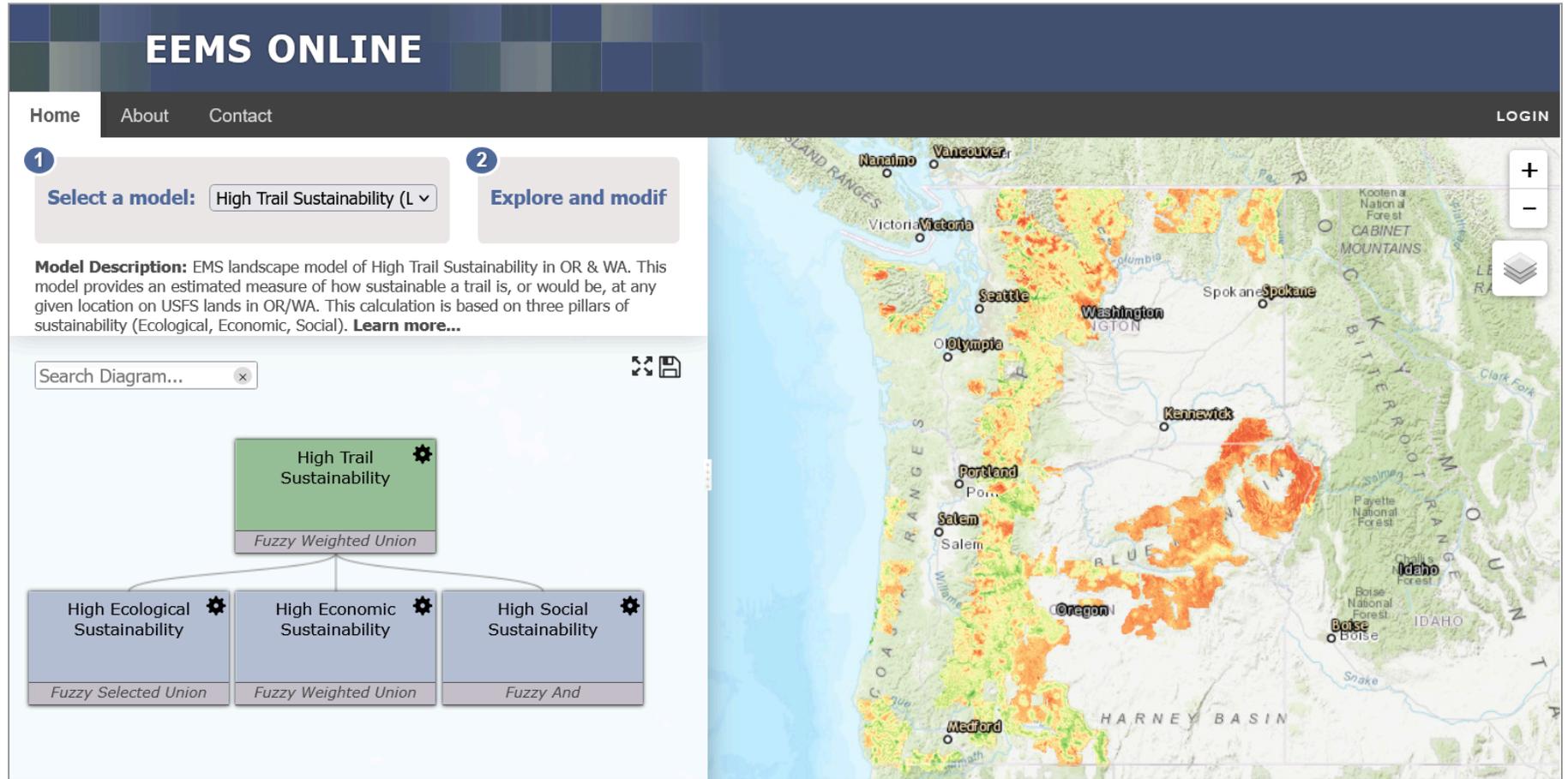
