Targeted Tree Species Study

FINAL REPORT

March 31, 2022

Prepared for:

PG&E EVM Program

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Targeted Tree Species Study

REPORT CONTENTS

1. Introduction

2. Existing EVM Tree Assessment Tool (TAT) Overview

3. Additional Considerations for Improving Tree Assessment Tool (TAT)

Appendices

1. INTRODUCTION: PROJECT OVERVIEW & PHASES

1.1 PROJECT OVERVIEW

The Pacific Gas & Electric distribution vegetation management team "inspects and identifies maintenance on all distribution circuit miles in PG&E's service territory on a recurring cycle using a combination of different patrol types including Enhanced Vegetation Management (EVM). The EVM program is designed to go above and beyond compliance requirements and includes three main components: (1) expanded radial clearance beyond minimum requirements; (2) overhang clearance; and (3) evaluation of the condition of any tree tall enough to strike electrical lines or equipment (referred to as trees with "strike potential"), documentation of this inventory of trees, and removal of trees that did not pass assessment using the Tree Assessment Tool (TAT). The TAT is a tool that evaluates an individual tree's likelihood of failing and indicates whether to abate the tree. TAT incorporates historical data on tree failures, regional species risk, and local wind gust data and assesses different components of an individual tree's health to determine the risk of falling into PG&E lines or equipment". (*Reference: Appendix J: PG&E WMP 2022*). The Tree Assessment Tool (TAT) was developed to assist vegetation inspectors with standardizing in-field tree abatement decisions. Specifically, TAT employs Boolean parameters (automatic abatement) and scored parameters based on tree health, its surrounding environment and whether a tree has the potential to strike the distribution asset if it were to fail. Formation conducted the Targeted Tree Species Study to analyze TAT records and individual input parameters to determine if there are correlations with TAT tree abatement decisions and trees (species and other conditions) that failed, causing an outage and/or ignition.

Targeted Tree Species Study Purpose:

Formation Environmental was engaged to conduct analysis on the Tree Assessment Tool and identify trends with species, tree health, and tree environment. Specifically, PG&E's stated purpose (per the RFP provided by Mason, Bruce & Girard) is as follows: *"PG&E's Targeted Tree Species Study (TTSS) is intended to identify species that are more likely to fail near PG&E facilities, thereby creating potential wildfire ignitions. PG&E will use the information obtained through the study to evaluate performance of the species risk rating component of their TAT. The study will include an analysis of tree mortality rates related to precipitation as well as impacts of seasonal precipitation on growth. PG&E will also use the precipitation information to evaluate scheduling for patrol cycles as part of their vegetation management responsibilities."*

Formation evaluated six PG&E datasets, including the 17 TAT parameters, to determine (1) the effect each parameter has in the current TAT model with regard to final abatement decisions, (2) the accuracy and consistency of parameter values as compared to external datasets (where quantitative datasets were available), (3) species-specific correlations and trends related to abatements and compared to outages and ignitions, (4) species trends associated with regional fire risk, and (5) tree mortality trends associated with TAT tree health parameters and species. The analysis also included evaluation of new parameters for correlation to outages and ignitions, with the purpose of identifying species-specific parameters and regional prioritizations as a potential input to the TAT model and to assist with subsequent abatement decisions. The new parameters evaluated include the following:

- Ecoregions for Regional Species Fire Risk Rating
- Event-Driven Normalized Wind Risk Model
- Tree Height to Diameter Ratio for Selected Species
- Precipitation, Actual Evapotranspiration (ETa), and Standard Precipitation Index (SPI)

Additional quantitative parameters such as overstrike distance, fall paths to asset(s), and topographic and tree canopy exposure were considered but not evaluated at this time due to LiDAR (Light Ranging and Detection) remote sensing data availability limitations. Recommendations for future analysis on these parameters are provided later in this report.

1.2 OBJECTIVES & RESEARCH QUESTIONS

Targeted Tree Species Study Primary Research Questions:

Is the EVM TAT effective at mitigating outages and ignitions caused by tree failures?

It was determined that this original research question cannot be answered directly (at this time) due to temporal constraints of the EVM TAT data and attribute limitations with the outage and ignition (O&I) and database. However, the research question was partially addressed in this analysis by asking and answering the following questions:

- Are tree species distributions for TAT abatements and O&I similar? Ideally, TAT would create abatement species compositions that align with legacy O&I events. The results are mixed and can be found in **Section 2.5 TAT Records Compared to O&I Distributions.**
- What decision would the EVM TAT model have produced for previous failure trees that caused outages or ignitions if the EVM TAT were in use at that time? After retrospectively employing the Boolean TAT decision tree against the O&I database, it was determined that the median amelioration/prevention of ignitions would have been 31.6% and outages at 20.4%. See **Section 2.7 Retrospective TAT Parameter Crosswalk to O&I Database.**
- To date, what is the effectiveness of the EVM Clear Verification program? While the EVM program has been in practice for a relatively short time, some work has been completed and cleared through the EVM Clear Verification process. Investigating 248 ignition occurrences, only 4.2% of these occurred on EVM clear circuit segments. The remainder ignited non-EVM clear circuit segments. **See Section 2.8 EVM “Clear” Effectiveness Evaluation.**

Do EVM TAT records have relationships with zones of high outage or ignition history?

Formation compared TAT record locations with historical outages and ignitions to determine if work performed is conducted in areas of historical hot spots. Expanded analysis included fall-in species (stem and root failures), and TAT abated species comparisons did not find a consistent correlation to field inspections and legacy outage and ignition rates. **See Section 2.4 Spatial and Temporal Harmonization of TAT and O&I Records.**

Which species have historical correlation with outages and ignitions?

O&I distributions for fall-ins were completed to evaluate legacy failure rates by tree species. Furthermore, the species fire risk rating was aggregated by EPA Level III Ecoregions. Tree health and defects by species were evaluated in these new regions. **See Section 2.5 TAT Records Compared to O&I Distributions and Section 3.1 EcoRegion Delineated Regional Species Fire Risk Rating.**

Do the recorded TAT parameters correlate with quantifiable precipitation and actual evapotranspiration (ETa) trends?

Formation evaluated time series of ETa (which has daily inputs) and aggregated to a seasonal/annual unit to identify trends that may inform targeted areas of interest affecting tree mortality. A weak correlation to ETa was found and there was no correlation(s) to precipitation trends. To refine future analysis, it is recommended to supplement the proposed analytical framework and ETa dataset with PG&E meteorology data, which offer better resolution and time series duration as compared to the publicly available data used in this study. **See Section 3.4 Climate Database to Evaluate Trends in TAT Recorded Dead Trees.**

Based on PG&E data, how well do TAT parameters provide correlation to inform tree abatement decision-making?

This study evaluates the effect of each TAT parameter on abatement outcomes and compared TAT abatements to O&I trees. Looking back at O&I data, TAT Boolean abatement decisions would have a median ameliorated/prevented 31.6% of ignitions and 20.4% of outages. **See Section 2.7 Retrospective TAT Parameter Crosswalk To O&I Database.**

These primary research questions were adopted early in the TTSS project prior to completion of Data Intake, QA/QC and Review. As the data review process was completed, it was necessary to modify the questions in some instances to correspond with the strengths and limitations of the data. Overall, the report provides a comprehensive account of all analysis that was performed, which extends somewhat beyond these initial research questions.

1.3 DATA EMPLOYED

See Appendix A: Data Descriptions for an exhaustive data review.

Tree Assessment Tool (TAT) Data

- 640,501 TAT records collected between March 2020 and June 2021 cover 187 circuits; however, some of these are not completed circuits
- Well documented and comprehensive data attributes for all tree records, with a data dictionary to cross-reference all parameter descriptions
- Relatively accurate spatial accuracy for each tree record
- Uses Boolean (“Yes/No”) Criteria and, in some cases, scored abatement outcomes based on tree health and environmental parameters

Distribution Routine Tree Work History Database

- ~38 million records, dating back to January 2012
- Relatively inaccurate spatial accuracy for each tree record
- TAT uses these data to calculate tree species compositions used in the regional species fire risk rating scores

EVM Clear Circuit GIS Layer

- 853 total circuits, comprising 28,060 circuit miles, of which 4,973 circuit miles are EVM clear circuit segments
- EVM Clear Circuit GIS layer has poor spatial accuracy relative to actual circuit locations

PG&E Distribution Outage & Ignition Records

- Vegetation-caused Outages: 84,794 records dating back to 2003
- Vegetation-caused Ignitions: 1,435 records dating back to 2007
- Not all records have location data
- Errors and inconsistencies in report ID numbers complicate joins between these databases

Distribution LiDAR Data

- Location: Tier 2 & Tier 3 High Fire-Threat Districts (HFTD)
- ~7.5 million delineated trees, collected October 2019 through March 2020
- Used by PG&E asset team to create spatially accurate digital twins of electrical assets (conductors, poles, etc.)
- Fall-In distances and encroachments were calculated by PG&E for delineation of trees
- Species are reported, but not verified/validated

North American Land Data Assimilation System (External to PG&E)

- Used for wind estimation, extending back to January 1979

1.4 PROJECT SCHEDULE & DELIVERABLES

The TTSS consisted of three primary Phases: (1) Data Intake & QA/QC, (2) Tree Assessment Tool (TAT) Analysis (including Environmental and EcoRegion Analysis), and (3) Peer Review Engagement (Figure 1.1). Throughout the duration of the project, bimonthly meetings were conducted with PG&E to communicate progress, to discuss preliminary findings, and to provide interim deliverables that facilitated continuous TAT improvements, which were being conducted concurrently with this project. These meetings also included dialogue with PG&E subject matter experts to provide feedback on preliminary findings, which periodically resulted in requests for additional analysis on a particular finding. A DRAFT report detailing data, methods, findings and recommendations was submitted to PG&E on January 31st, 2022. Peer review feedback on the DRAFT report was incorporated into this FINAL report.

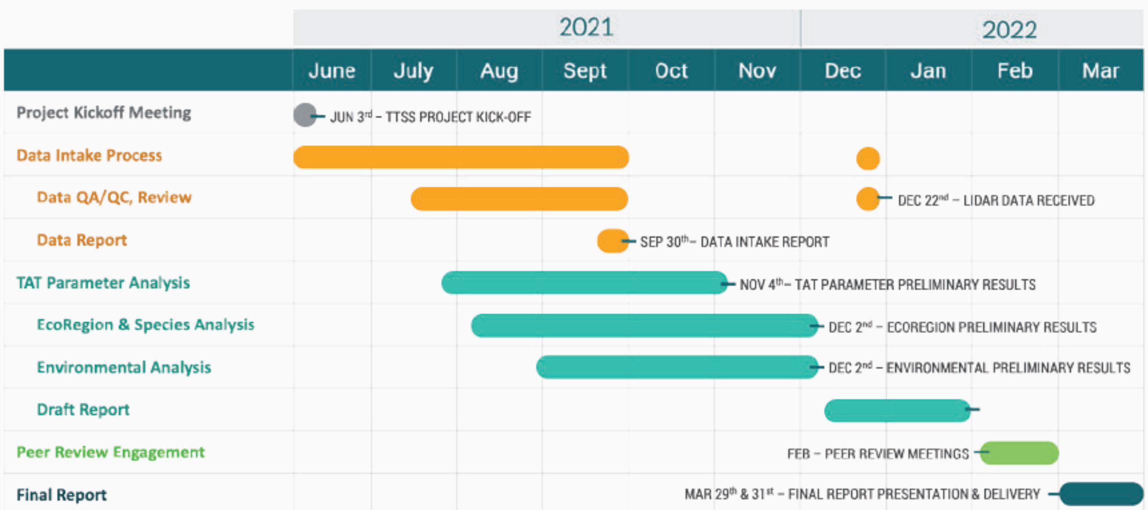


FIGURE 1.1: Targeted Tree Species Study Project Schedule

In addition to the data intake and final reports delivered to PG&E, Formation developed the following data deliverables:

- **EPA Level III Ecoregions** – containing all 13 ecoregions for the state of California and delivered in a GIS feature class format.
- **Historical Outages and Ignitions Appended with Level III Ecoregions** – all outages and ignitions with location information were appended with ecoregion information and delivered in a GIS feature class format.
- **Revised TAT Wind Scoring Models** – two datasets consisting of the two proposed wind model results and delivered in a GIS feature class format.
- **H:DBH Ratio Thresholds** – species-specific height to DBH ratios (statistically significant) corresponding to proposed H:DBH parameter implementation and delivered in tabular (CSV/spreadsheet) format.
- **Revised Ecoregion-based Regional Species Fire Risk Rating Scores** – consists of proposed Regional Species Fire Risk Rating scores utilizing ecoregion delineations and multiple years of routine work history data and delivered in tabular (CSV/spreadsheet) format.

1.5 PEER REVIEW PROCESS

An open and transparent peer review process is an important element to ensure that methods and data used for the evaluation of the Tree Assessment Tool (TAT) are based on sound and defensible science. Following the completion of Formation's draft TTSS report, an independent peer review was conducted in February 2022. Reviewers were charged with providing feedback on each component of Formation's analysis, including an overall assessment and scientific appropriateness of the current methods used to evaluate the TAT records, as well as any important recommendations for improvement of the analysis, with the goal of identifying opportunities for improvement to the TAT. As demonstrated by the summary statements from the peer review team, the TTSS is scientifically rigorous and achieves the objectives of the study, with the caveat that input data limited the ability to fully test TAT for EVM effectiveness at this time. In addition to comments specific to Formation's current analysis of TAT, peer reviewers provided recommendations for additional analysis that may provide PG&E with additional insight regarding vegetation risk throughout its electric distribution system.

Peer Review Experts were selected through the combined effort of Mason, Bruce & Girard and Formation Environmental team members, with the goal of selecting a panel of reviewers with expertise spanning data science, remote sensing, arboriculture, and utility vegetation management. The peer reviewers were divided into two teams; Internal (employed by PG&E) and External (not employed by PG&E). To avoid conflict of interest, internal PG&E reviewers were selected from business units not involved in the design and implementation of TAT, but do have considerable experience with data science, meteorology, and remote sensing applied to assessment of vegetation risk along utility corridors. Only one internal PG&E reviewer submitted a recommendations report while three others attended meetings and/or provided verbal feedback to the Formation team. The external review team consisted of academic and private consulting experts with arboriculture, data analytics and utility vegetation management backgrounds.

Peer review engagement took place throughout the month of February and consisted of an initial meeting to introduce the panel to the TTSS DRAFT REPORT as well as review study objectives, analytics performed, results and Formation's initial recommendations. Subsequent meetings were held to clarify questions posed by the peer reviewers. A total of five peer reviewers (4 external, 1 internal) submitted written final comments and recommendations to Formation. The Formation team organized recommendations into related topics, then provided responses and references to the final report, when applicable. In some cases, the recommendations were outside the scope of the TTSS but were provided in this report to convey the information to PG&E. Peer review recommendations and Formation responses can be viewed in **Appendix H**.

2. EXISTING EVM TREE ASSESSMENT TOOL (TAT) OVERVIEW

2.1 TAT Abatement Decision Tree

This section details the TAT decision tree process, quantifies components of TAT that lead to abatement outcomes, and describes how users should interpret the resulting TAT data.

The EVM TAT database has 640,501 records (collected March 2020 through June 2021), each representing an individual tree. Figure 2.1 depicts the cascading decision tree that the TAT assessment follows, leading to "abate" or "do not abate" outcomes.