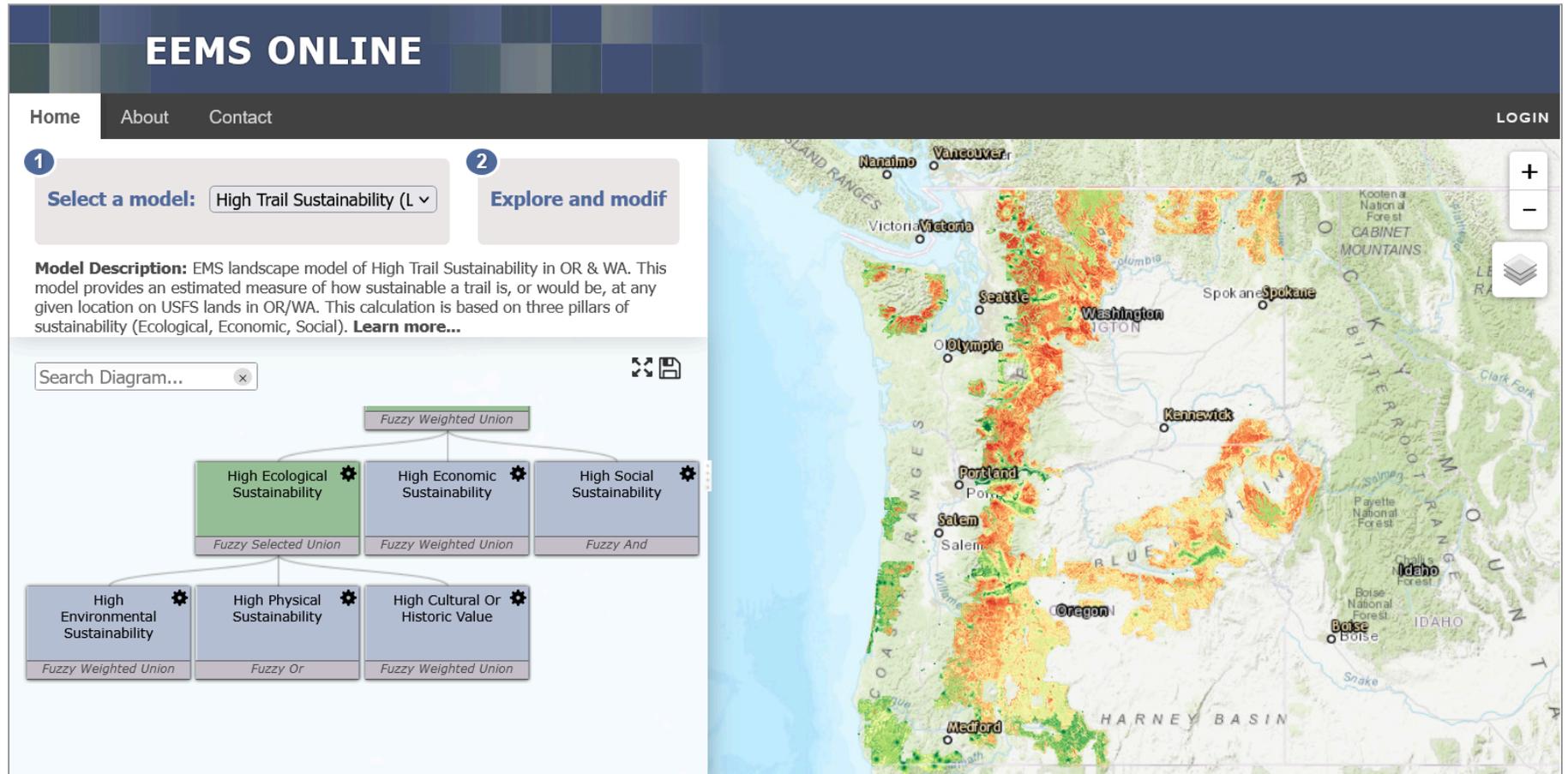


Figure 5: Overall Trail Sustainability is an average of ecological, economic, and social sustainability metrics. Green areas on the map have higher trail sustainability scores, red areas have lower sustainability scores, and yellow areas have intermediate trail sustainability scores.

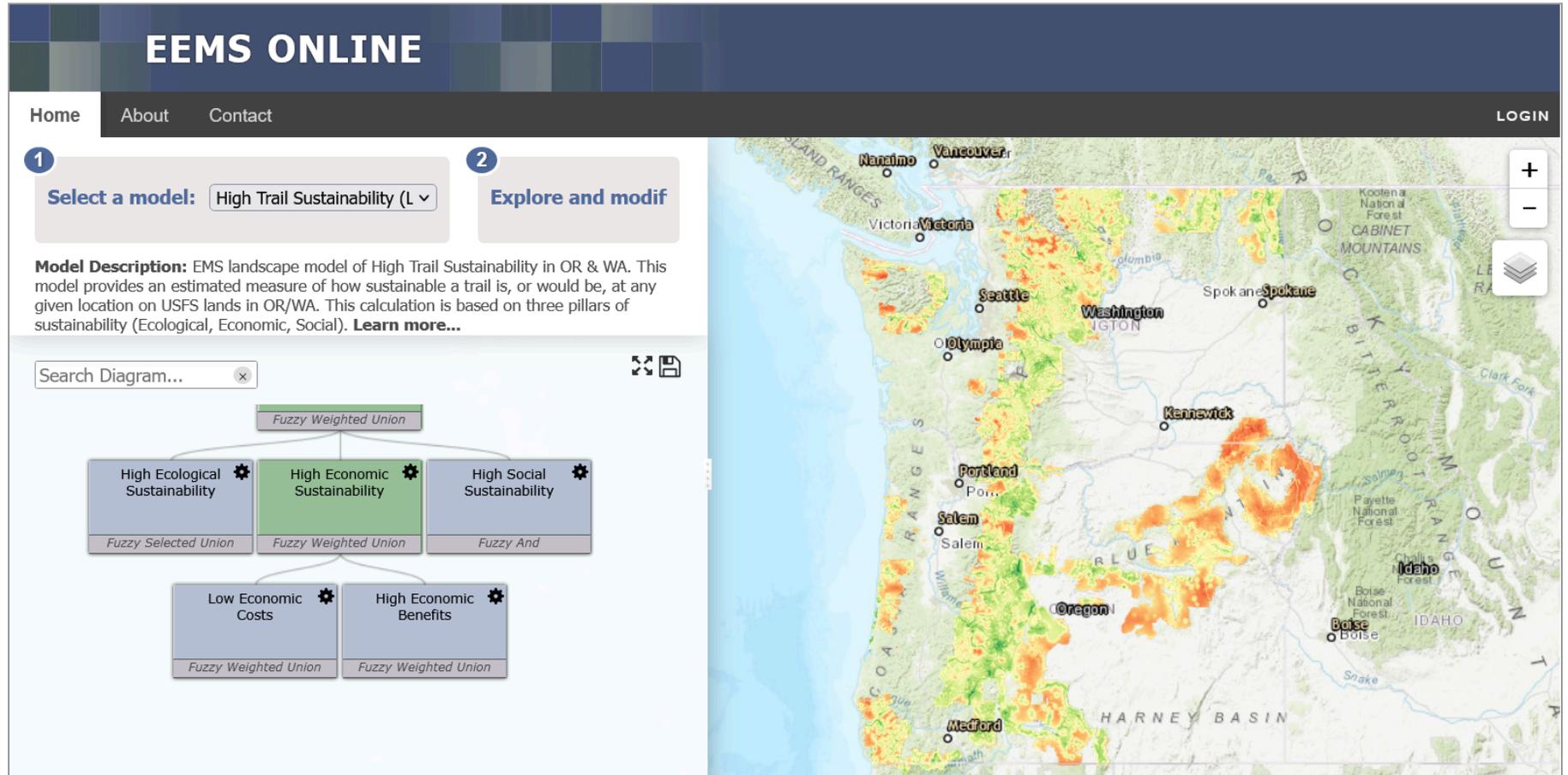
# Ecological Sustainability



**Figure 6:** Ecological Sustainability comprises: 1. Environmental Sustainability metrics (focal species impacts, habitat impacts, human modifications, wildfire hazard potential); 2. Physical Sustainability metrics (surface stability, landslide susceptibility, avoidance of flat terrain, fire and water impacts); and 3. Cultural/Historic Value metrics. Green areas on the map have higher trail sustainability scores, red areas have lower sustainability scores, and yellow areas have intermediate trail sustainability scores.