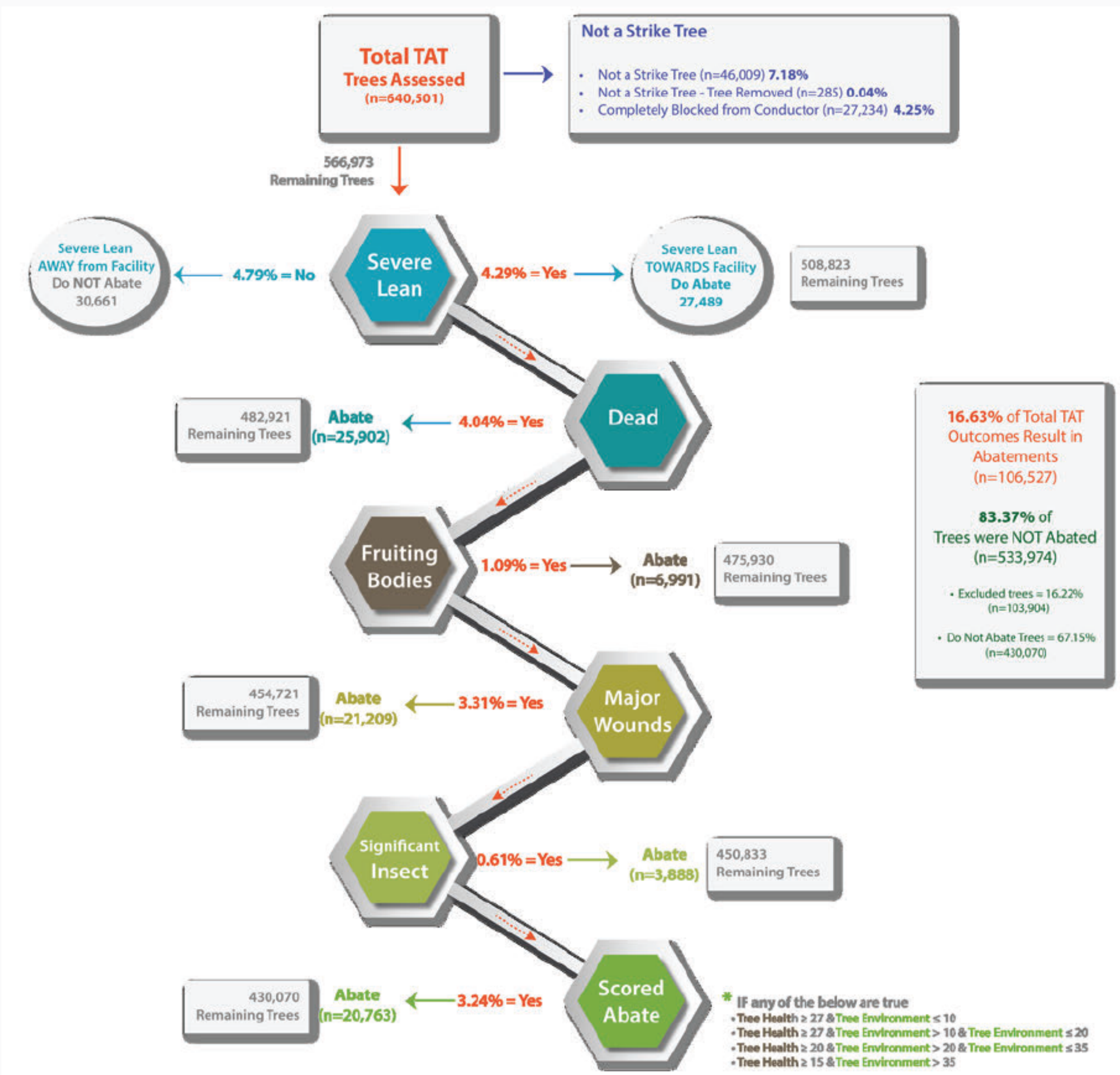


Figure 2.1. TAT Abatement Procedures and Outcomes (Note that ~17% of TAT Outcomes Result in an "Abatement" Decision)

The field inspector collects a baseline of data (e.g., species, DBH, height, lean). If it is determined that the tree cannot impact electrical assets, it is deemed "not a strike tree," whereby the TAT process is terminated, and no actions are taken (7% of trees in the TAT are categorized as "not a strike tree"). If the tree is considered a threat to electric assets (i.e., "Strike Tree") then a series of tree defect/health Boolean (i.e., "Yes" or "No") assessments are made. With any "Yes" Boolean outcome, the TAT process is concluded, resulting in an abatement decision (13% of trees are categorized with a Boolean abatement decision and 80% of abatements are from Boolean parameters). In order, the Boolean criteria are: severe lean towards facilities, tree is dead, fruiting bodies (sporophores) on the trunk or butt, major wounds, and/or significant insect infestation. If a strike tree has all "No" Boolean scores, the final process is a detailed scoring procedure based on four tree health parameters and six environment parameters.

The TAT procedure ends with any Boolean "Yes" abatement outcome stopping the cascading assessment process. For example, "Dead" trees are not assessed for "Fruiting Bodies." Trees with "Major Wounds" are not assessed for "Significant Insect" infestations, and so on. Therefore, when evaluating the TAT Boolean data records, users should know that a dead tree, for example, may very well have had any of the other Boolean abatement outcomes, even though the tree record will only list "Dead – Yes" because the TAT assessment was stopped, and the remaining parameters received a null value. While complex, Boolean parameters that precede an abatement are a "No" or "Negative" value, while parameters that succeed (e.g., come after) an abatement outcome are "Null" as these have not been assessed.

In total, the EVM TAT model process has assigned 17% of trees an abatement outcome (see Figure 2.2). Note that abatement rates vary by species, as shown in Figure 2.3 (page 12). When considering the TAT abatement population, Boolean decisions for severe lean and dead

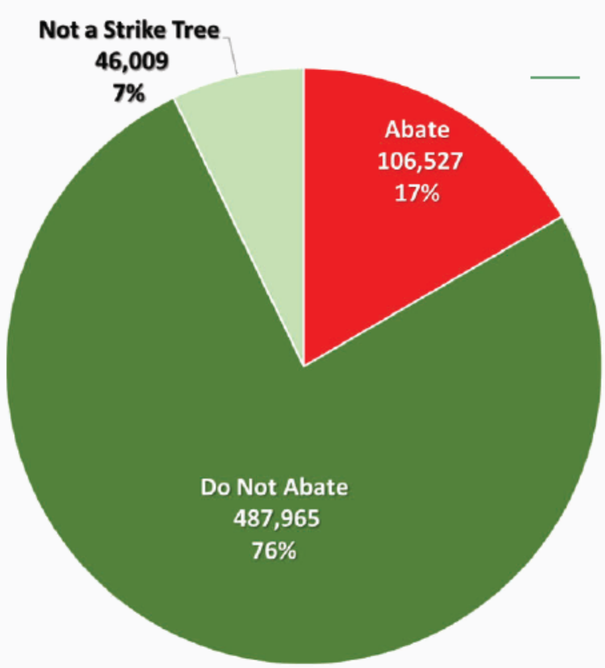


Figure 2.2.
EVM TAT Model
Tree Abatement Outcomes
(N=640,501) in Period
March 2020 – June 2021

trees combined resulted in ~50% of the total abatement outcomes, with major wounds (20%) and fruiting bodies (6%) and significant insect infestation (4%). The remaining 20% of abatements come from the tree health and tree environment scoring process (Figure 2.4). Abatement rates and decisions are somewhat variable when considered by

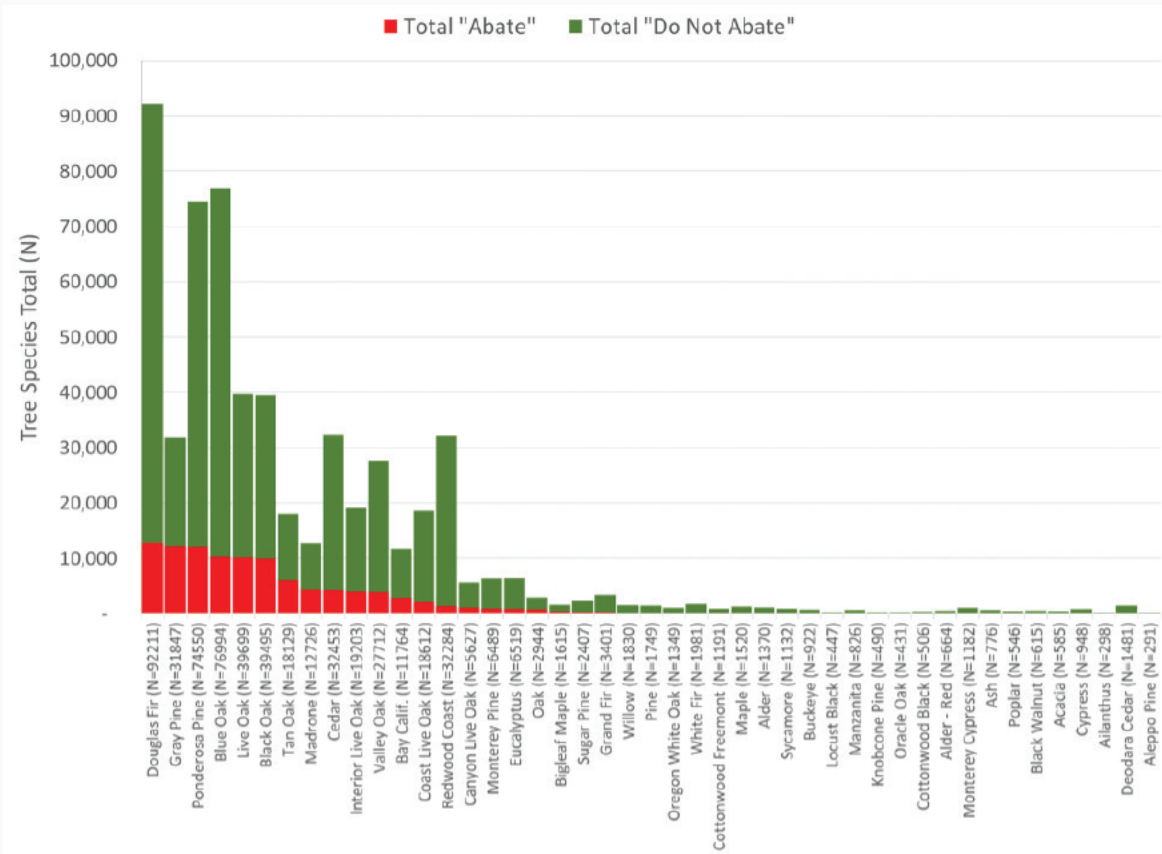


Figure 2.3. Species-specific Tree Abatement Outcomes (N=640,501) in Period March 2020 – June 2021

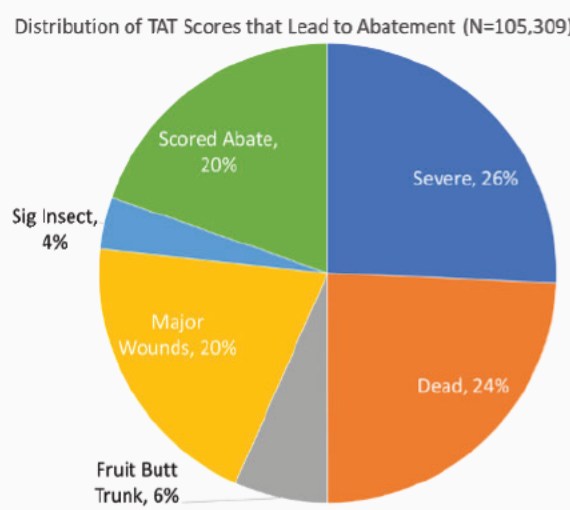


Figure 2.4. Distribution of TAT Parameters that Led to Abatement (N=105,309)

species. For example, when looking at the primary reasons for abatement (Table 2.1) we see that severe lean and dead trees are dominant TAT Boolean parameters for abatement. Exceptions include Gray Pines, which have a majority of abatements resulting from the scoring process. Live Oak, Tan Oak, and Coastal Redwoods have major wounds as a dominant abatement outcome. Abatement rates vary from a high of 38% for Gray Pines to a low of 4% for Coastal Redwoods. That said, for many of the species, results are mixed/balanced in terms of which TAT decision processes lead to abatement outcomes. Figure 2.5 (page 14) lists the reasons for TAT abatements (A) by species by count and (B) species abatement rate broken down by percentage abatement causal factor.

Species	Count	Severe Lean	Dead	Fruit_ Butt_ Trunk	Major Wounds	Sig Insect	Scored Abate	Abatement Rate
Douglas Fir	12,794	16%	31%	18%	14%	4%	17%	14%
Gray Pine	12,160	37%	12%	1%	5%	4%	41%	38%
Ponderosa Pine	12,015	15%	25%	5%	20%	14%	22%	16%
Blue Oak	10,253	14%	37%	5%	26%	2%	17%	13%
Live Oak	10,139	26%	18%	10%	28%	2%	17%	26%
Black Oak	9,924	35%	19%	6%	20%	1%	20%	25%
Tan Oak	5,999	22%	18%	5%	31%	1%	23%	33%
Madrone	4,473	37%	28%	1%	26%	0%	8%	35%
Cedar	4,391	22%	35%	2%	18%	4%	19%	14%
Interior Live Oak	3,945	36%	17%	10%	26%	2%	9%	21%
Valley Oak	3,870	27%	21%	5%	21%	1%	26%	14%
California Bay	2,861	39%	22%	11%	24%	1%	3%	24%
Coast Live Oak	2,015	35%	23%	7%	22%	2%	12%	11%
Coast Redwood	1,374	19%	28%	2%	42%	1%	8%	4%
Canyon Live Oak	1,117	37%	17%	8%	22%	3%	13%	20%
Monterey Pine	964	26%	41%	2%	8%	3%	19%	15%
Eucalyptus	891	30%	22%	4%	25%	3%	16%	14%
Oak	819	29%	43%	5%	16%	0%	6%	28%
Bigleaf Maple	421	41%	31%	3%	17%	1%	8%	26%

Table 2.1. Top 95th Percentile (2σ) Abatement Species and Percentage of TAT Outcomes that Led to Abatement (Abatement Rate is the Percentage of Trees Scheduled for Removal Compared to Total Trees Species Assessed) (Note that There Are Bulk Species Codes [e.g., Oak: *Quercus*, Pine: *Pinus*, Maple: *Acer*])

While 80% of abatements come from tree health/defect Boolean parameters, the remaining 20% of abatements come from the scoring process performed on strike trees. Consider what this grouping of "scored abatements" represent: these are essentially trees without gross outward defects that did not register at a level to trigger a Boolean abatement.