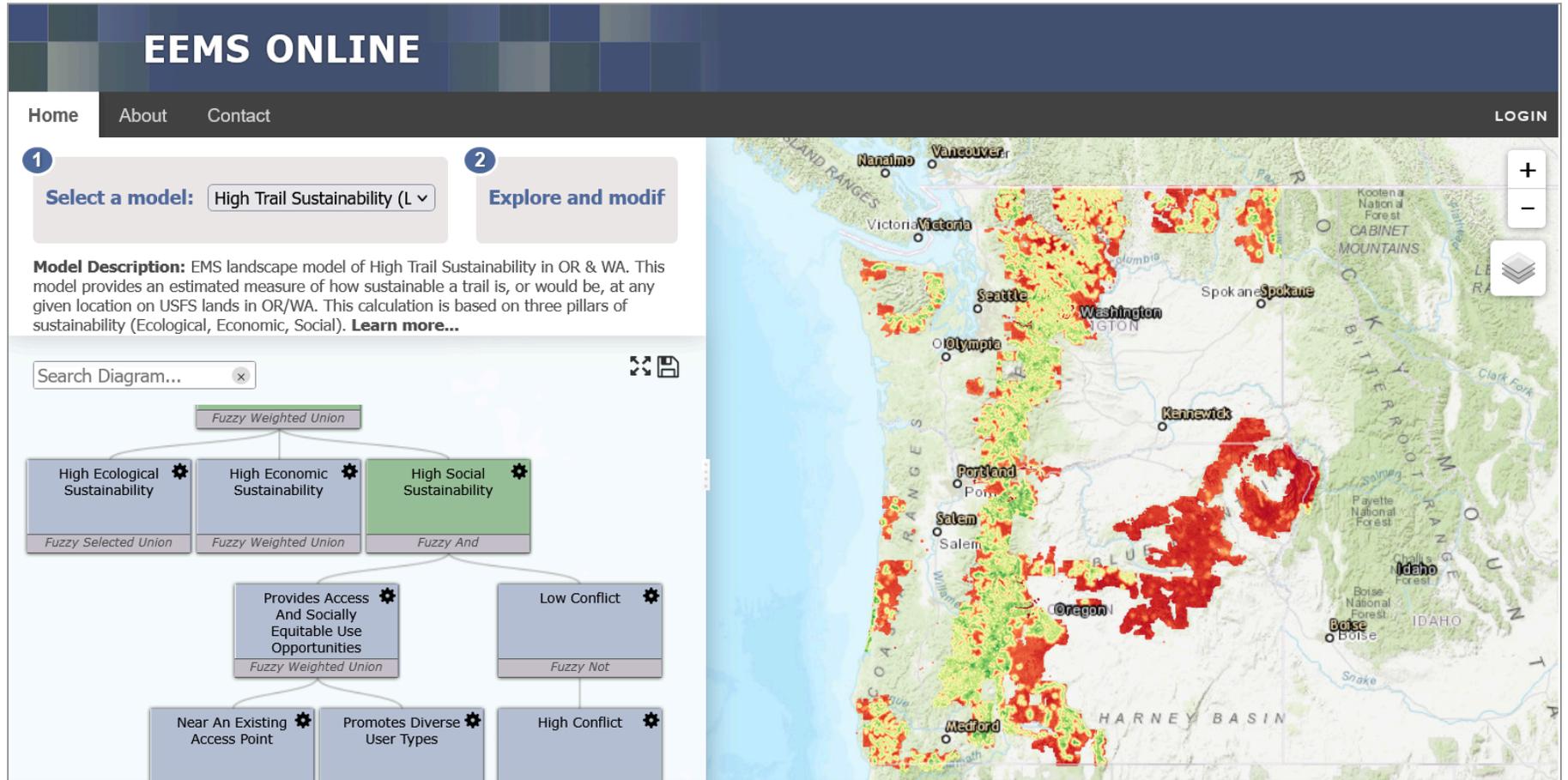
# Economic Sustainability



**Figure 7:** Economic Sustainability comprises: 1. Economic cost metrics (access and maintenance costs, proximity of existing trail amenities) and 2. Economic benefit metrics (direct benefits to the local economy, synergistic effects, user experience benefits). Green areas on the map have higher trail sustainability scores, red areas have lower sustainability scores, and yellow areas have intermediate trail sustainability scores.



# Social Sustainability



**Figure 8:** Social Sustainability comprises: 1. User access metrics (proximity of existing access points), 2. Diverse use opportunities metrics (promotion of diverse user types), and 3. User conflict potential metrics. Green areas on the map have higher trail sustainability scores, red areas have lower sustainability scores, and yellow areas have intermediate trail sustainability scores.

## USFS Trail Sustainability Model Applications

The USFS Trail Sustainability Model developed by CBI offers several advantages for region-wide assessment and planning support. The draft analysis framework integrates numerous and diverse data into a transparent system that provides a foundation to execute an in-depth, multifactorial sustainability assessment for proposed or existing trails across National Forests in Oregon and Washington. It utilizes an extensive suite of complex spatial data, alongside more general information provided by experts and managers, and summarizes information to quantify ecological, economic, and social dimensions of trail sustainability and their drivers. It has utility as a standalone product and is also a significant step towards deployment of a USFS Trail Manager application, to offer an in-depth information management system and additional functionality.

### Next Steps

In the future, the USFS Trail Sustainability Model and its comprehensive suite of thematic metrics can be refined with further stakeholder and agency involvement and resulting products incorporated into the accessible, multi-use online application, the Trail Manager. This advanced application will more readily allow forest managers, agency partners, and other stakeholders in USFS Region 6 to explore and visualize metrics via interactive maps offering transparency into sustainability drivers, alongside an additional suite of functionality to support trail information management.