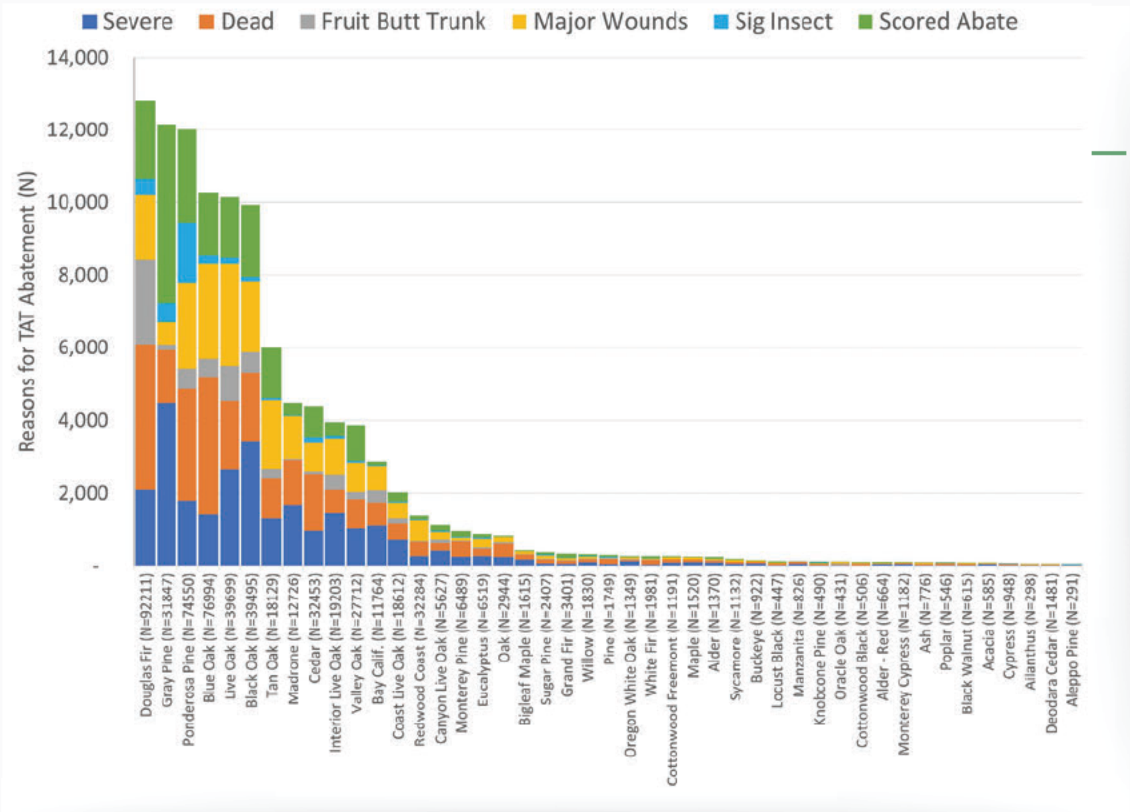


Figure 2.5A. Reasons for TAT Abatement, Count by Species

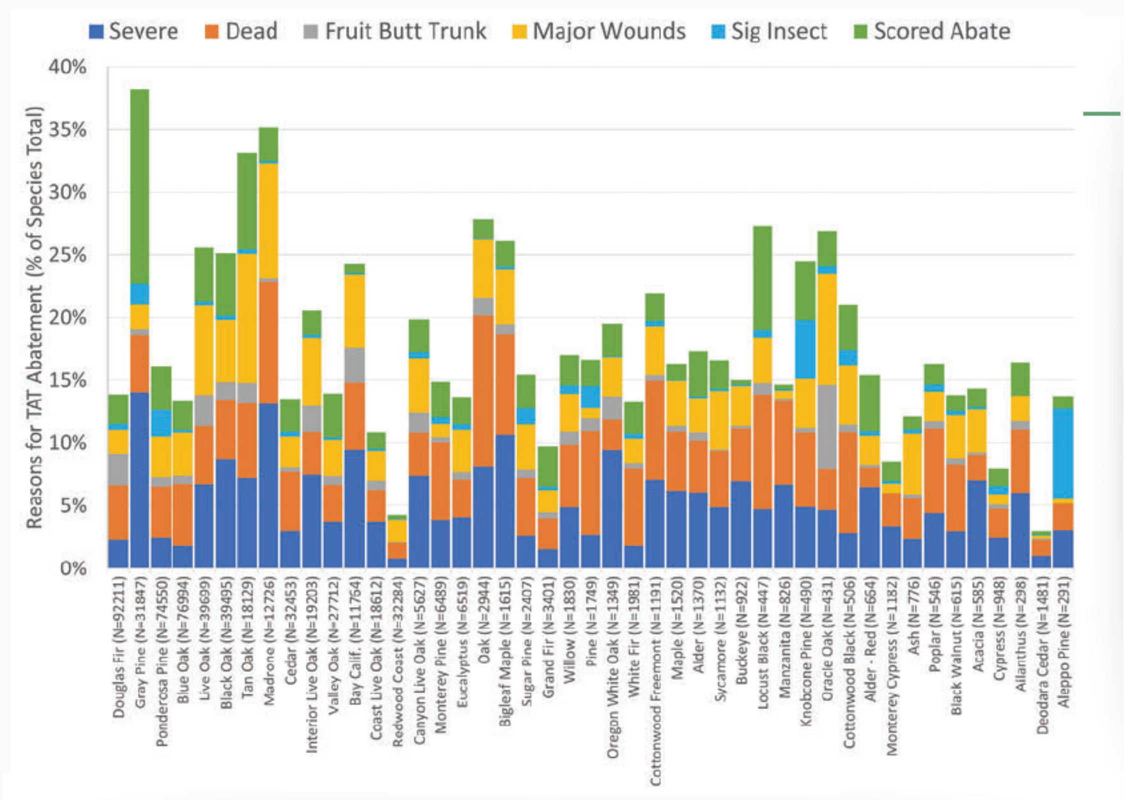


Figure 2.5B. Reasons for TAT Abatement, % of Species Total

The scoring process is complex and adds four tree health parameters and six tree environmental parameters, respectively, and then uses thresholds/criteria to create an abatement decision. Here are the scoring parameters:

Tree Health Parameters

- Crown Health
- Minor Wounds (and location on tree)
- Lean
- Codominance

Tree Environment Parameters

- Regional Species Fire Risk Score
- Surrounding Risk
- Slope
- Terrain
- Wind Condition
- Area Disturbance

These scored abatements are assigned an “Abate” if any of these thresholds/criteria are true:

- Tree Health ≥ 27 & Tree Environment ≤ 10
- Tree Health ≥ 27 & Tree Environment > 10 & Tree Environment ≤ 20
- Tree Health ≥ 20 & Tree Environment > 20 & Tree Environment ≤ 35
- Tree Health ≥ 15 & Tree Environment > 35

Note: The scoring thresholds are listed here for completeness. Currently, there is not a known way to map these scoring thresholds to actual tree failure probabilities.

A closer look at combinations that result in scored abatement decisions measured effective correlation strength for tree health and tree environment scores.[1] All tree species health scores are “Very Strong” correlates to scored abatement outcomes. Environment scores are variable and generally 50% lower than correlation strength, compared to Tree Health parameter scores (see Figure 2.6).

Using Glass’ Delta to calculate correlation strength for Tree Health & Tree Environment by comparing Abate (test) vs. Do Not Abate (control) populations by species.

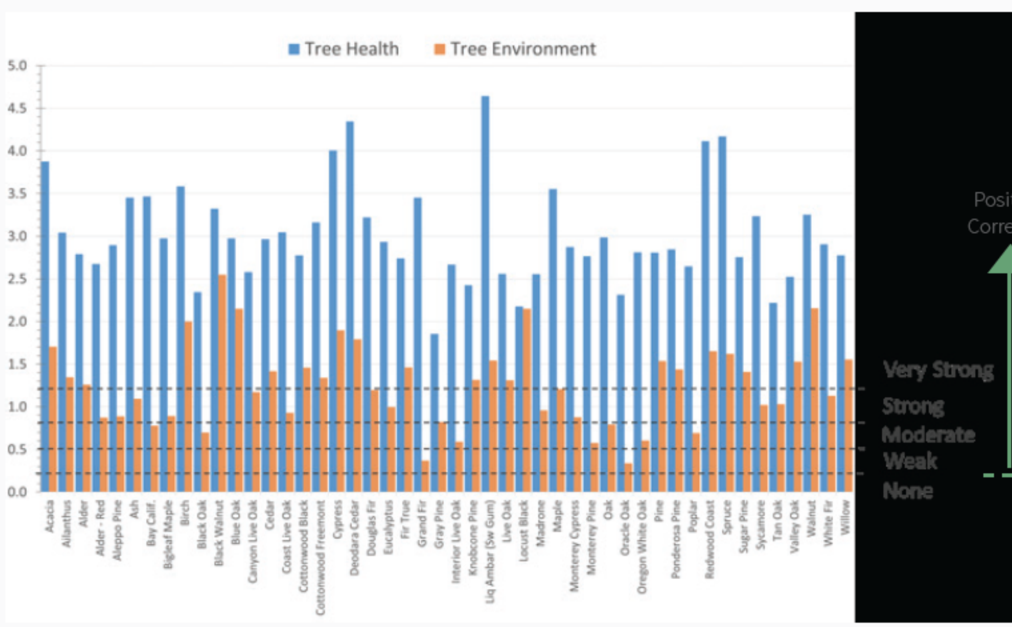


Figure 2.6. Correlation Strength of Tree Health and Tree Environment Parameters for Scored Abatement Outcomes (Some Aggregate Species are Used in This Analysis)

[1]In this case, Glass’s Delta was used to calculate correlation strength by comparing “Abate” Trees vs. “Do Not Abate” populations by species. (“Glass’s delta is defined as the mean difference between the experimental and control group divided by the standard deviation of the control group.” https://media.pluto.psy.uconn.edu/stats/es.htm)

A final approach quantified the relationship strength (effect size) for TAT parameters driving abatement outcomes. Starting at "negligible" relationship strength, the wind condition score is not significant and has virtually no relationship to abatement outcomes (see Table 2.2). Environmental parameters have the least impact on abatement decisions, with terrain and slope scores being negligible. These results align to other correlation analyses that found slope/terrain as weak correlates to tree failure (Formation Environmental Tree Risk Score Back Testing Phase 3, internal PG&E document). As expected, the tree health parameters have moderate strength. The Boolean tree parameters have the strongest relationship to abatement decisions.

	TAT Parameter	Significant[1]	Cramer's V	Strength[2]
Tree Environment	TAT_WIND_COND	No	0.001	Negligible
	TAT_TERRAIN	Yes	0.054	
	TAT_SLOPE	Yes	0.081	
	TAT_REGION_RISK_RATING	Yes	0.152	Weak
	TAT_SURR_RISK	Yes	0.175	
	TAT_DISTURBANCE	Yes	0.182	
Tree Health	TAT_CODOMINANCE	Yes	0.232	Moderate
	TAT_LEAN	Yes	0.265	
	TAT_CROWN_HEALTH	Yes	0.277	
	TAT_LOCATION_WOUNDS	Yes	0.292	
Boolean	TAT_SEVERE	Yes	0.339	
	TAT_FRUIT_BUTT_TRUNK	Yes	0.346	
	TAT_SIG_INSECT	Yes	0.388	
	TAT_DEAD	Yes	0.541	Relatively Strong
	TAT_MAJOR_WOUNDS	Yes	0.661	Strong
	TAT_STRIKE	Yes	0.708	

Table 2.2.
TAT Parameter Statistical Significance and Relationship Strength for Abatement Outcomes

Classification	Value Range
Less than 0.1	Negligible
Between 0.1 and 0.2	Weak
Between 0.2 and 0.4	Moderate
Between 0.4 and 0.6	Relatively Strong
Above 0.6	Strong

[1]Significance value defined as p-value ≤ 0.05 using Chi-square test for independence
[2]Strength measured as Cramer's V Classification

2.2 TAT Parameter Validation with External Data

When considering TAT parameter accuracy, it became important to compare external data for validation(s). Unfortunately, LiDAR data were not available for this phase of the study. It is our opinion that LiDAR data would have benefited this effort greatly. In short, as the external data available at the time, USGS digital elevation data were used to compare TAT slope and terrain input. Generally, good agreement was found for terrain and slope. See Appendix B: TAT Parameter Validation with External Data for results.

2.3 TAT Genus and Species Representations

This section explores how tree species are currently recorded in the TAT and provides a recommendation to record consistent species-level identification, with a few consistent Genus aggregates. The goal is to harmonize TAT tree speciation with the O&I database so that future comparisons are more consistent. See Appendix C: TAT Species and Genus Compositions for a detailed listing of TAT tree identifications.

Ideally, a species level analysis should be just that. Generally, the TAT tree codes were recorded at the species level. It was found that 19,723 trees were recorded at the genus level (aggregate) out of the total population of 640,501 recorded trees. This represents 3% tree genus aggregate codes in TAT records. This small number of instances becomes problematic when important species are "highly" aggregated into genus. If aggregate genus tree codes were simply removed, some species populations (N) would become severely underrepresented and preclude robust/inclusive analysis. Further, if tree species codes were recorded with a different protocol/method in the O&I database, then TAT species comparisons may become spurious. Table 2.3 lists the genus aggregates. As an example, *Pinus* (Pine) has a relatively high number of

Genus	Common Name	N	Aggregated by Genus	Distinct Genus & Species
Abies	Fir	5,804	3%	97%
Acacia	Acacia	904	75%	25%
Acer	Maple	1,648	44%	56%
Alnus	Alder	2,477	62%	38%
Cupressus	Cypress	2,827	37%	63%
Eucalyptus	Eucalyptus	6,938	89%	11%
Ficus	Ficus	52	8%	92%
Fraxinus	Ash	902	93%	7%
Juglans	Walnut	1,283	33%	67%
Pinus	Pine	125,176	2%	98%
Populus	Poplar	2,481	24%	76%
Quercus	Oak	255,334	1%	99%
Salix	Willow	2,299	97%	3%
Ulmus	Elm	370	65%	35%

Table 2.3. Summary of TAT Genus Aggregates (Shaded Genus Conform to Aggregates Nomenclature Prescribed in the OEIS Ignition Data Standard)

TAT tree records, and only 2% of *Pinus* species are genus aggregates. In this case, it makes sense to omit these *Pinus* genus aggregates from future analysis. The same rationale can be applied to *Quercus* (Oak). The problem emerges when looking at TAT tree codes with high percentages of genus aggregates. *Alnus* (Alder) comprises 62% TAT tree records in the genus aggregate. *Acer* (Maple) is another problematic example, where 44% of the respective TAT tree records would be excluded if this genus aggregate were omitted.

At some point, there should be limited inclusion of genus aggregates, so as not to omit valuable TAT records. Where to draw that line can become subjective. Whatever method is adopted should align/replicate species and genus aggregation rule sets used for O&I data collection.

As such, a standard was proposed in the Office of Energy Infrastructure Safety's (OEIS) Geographic Information Systems Data Standard, *DRAFT* version 2.2, in Section 3.4.3 Ignition (Feature Class), page 71.

"VegetationSpecies": Species of vegetation. Do not use "sp." except for the following genera: Ailanthus, Albizia, Acacia, Agave, Arctostaphylos, Calistemon, Casuarina, Catalpa, Ceanothus, Citrus, Eucalyptus, Lagerstroemia, Malus, Melaleuca, Photinia, Pittosporum, Podocarpus, Prunus, Salix, Tamarisk. This field may be filled out as "sp." or left blank for the above genera, and may be left blank for palms. Not required unless "ObjectContact" is "Vegetation."

Using this proposed standard, the genus aggregations that conform to the OEIS ignition data standard are highlighted in Table 2.3. Those that are not highlighted should not be recorded at the genus species level in future TAT inspections and record creation.

Recommendation 1: Implement a rule set, harmonized with O&I procedures, for TAT to record at species level, with only specified genus allowed as aggregates. Adopt definitions proposed in the OEIS Geographic Information Systems Data Standard, *DRAFT* Version 2.2, in Section 3.4.3 Ignition (Feature Class), Page 71.

2.4 Spatial and Temporal Harmonization of TAT and O&I Records

There was limited success in spatially and temporally aligning TAT and O&I records to look at annual and monthly ignition rates compared to TAT field-level inspections. It is recommended to improve the spatial accuracy of O&I records and to retroactively perform a TAT inspection on future O&I trees (to the best practical effort) to aid back-testing of TAT parameterizations.

This analysis was conducted to understand (1) where EVM TAT inspections were conducted relative to historical outage and ignition locations (hot spots) and (2) to evaluate TAT tree abatements spatially. The EVM circuit data consisted of vector data for 28,060 EVM circuit miles, of which 4,973 circuit miles were denoted as EVM Clear. Figure 2.7 (page 19) displays EVM and EVM clear circuit segments (miles and density). Data contain fields, including Circuit Name, Unique Segment ID, and Work Verification, which are used to denote whether the Circuit segment is EVM Clear. The Unique

Segment ID comprises 883,307 records, with each corresponding to a circuit segment with the potential to link to other data; however, a series of positional errors in this circuit representation limits the ability (and validity) of linking these spatial representations of EVM circuits to actual EDGIS digital twin (spatially accurate) EVM circuits. These positional errors manifest as varied (unbiased) misalignments when compared to other external data, including O&I and TAT records. The TAT records include data containing the full TAT decision-making procedure for Boolean and scored outcomes. The data used in this analysis were collected between March 2020 and June 2021 with 640,501 total records, resulting in 106,527 abatement outcomes, for a 17% abatement rate.

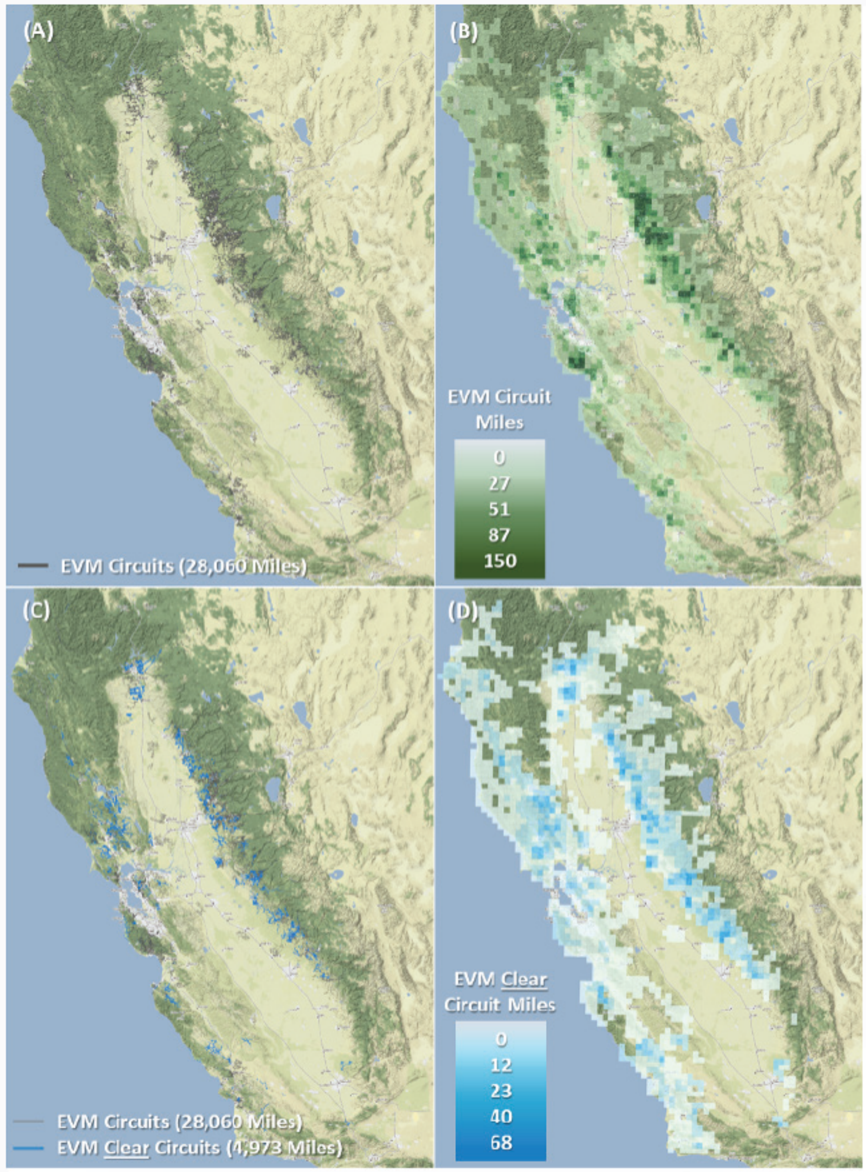


Figure 2.7. Enhanced Vegetation Management (EVM): (A) Circuits, (B) Circuit Miles, (C) Clear Circuits, and (D) Clear Circuit Miles

Seasonality for field TAT record collections seem to be focused during the spring (Figure 2.8 - page 20). Positions for TAT tree records are perhaps the most geospatially accurate data among the PG&E datasets employed for TTSS , likely reflecting better field GPS equipment than that used for O&I data recording. The locational focus over the ~15 months for TAT can be seen in the Figure 2.9 (page 20) heatmap of TAT records and calculated TAT records per circuit mile, which range from 0 to 799. Note that "0" TAT records per circuit mile can represent an area where no TAT work was performed or where there was no tree/vegetation to assess in an EVM circuit segment, therefore not indicating TAT prioritization.

Resulting abatements can be seen in the abatement heatmap and abatements per EVM circuit mile, which range from 0 to 289.

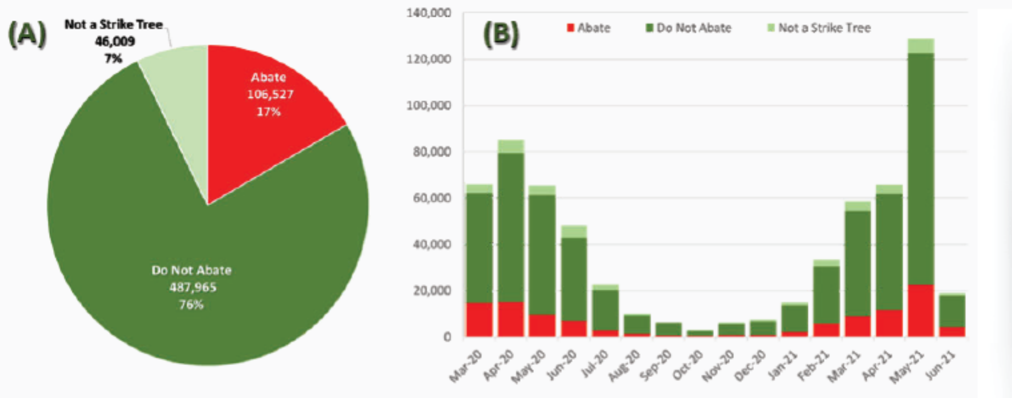


Figure 2.8. (A) TAT Outcomes (March 2020 – June 2021) and (B) TAT Record by Creation Date (Note that June 2021 is an Incomplete Month)

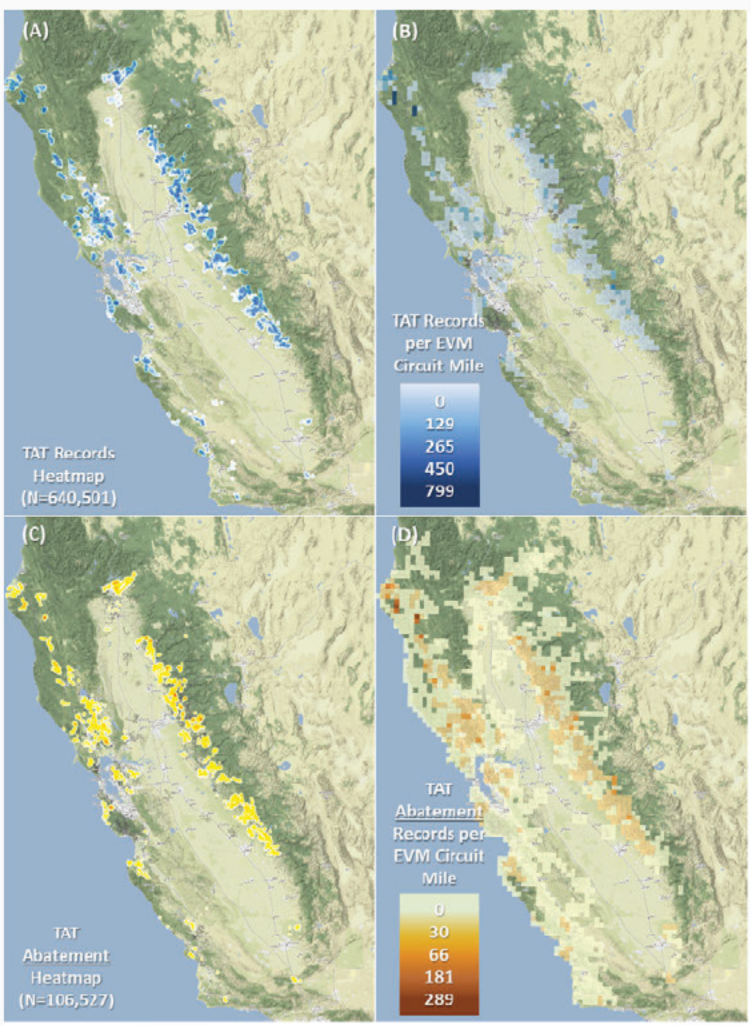


Figure 2.9. Tree Assessment Tool (TAT): (A) Heatmap of Records, (B) TAT Records per Circuit Mile, (C) Heatmaps of TAT Abatements, and (D) TAT Abatement Records per Circuit Mile

Spatial variability of abatement outcomes per TAT record ranges from 0 to 100%, displaying the degree to which the TAT is determining abatements across the EVM circuits. Figure 2.10 (page 21) depicts the abatement rate and abatements per EVM circuit mile, which have a large range from 0 to 947. Note that in this case, “0” abatements per mile should be interpreted as having TAT records within a circuit segment, but without abatement outcomes.

In this sense Figure 2.10(B) is a representation of where TAT is creating the highest number of tree abatements/removals across the EVM circuits.

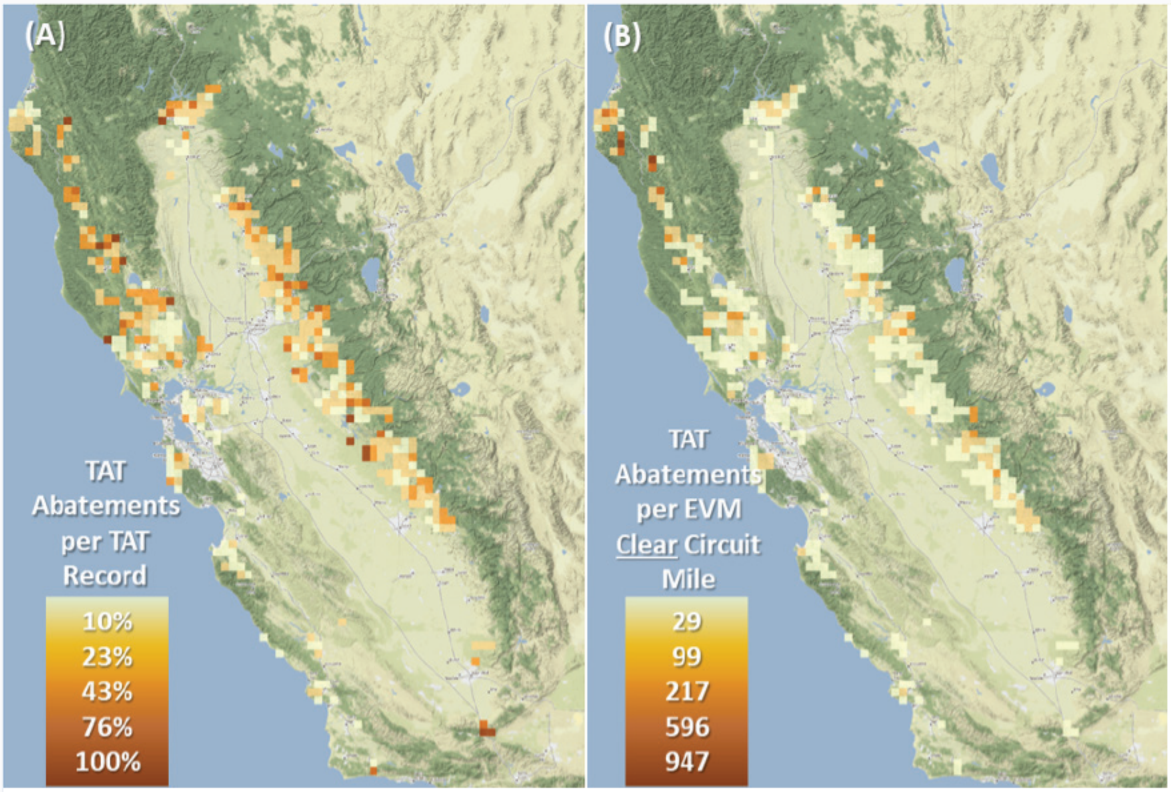


Figure 2.10. (A) TAT Abatements per TAT Record and (B) TAT Abatements per EVM Clear Circuit Mile

Both the Outage and Ignition data have a high degree of positional inaccuracy. Figure 2.11(A) (page 22) displays the mapped reported positions of the full records for both outage and ignitions. In the case of the 89,904 outages, note that orange indicates outages that occurred within 1 mile of EVM circuits, while yellow outages are in excess of 1 mile. Many outages are not within the EVM circuit 1-mile buffers, and some appear well outside of the PG&E service area. When outages are selected 1-mile proximity to EVM circuits, there are 42,460 outages that can be associated with EVM circuits, as shown in Figure 2.11(B). Ignition data also bear positional errors, as seen in a similar analysis in Figure 2.11(C), where of 501 ignitions, 383 occur within 1 mile of EVM circuits (D).

While not ideal, it must be recognized that due to the poor outage and ignition location data, compounded by spatial inaccuracies of the EVM circuit data vectors, it is difficult to associate with certainty that any one vegetation-caused outage or ignition corresponds to an EVM circuit span. In this case, these outages and ignitions that are reported within 1 mile of EVM circuits are referred to as “EVM Associated Outages” and “EVM Associated Ignitions.”

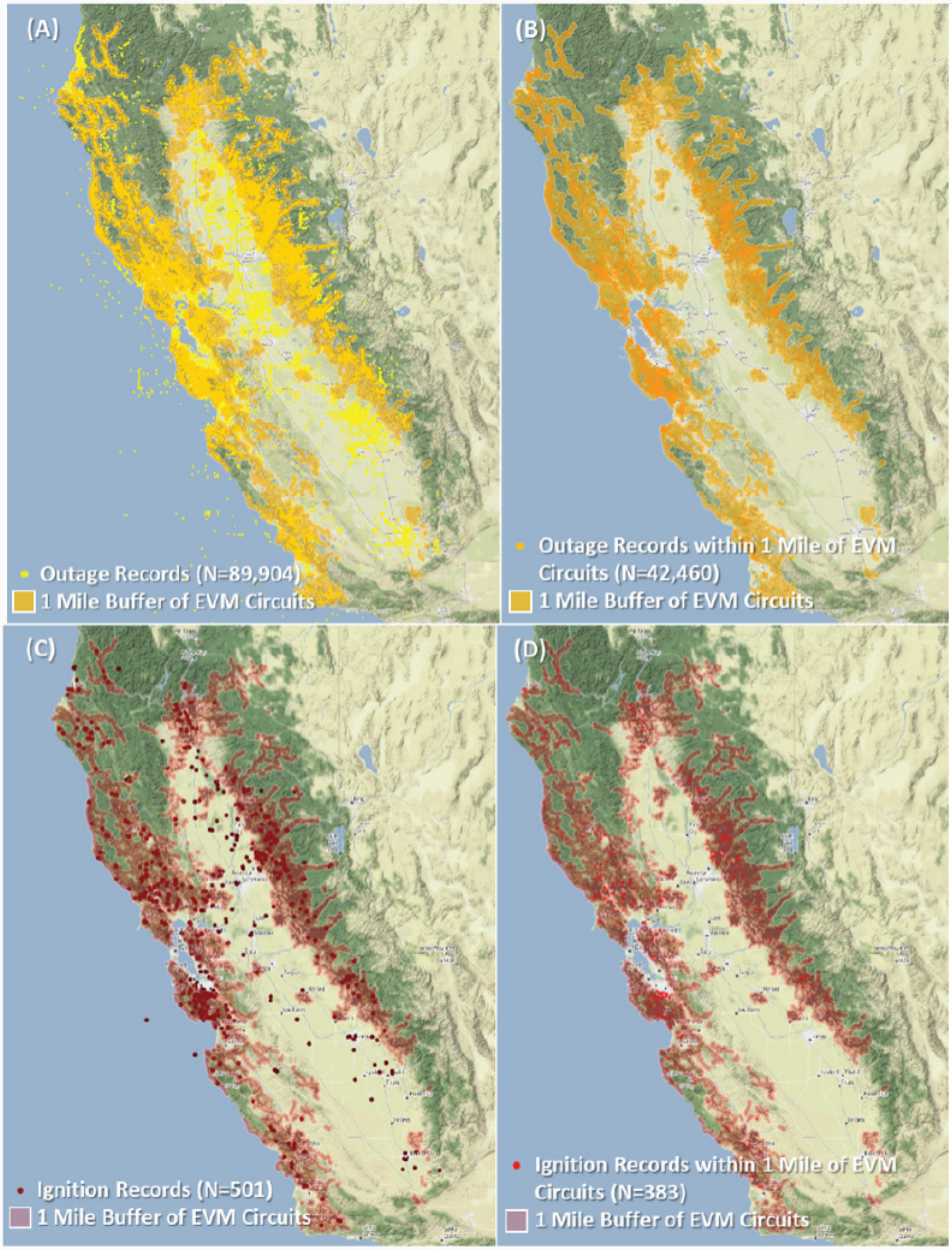


Figure 2.11. (A) All Outages and Outages within 1 Mile of EVM Circuits, (B) Outages Assigned to EVM Circuits, (C) All Ignitions and Ignitions within 1 Mile of EVM Circuits, and (D) Ignitions Assigned to EVM Circuits

Resulting EVM associated outages in Figure 2.12 (page 23) are presented as a heatmap and per circuit mile, ranging from 0 to 117 outages per EVM circuit mile. While the outages appear concentrated in some areas in the heatmap, these also reflect higher numbers of EVM circuit segments, as can be seen when normalized by circuit mile. EVM associated ignitions also can be seen as a heatmap and displayed as ignitions per EVM circuit mile.