The logistical next steps towards execution of the Trail Manager application for USFS include: 1. Refine the preliminary landscape-level sustainability model with further agency and partner involvement; 2. Create a sustainability model for existing trails based on attributes in the USFS database to complement the landscape-level assessment; 3. Incorporate the sustainability model outputs and key contextual data into the custom web application; 4. Customize functionality of the Trail Manager for USFS agency and partner needs, relating to the user account system, information management tools, query/summary functionality, and sustainability assessment display; 5. Deploy the final version of the Trail Manager web application and provide training, documentation, and a user guide to USFS agency staff and partners.

In practice, the USFS Trail Manager will fill critical agency and partner needs for a data-driven tool to support collaborative and objective decision making around trail system planning, management, and resource prioritization.



## Basis for Additional Applications

Much investment in the sustainability modeling and Trail Manager can be leveraged towards building similar web-based applications, tailored to other use cases dictated by various agency, administrative, NGO, industry, and/or partner client needs. The Trail Manager was showcased at the 2024 Washington State Trails Conference and in the 2025 American Trails Advancing Trails Webinar Series, generating much audience interest as to its current and future potential to support different aspects of data-driven planning and management of trail systems. Some future directions for use cases include customization of the sustainability models to incorporate different drivers and/or expansion of the application's information management system to track additional information, relating to trail maintenance activities, recreation/visitor use and activities, trail funding and fees structures, alignment with target community needs, etc.

## Credits

Degagne, R., Gough, M., Joseph, G., Pizzino, D., Smith, C., Stevenson-Molnar, N. 2025. Data-Driven Decision Support for Sustainable Trail Management across PNW National Forests.

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