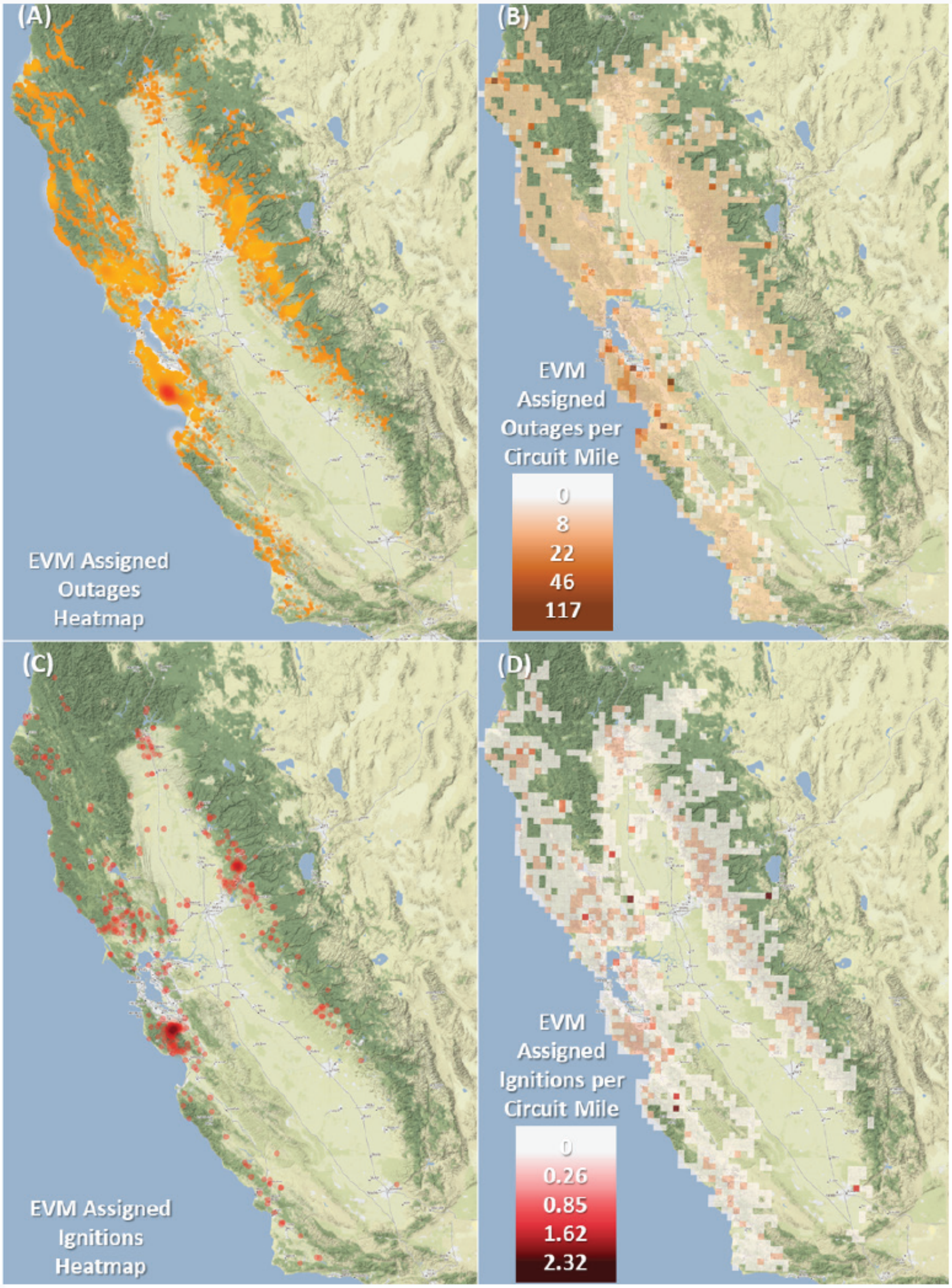


Figure 2.12. (A) EVM Assigned Outages Heatmap, (B) EVM Assigned Outages per Circuit Mile, (C) EVM Assigned Ignitions Heatmap, and (D) EVM Assigned Ignitions per Circuit Mile

It becomes possible then to compare the EVM associated outages and ignitions. Figure 2.13 (page 24) shows the ignitions per outage, as a percentage and outages per ignition, which range from 0 to 548. Lower numbers of outages per ignition can reflect the regionality of fire-prone vegetation and/or seasonality of outages per region.

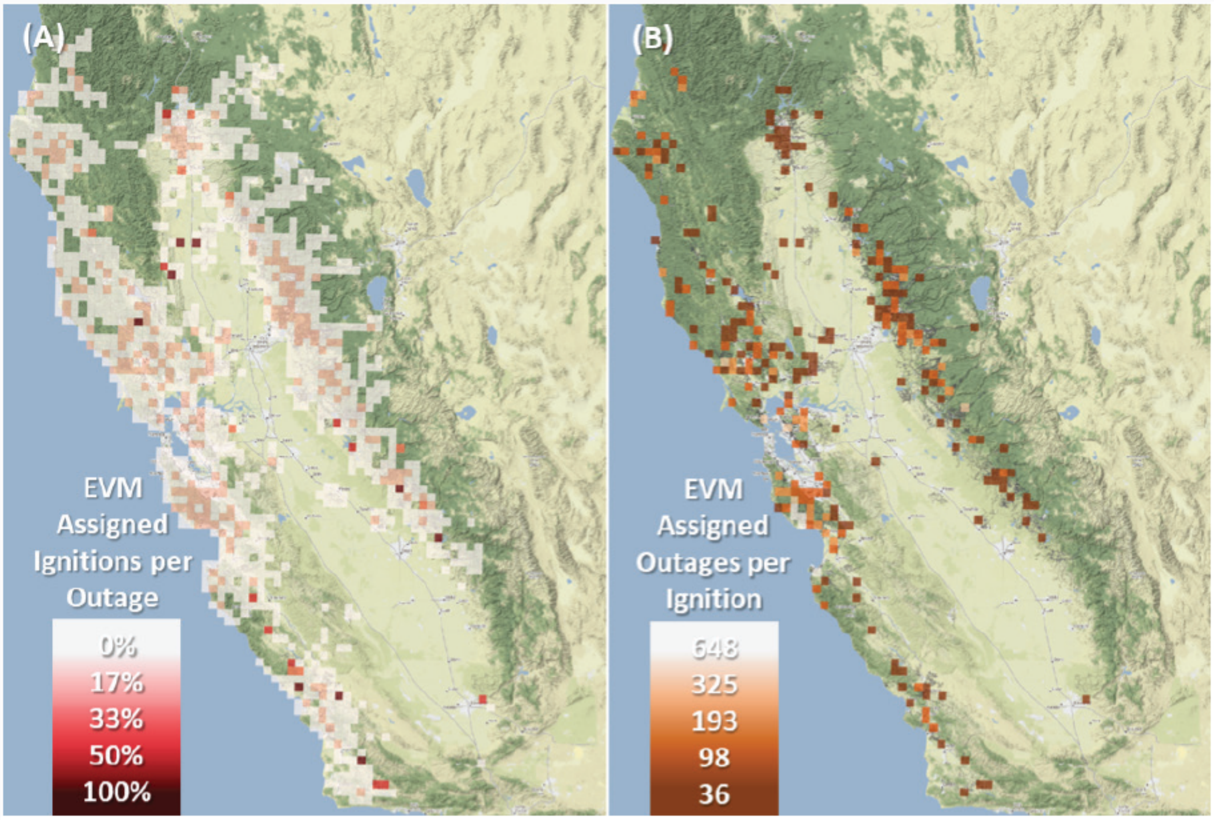


Figure 2.13. (A) EVM Assigned Ignitions per Outage and (B) EVM Assigned Outages per Ignition

It is just as important to look at the period of records for both associated vegetation-caused outages and ignitions to temporally harmonize when each has occurred, especially when considering that any one outage created an ignition. For example, when looking at the EVM associated ignitions per year, one can see those records within 2015-2017 are incomplete as seen in Figure 2.14(A).

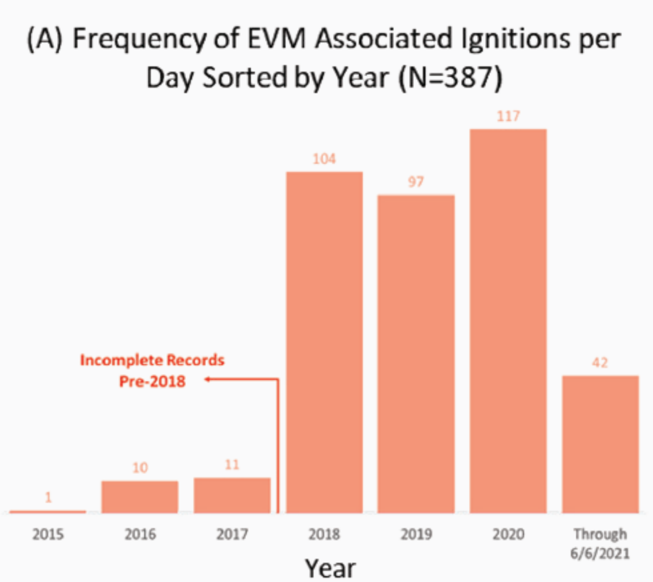


Figure 2.14. (A) EVM Associated Ignitions (2015 through 2021)

It is even more appropriate to consider these EVM associated ignitions normalized by day for each complete year of records (B), where ignitions are relatively consistent between years (0.27 to 0.32 ignitions per day, reported by year). Using complete annual EVM associated records, it is relevant to consider ignitions per day sorted by month for the period 2018 through June 6, 2021, where May through October is 3-5 times more fire-prone (C). For example, while 2.32 ignitions per day occur in July, only 0.16 per-day ignitions occur in January.

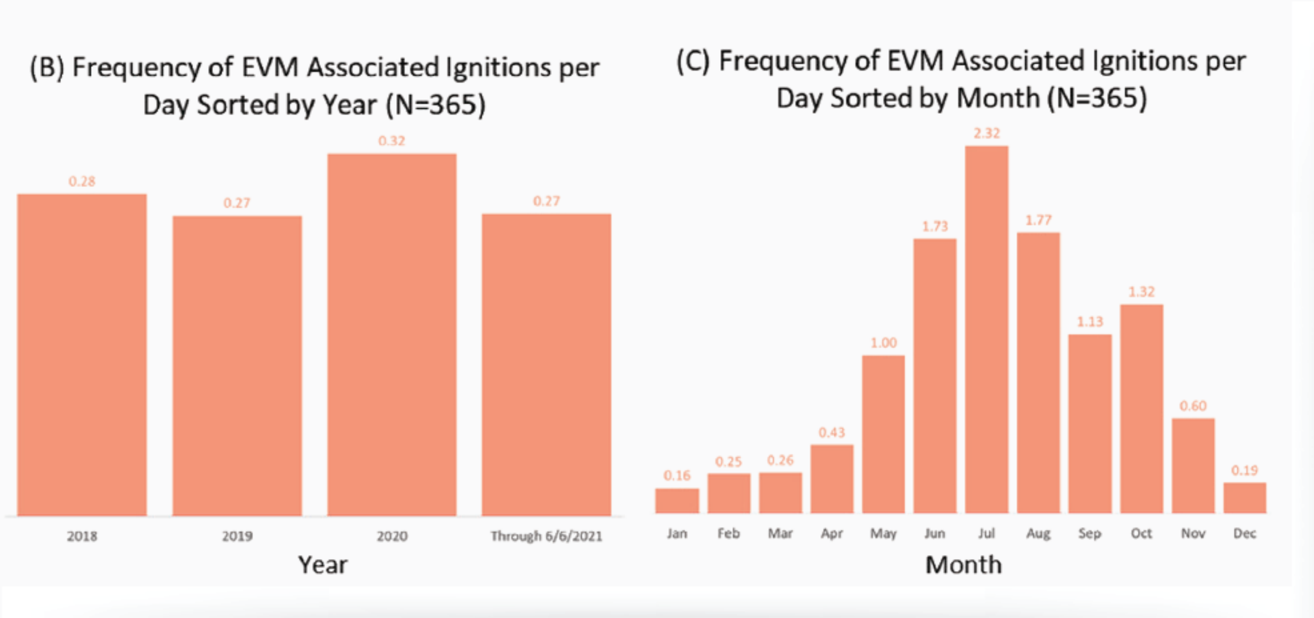


Figure 2.14. (B) & (C) EVM Associated Ignitions (2018 through 2021)

A similar approach can be used to temporally assess the EVM associated outage data, where it is apparent that pre-2008 data are incomplete data records (Figure 2.15(A)). Using only complete years, EVM associated outages per day can be calculated and summarized by year, manifesting considerable interannual variations. While 2013 experienced ~4 outages per day, 2019 experienced ~15 outages per day, contrasted to the relatively stable ignitions per day shown in Figure 2.14. The seasonality of outages is captured when summarizing the EVM associated outages per day, sorted by month, where winter months experience ~4 times more outages than the summer months (Figures 2.15 (B) & (C)).

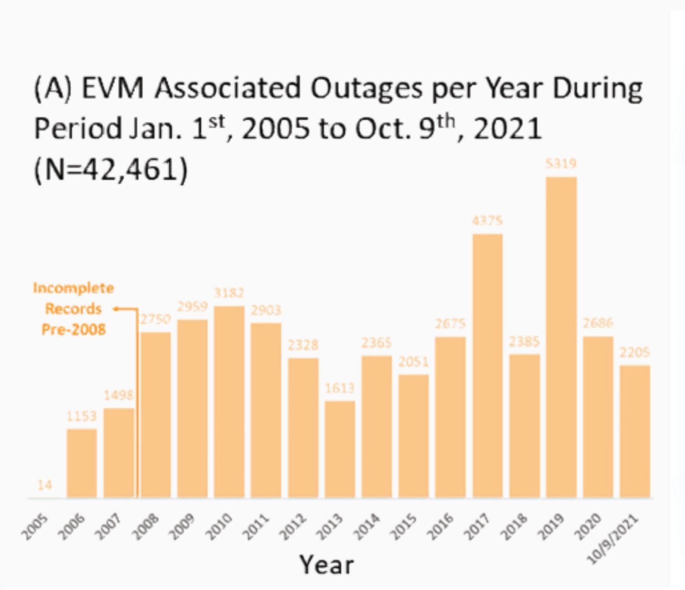


Figure 2.15. (A) EVM Associated Outages (January 1, 2005, through October 9, 2021)

Ultimately, the goal is to harmonize outages to ignitions both spatially (using EVM circuit associations) and temporally (using complete overlapping time periods). In this case, the ratio of outages per ignition can be considered for the completed record period of January 1, 2018, to June 6, 2021, using 12,056 Outages and 361 Ignitions. The frequency of EVM associated vegetation-caused outages to ignition for this period is summarized in Figure 2.16(A), depicting a disproportionately high ratio of outages without causing ignitions between December through March (43 to 125 Outages per Ignition), while it takes far fewer outages to create an ignition between April through November (2 to 18 Outages per Ignition).

Finally, a harmonized ratio of ignitions per outage shows clear seasonality in Figure 2.16(B) with 42% of outages resulting in an ignition during July (max) compared to only 1% of outages creating ignitions during January. These results are expected and are largely built into the TAT analysis. However, the

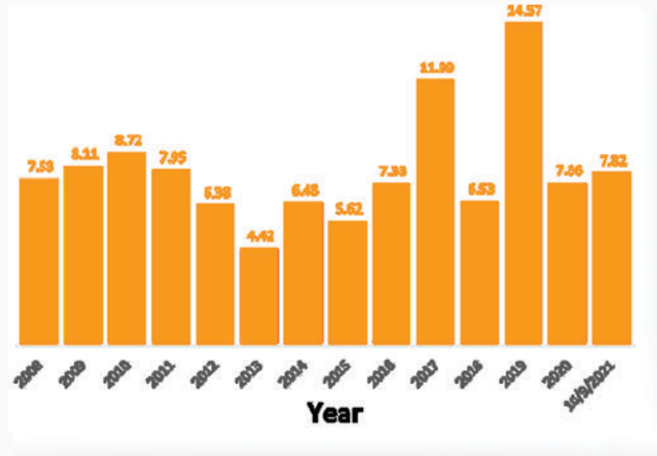


Figure 2.15. (B) EVM Associated Outages per Day (Sorted by Year) January 1, 2008, through October 9, 2021. N=39,796

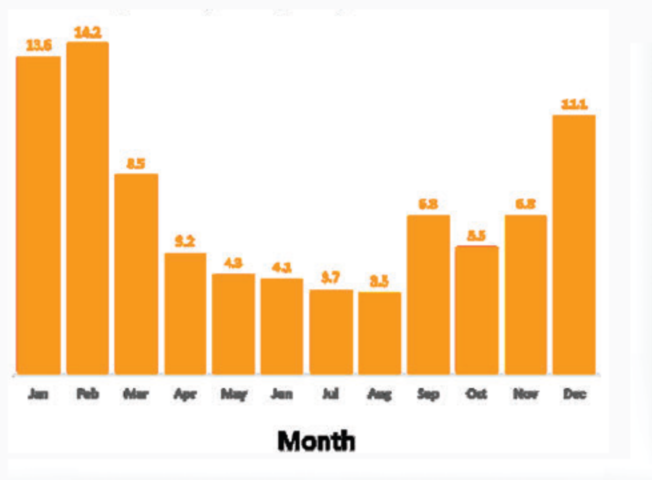
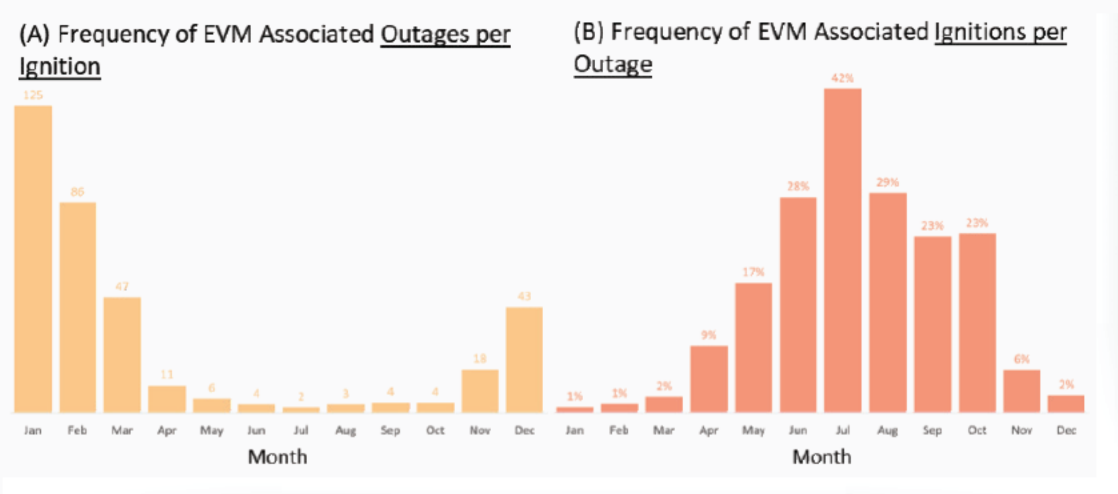


Figure 2.15. (C) EVM Associated Outages per Day (Sorted by Month) January 1, 2008, through October 9, 2021. N=39,796

Figure 2.16 (A) Spatially and Temporally Harmonized Frequency of EVM Associated Outages (N= 12,056) and (B) Ignitions (361 Ignitions) Sorted by Month for Period January 1, 2018, to June 6, 2018



magnitude of so few outages in summer months creating highly probable ignitions is notable and underlies the challenge at hand in designing a process to reduce wildfire risk in the EVM program. Regional focus and prioritization(s) should consider areas with high ignitions-per-outage ratios as reflected in using spatial EVM associations and temporal harmonization for outage and ignition data.

Circling back to TAT records, field-level activities may reflect prioritizations. For example, a higher TAT record count per legacy outage, or better yet, per ignition, may imply a higher degree of activity where there is greater wildfire risk to EVM circuits. Figure 2.17 displays the TAT record to EVM assigned outages and TAT records to ignitions. In this case, as many as 2,050 TAT records are created for every legacy EVM-associated outage, and as many as 19,978 TAT records are created for every legacy ignition. In this case, as many as 2,050 TAT records are created for every legacy EVM-associated

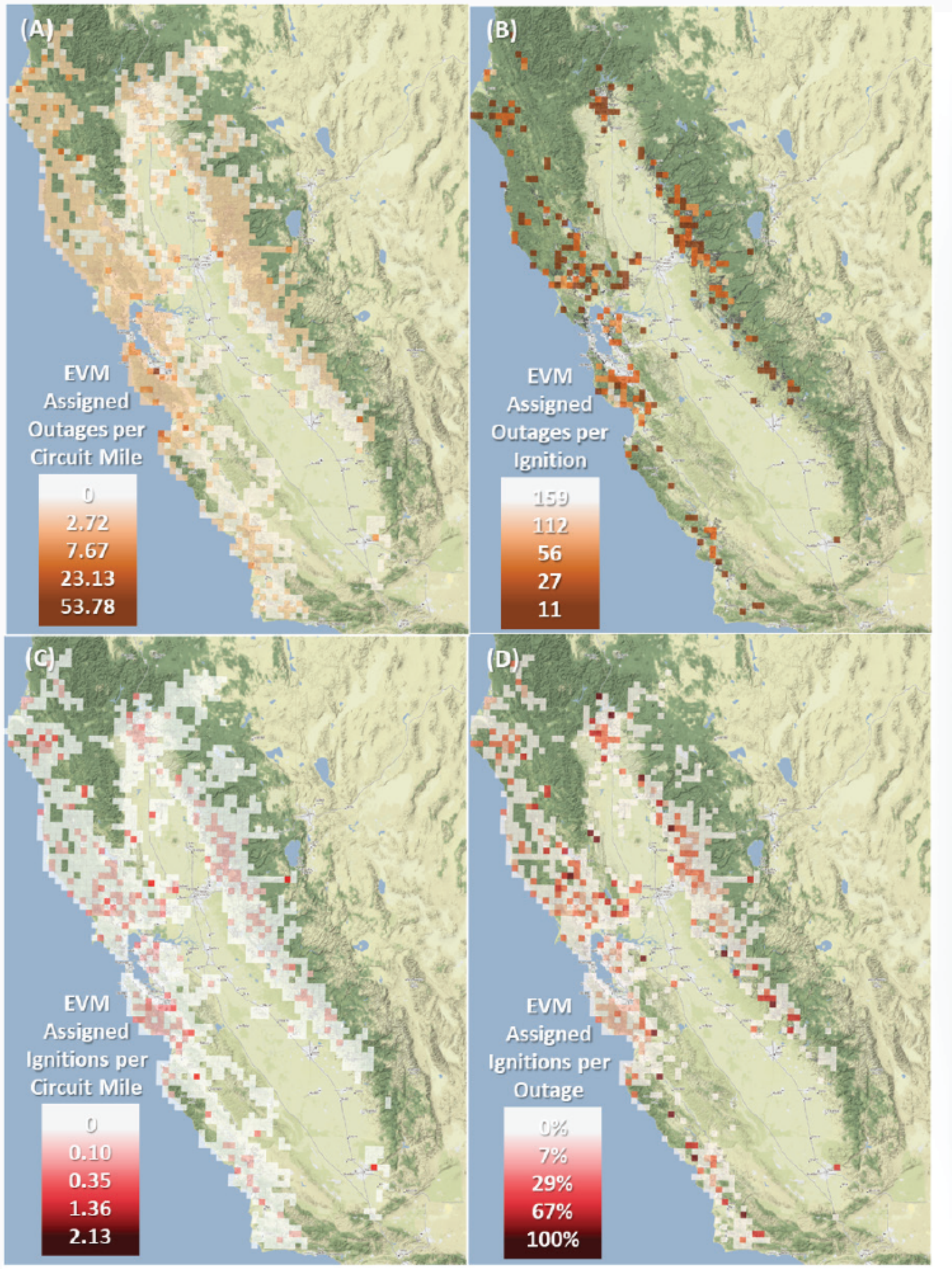


Figure 2.17. Harmonized Outage and Ignition Period for January 1, 2018, through June 6, 2021: (A) EVM Assigned Outages per Circuit Mile, (B) EVM Assigned Outages per Ignition, (C) EVM Assigned Ignitions per Circuit Mile, and (D) EVM Assigned Ignitions per Outage

outage, and as many as 19,978 TAT records are created for every legacy ignition. Reflect on the level of effort required in the field to assess ~20,000 trees for every legacy ignition. Recall that 17% of TAT records result in abatement decisions. Using actual abatement decisions per TAT record allows comparison of these to legacy outages and ignitions. A high of 327 TAT abatements is required for every legacy outage, and up to 2,852 TAT abatement decisions are being performed per legacy EVM associated ignitions (Figure 2.18).

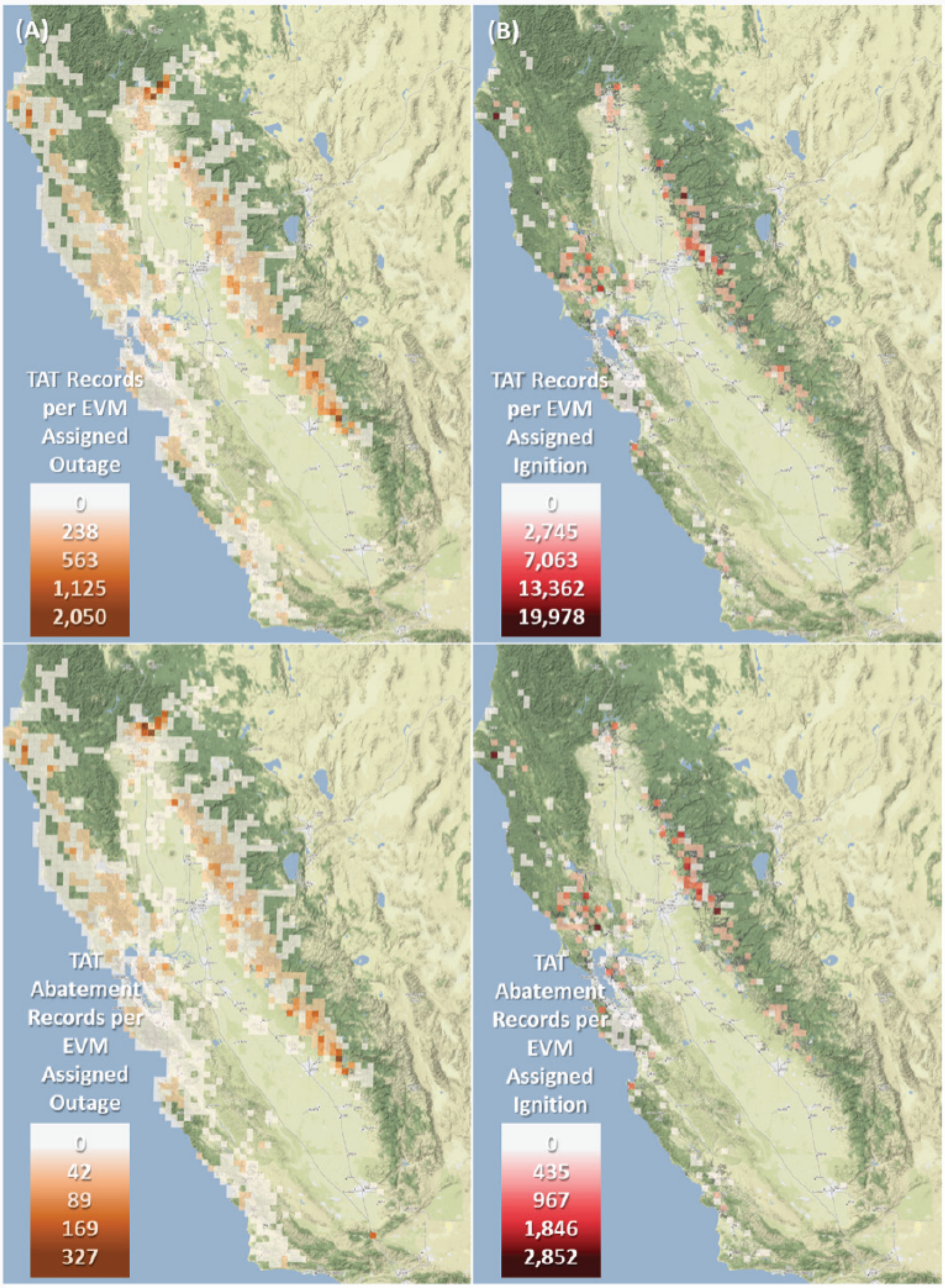


Figure 2.18.
(A) TAT Records per EVM Assigned Outage, (B) TAT Records per EVM Assigned Ignition, (C) TAT Abatement Records per EVM Assigned Outage, and (D) TAT Abatement Records per EVM Assigned Ignition

Discussion

These metrics do not measure the efficacy of TAT or whether legacy vegetation-caused O&I would have been abated, even if the offending trees had been assessed and abated. Instead, these results reflect level of activity (TAT record creation) over EVM circuits that experienced higher legacy outage and ignition risk.

This section concludes with a final discussion on data positional accuracy and time scales. The data review exposed, and take steps to resolve, underlying deficiencies in O&I data. Namely, the positional data are often inaccurate and unreliable. Further data records appear incomplete for multiple years, and these data only temporally overlap for 3.5 years. That said, perhaps incomplete outage and/or ignition data were received for review by the TTSS team. Regardless, some incorrectly located and associated O&I records relative to the EVM circuits and TAT records remain. Our intention (and hope) is that after completing spatial and temporal associations, enough of the records are correct to create valid results that are reflective of legacy O&I patterns, relative to TAT records. However, there is no way to confirm that this is the case.

It is recommended that future O&I investigations should record accurate (dual-phase GPS) positions and be assigned to an EVM circuit span that correlates to geo-rectified and spatially conflated PG&E EDGIS digital twin vector data. If possible, O&I trees would be associated to the LiDAR tree segmentation ID. The result would improve the confidence when using these data in geospatial analysis. Lastly, there has not been sufficient time elapsed to evaluate TAT abatements relative to outages and/or ignitions. The TAT program in its current form has only had one full year of tree abatements and requires a longer period to measure effectiveness. We recommend that the TAT efficacy review continue over future annual cycles. When recommendations are implemented, we expect that more accurately positioned O&I data, associated to the more accurate EVM circuit digital twin data, will dramatically simplify TAT efficacy assessment and produce more defensible outcomes.

Recommendation 2: Outage and/or ignition investigations should record accurate (dual-phase GPS) positions and be assigned to an EVM circuit span that correlates to geo-rectified and spatially conflated PG&E EDGIS digital twin vector data. Similar to PG&E Transmission VM, where possible, associate the O&I tree with a LiDAR tree segmentation ID to further improve tree locational accuracy, and future tracking.

2.5 TAT Records Compared to O&I Distributions

When comparing TAT abatement and O&I species distributions, it was found that certain abatement species are over-/ under-represented. It is recommended that, over time, a programmatic Key Performance Indicator (KPI) could harmonize the distribution of TAT abatement tree species to the O&I species distributions.

TAT abatement species distributions should be similar to the O&I species distributions (when normalized for location). Simply put, TAT abatement decisions should mirror outage and wildfire risk patterns. A few data transformations were required to address this question. First, it was necessary to ensure that similar species compositions were selected in the legacy outages that occurred proximate to where TAT records have been collected. A five-mile buffer around all TAT records was created and used to clip out proximate outages. Second, only root- and trunk-failure-caused outages were filtered. Third, aggregate genus clusters were then removed (e.g., Pine, Oak) because these poorly represent and confuse species specificity. The resulting datasets are displayed in Figure 2.19.

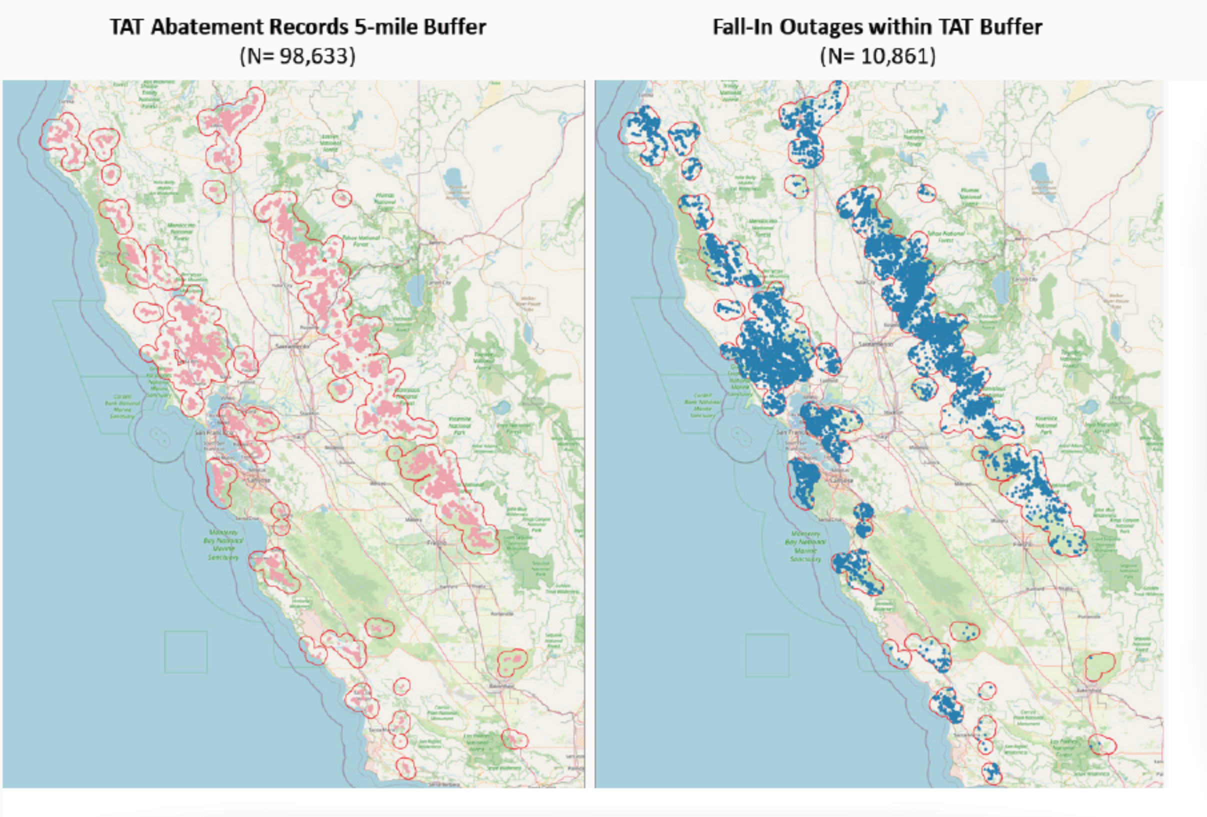


Figure 2.19. TAT Abatements and Fall-In Outages Clustering to Ensure Comparable Species Compositions

The outage tree distribution includes 8 species in the top 67% (1σ) as rank summarized (Figure 2.20), compared to 7 species in the top 67% (1σ) in the TAT abatement distribution, as rank summarized (Figure 2.21).

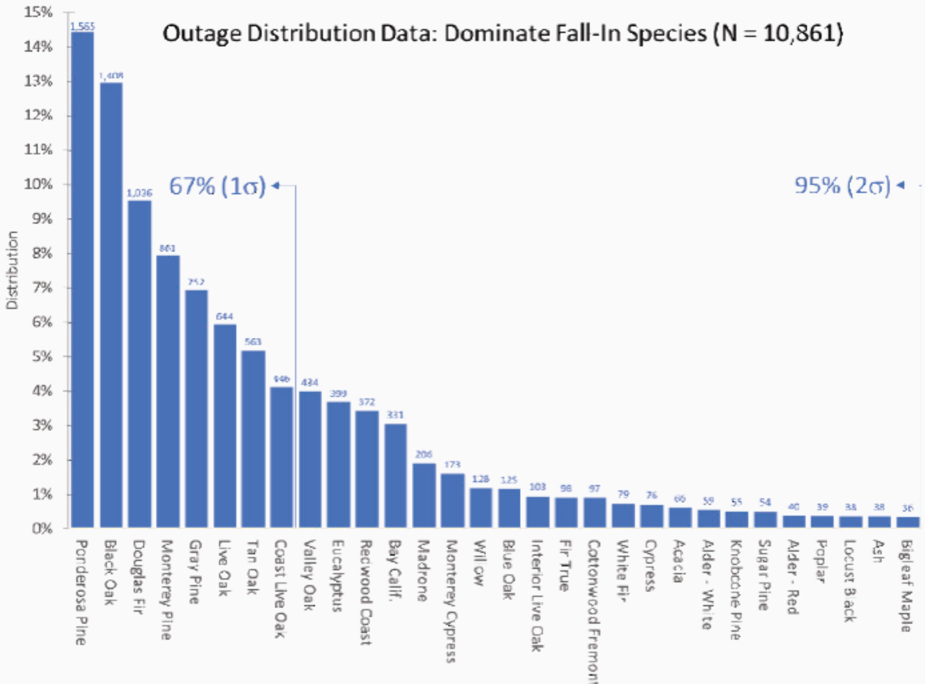
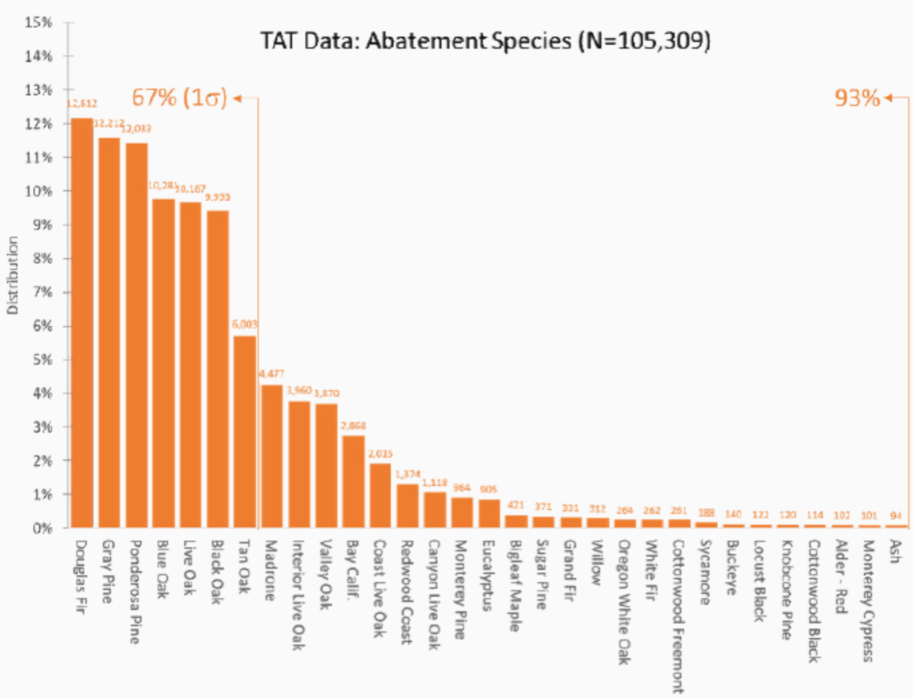


Figure 2.20. Fall-In Outage Tree Distribution by Species

Figure 2.21. TAT Tree Distribution by Species



General alignments are shown when looking at the top 95% of Outage Fall-Ins and TAT abated trees as a percentage of total respective populations (e.g., Ponderosa Pine, Black Oak, Tan Oak, Valley Oak, and Bay Calif.). There are TAT abatement tree species over-represented, such as Gray Pine, Live Oak, Blue Oak, and Interior Live Oak. TAT abatement trees under-represented include Monterey Pine, Coast Live Oak, Eucalyptus, Coastal Redwood, and Monterey Cypress (see Figure 2.22(A)). The differences in the TAT Abatement and Outage distributions are shown in Figure 2.22(B) with deltas less than -1% in red and greater than 1% in blue.

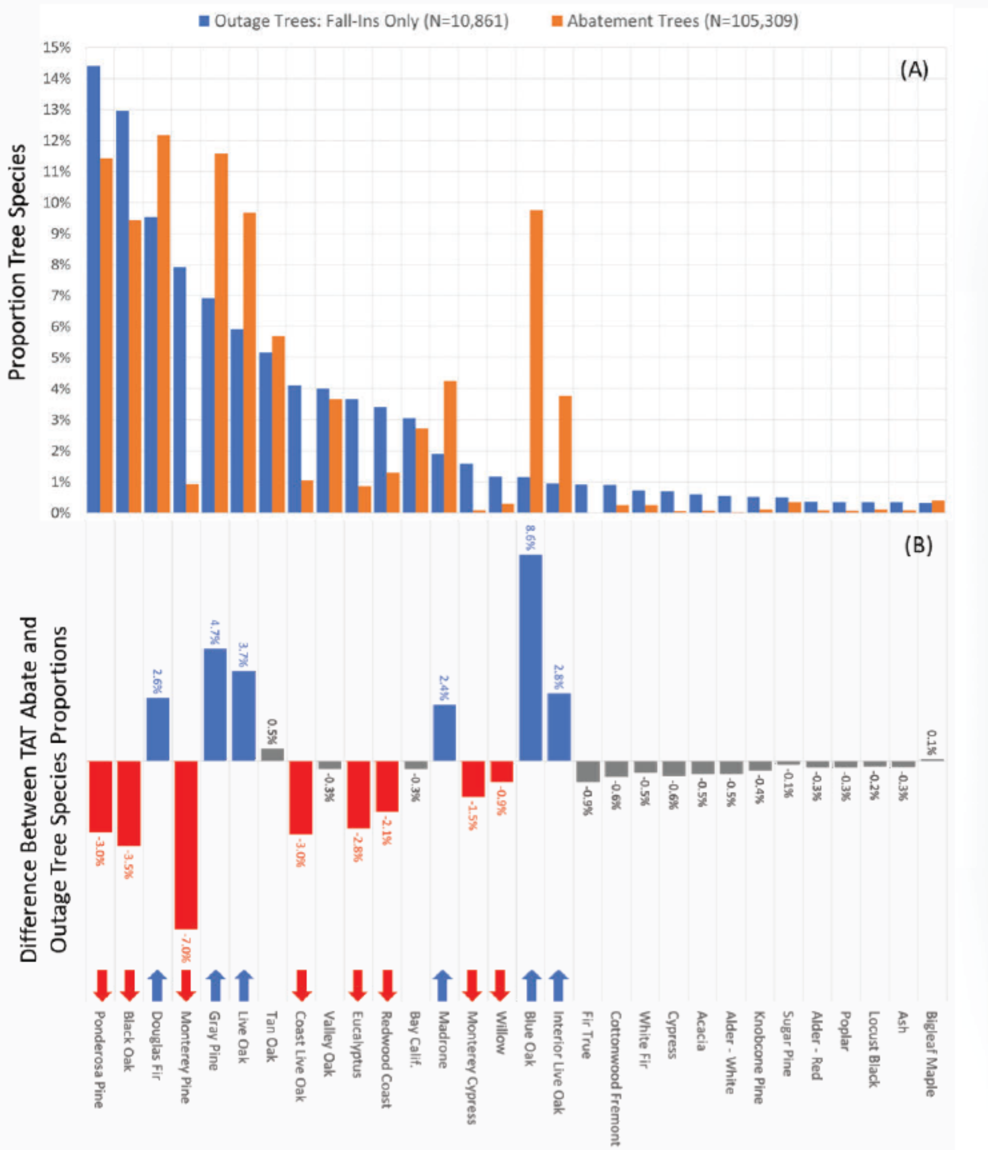


Figure 2.22. (A) Proportion of the Top 95% (2) Outage Fall-In Tree Species (N=10,861) Compared to TAT Abated Trees (N=98,633) and (B) Differences Between TAT Abatements and Outage Tree Distributions (It Is Conceivable that Red Species are Under-Abatements and Blue Represent Over-Abatements)

Recommendation 3: Track TAT abatement species compositions and compare to outage and ignition species distributions. Note potential over-/under-abatements. Over time, this can serve as a programmatic KPI.

2.6 Initial Plan to Evaluate TAT Effectiveness

An original research question was posed to assess the effectiveness of the EVM TAT in mitigating outages and ignitions (Figure 2.23). The most explicit method is to simply compare TAT abatements against observed trends in O&I.

Unfortunately, the project RFP incorrectly described the EVM TAT inspection record databases as having been collected over a 12+ year timeframe (from 2008 – 2020+), when in fact the earliest EVM TAT records available were collected in March 2020 and were available to June 2021 (the time the dataset was received). This limited time-frame of EVM TAT records makes it difficult or

Figure 2.23. EVM Effectiveness Evaluation Initial Research Question.

or impossible to rigorously evaluate the wildfire mitigation effectiveness of the EVM TAT model. There simply has not been enough elapsed time to facilitate a meaningful analysis on the TAT outcomes. When a tree is inspected with TAT and is prescribed with an abatement outcome, a work order is assigned to a tree removal contractor. As a result of a number of challenges such as customer refusals and environmental constraints, it may take up to 12 months for a tree to be worked/removed. The bare minimum elapsed time-frame required post-abatement to meaningfully assess any potential reduction in vegetation-caused outages or ignitions should be at least one full fire season following tree removal (versus TAT inspection), with additional elapsed time beyond one fire season to further strengthen the analysis (see Figure 2.24).

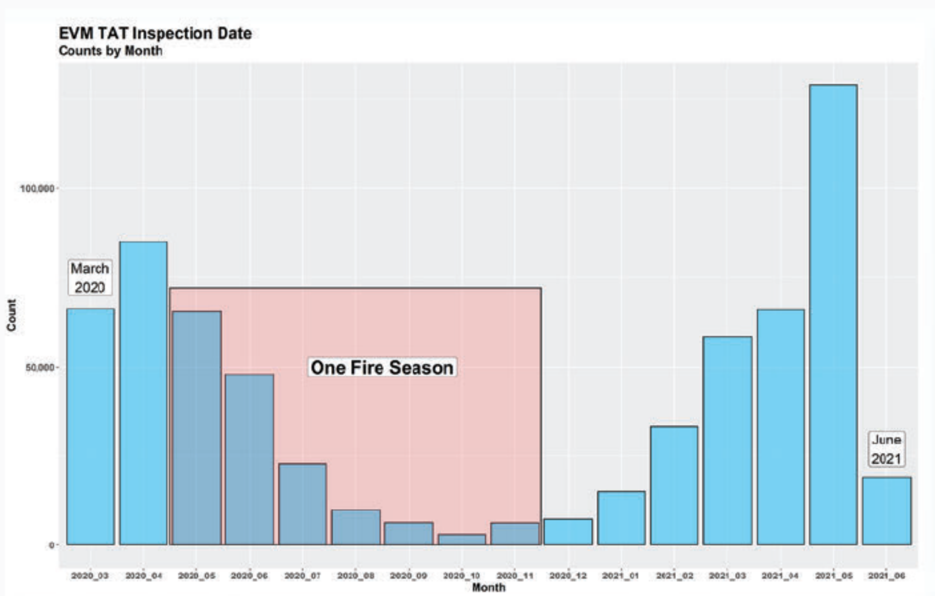


Figure 2.24. Histogram of EVM TAT Tree Inspection Records Created by Month

To further complicate matters with the initial plan to evaluate EVM effectiveness, there is no direct link between the EVM TAT inspection record and the work history records, making it impossible to determine with certainty whether or not any particular tree designated for abatement by the EVM TAT has in fact been removed.

Two alternative analyses were conducted to estimate the effectiveness of the EVM TAT in a more conceptual framework, while still attempting to be as rigorous as possible within the data constraints.

- Firstly, the EVM TAT model was "crosswalked" back to the historical outage and ignition database to ask and answer the question: "What percentage of historical outages and ignitions may have been avoided if the EVM TAT program were in use at that time?" (see Section 2.7)
- Secondly, "EVM effectiveness" was characterized by assessing whether recent ignitions had occurred on circuit segments designated as EVM Clear (see Section 2.8).

2.7 Retrospective TAT Parameter Crosswalk to O&I Database

The O&I database was used to identify which trees would have been abated using the outward defect Boolean TAT parameters. This analysis (1) shows how difficult it is to associate the O&I database to TAT parameters and (2) supports considering additional parameterizations or scoring that increase "green trees" (trees without outward/observable defects) into abatement consideration.

The "crosswalk" evaluates which historical tree failures (resulting in outage and/or ignition) would have been mitigated as an EVM TAT abatement. The O&I database is not harmonized with TAT parameters. Each respective database records different parameters and assigns different severity levels and thresholds. The net effect is a lack of a direct 1:1 relationship(s) between the TAT and O&I databases.

To resolve these misalignments, several assumptions were made:

1. Only root and stem failure records from the O&I database were considered.
2. O&I parameters can, to a degree, align to these four TAT Boolean tree health and defect parameters. These account for 56% of all abatement decisions.
    a. Tree Mortality (24% of abatements)
    b. Fruiting Bodies (6% of abatements)
    c. Major Wounds (20% of abatements)
    d. Insect Attack (4% of abatements)

3. The fifth TAT Boolean parameter, Significant Tree Lean (26% of abatements) was excluded due to the poor data quality and null values for this parameter in the O&I database.
4. Trees in the O&I database that meet the four TAT Boolean thresholds would be abated in the current version of the TAT.

Given these assumptions, somewhere around ~50% of the legacy outages and ignitions would be expected to have been abatements under the current TAT model.

Methodology for Creating the Crosswalk between O&I Parameters and TAT Boolean Parameters

The tree mortality Boolean parameter in the EVM TAT maps directly/unambiguously to a binary tree mortality field called "bTreeDead" in the historical O&I database. The remaining three Boolean EVM TAT parameters do not map directly to individual fields in the O&I database. Alternatively, the O&I data field called "cDefect" was used, which may consist of one or more categorical tree defects or health issues noted by the inspector during the outage investigation of a failure tree. The significant insect attack EVM TAT parameter corresponds to an O&I database defect entry called "InsectDamage." While there is no exact "major wound" field in the O&I database, there are two categorical tree defect values called "BasalWound" and "StemBranchWound," which are considered to be indicative of major wounds as intended in the EVM TAT assessment. The remaining Boolean EVM TAT parameter, fruiting bodies, is the most complex in its mapping to the historical O&I database (Figure 2.25).

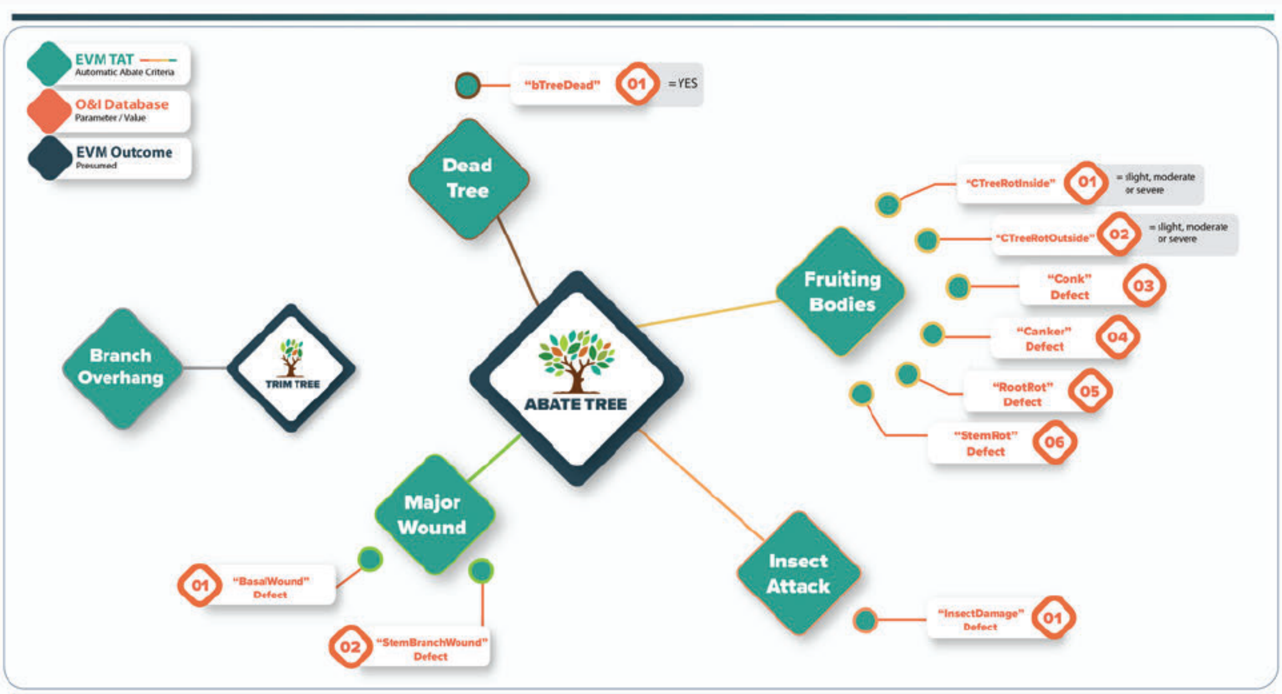


Figure 2.25. Methodology for EVM TAT Parameter Crosswalk to O&I Database Attributes

Among the categorical values in the O&I database's tree defect field, four defects were considered to potentially correspond to the presence of fruiting bodies: conks, cankers, root rot, and stem rot. Additionally, two fields in the O&I database named "cTreeRotInside" and "cTreeRotOutside" are both ordinal parameters with possible values of "slight," "moderate," or "severe" to describe the extent of internal or external rot observed on a failure tree during the post-outage inspection. These historical observations of tree rot were potentially indicative of the presence of fruiting bodies as intended by the EVM TAT assessment; however, the extent to which severity (i.e., slight, moderate, or severe) and location (i.e., external or internal) should be considered as a Boolean TAT abatement based on the presence of fruiting bodies.

Due to the uncertainty with O&I associations to TAT major wound and fruiting bodies parameters, a combinatorial analysis strategy considered a range of potentially reasonable parameter severity levels. For instance:

(1) What severity levels of interior or exterior tree rot would be likely to correspond to the presence of fruiting bodies on a still-standing tree and be visible to an inspector during an EVM TAT inspection?

(2) Is it reasonable that interior rot noted during a post-outage inspection of a downed tree would have been observed by an inspector in its pre-failure state?

(3) Is it reasonable and defensible to consider a historical failure tree with a single indicator of fruiting bodies as a presumably avoided historical failure?

Discussions with both PG&E and external vegetation management SMEs were unable to provide conclusive answers to these questions and in acknowledgment of that uncertainty, this analysis erred on the side of caution by analyzing a wide range of all reasonable crosswalk parameter mapping combinations and considering the results as a quasi-distribution of possible outcomes with regard to an overall presumed historical effectiveness value, rather than defining a single crosswalk classification translation with a high degree of uncertainty.

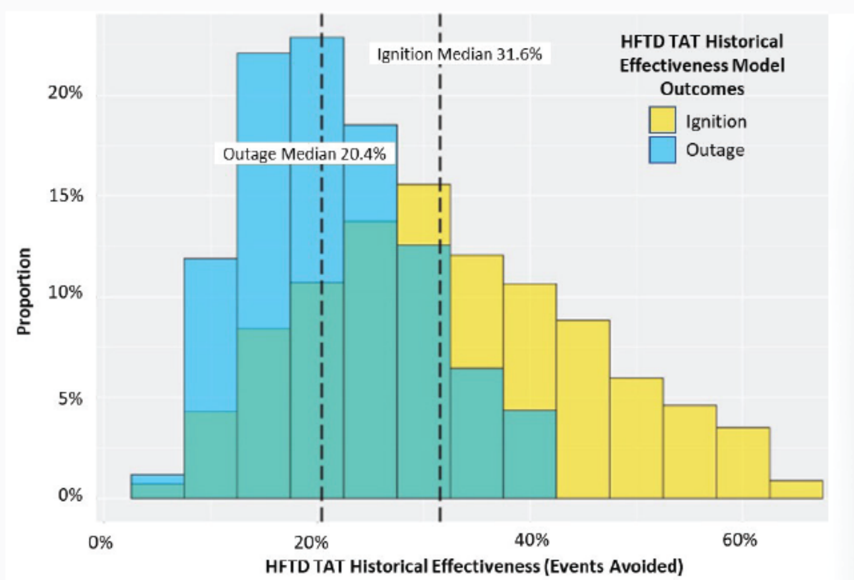
Tree mortality and significant insect damage Boolean EVM TAT parameters were held constant as unambiguous parameters. A range of possible combinations for O&I trees with major wound and fruiting bodies was employed. Care was taken to avoid illogical combinations of parameters. For example, only the slight severity of interior or exterior rot likely would not constitute the presence of fruiting bodies. All logical combinations of the O&I parameters for fruiting bodies and major wounds were evaluated, including the omission of each (e.g., configurations where each and all values of the fruiting bodies O&I parameter mappings were treated as being "false"). Reasonable crosswalk classification parameter mappings were compiled into a total of 765 different model configurations to be evaluated for historical effectiveness of the EVM TAT.

The TAT Historical Effectiveness results were modeled further to account for uncertainties using fuzzy logic[2]. This approach attempts to consider "real-world" factors, including: (1) the range of knowledge, experience, and overall performance of inspectors; (2) subjectivity in assessing a tree; (3) occasional errors, omissions, or mistakes made during the inspection; and (4) variable time lag between an abate decision and actual removal. These uncertainties were addressed by applying a range of simple programmatic effectiveness weights to the counts of hypothetically avoided outages and ignitions associated with each crosswalk configuration. Programmatic effectiveness weights were applied in 10% increments from 50% – 100% correct associations, creating 4,590 distinct model outcomes.

For clarity, the definition of TAT Historical Effectiveness (in this case) is the proportion of historical outages and ignitions that would have been abated using the four TAT Boolean parameters: Tree Mortality (24% of abatements), Fruiting Bodies (6% of abatements), Major Wounds (20% of abatements), and Insect Attack (4% of Abatements). These four Boolean parameters account for 56% of TAT abatement decisions.

Results

With all crosswalk configurations analyzed, TAT effectiveness values are presented in Figure 2.26. The range of values between the 25th and 75th percentiles are considered representative of the HFTD TAT Historical Effectiveness. TAT historical effectiveness for ignitions ranges from 22.7% – 42.1%, with a median of 31.6%. Outages range from 15.3% to 27.1%, with a median of 20.4%.



HFTD TAT Historical Effectiveness

	Ignitions	Outages
Minimum	5.4%	4.9%
25th Percentile	22.7%	15.3%
Median	31.6%	20.4%
Mean	32.7%	21.5%
75th Percentile	42.1%	27.1%
Maximum	64.5%	41.9%

Figure 2.26.
HFTD TAT Historical Effectiveness Model Results for Outage and Ignition Events Avoided.

[2] *Fuzzy logic builds into an analysis "degrees of truth" instead of simply "true or false" (1 or 0) Boolean logic. It can account for uncertainty based on "real-world" imprecise and/or non-numerical information.*

Discussion

Comparing the TAT Historical Effectiveness values for both ignitions and outages to the cumulative TAT 56% abatement rate suggests that these four Boolean parameters over-represent their combined abatement contribution to the TAT model. Consider that a median of 31.6% and 20.4% of historical ignitions and outages, respectively, had features that the TAT model would have identified and abated. Yet, 56% of the TAT abatements are coming from these same parameters, suggesting an over-abatement. It is potentially a good outcome, as it is conservative. But, the question remains, with the other 44% TAT parameter abatement outcomes, how are the outstanding non-prevented outages (79.6%) and ignitions (68.4%) being addressed? Would the remaining abatement parameters have sufficiently captured and abated these legacy vegetation-caused outages and ignitions? The TAT white paper (PG&E Vegetation Tree Assessment Tool Development and Application, November 19, page 5) notes that 76% of fire season outages and 82% of ignitions originate from "green trees" with "no health or structural issues."

"In keeping with the direction provided in 18-10-007, the TAT does not direct removal of trees that have no signs of health issues or structural defect. However, it does provide a species wildfire risk rating based on regional outage and ignition data considering the frequency of the species in the population. Only species determined to be of highest risk will be removed when exhibiting minor health or structural issues. Species with lower risk require a greater degree of health or structural issues to result in removal. However, it must be recognized that in complying with 18-10-007, the risk posed by trees exhibiting no health or structural issues remains unmitigated. Trees in this category were responsible for 76 percent of the May–November vegetation-caused outages in HFTD 2012-20191 and 82 percent of the HFTD vegetation-caused ignitions for the same time frame."

Thus, 24% and 18% of outages and ignitions, respectively, occur from trees with outward defects (such as those represented in the four TAT Boolean parameters. When compared to these values, better alignment is seen to the HFTD historical effectiveness results (31.6% and 20.4%, respectively). Yet, if the significant tree lean towards facilities parameter were added, 80% of the TAT abatements are coming from trees with health or structural issues that qualify for abatement under the Boolean portion of the TAT. This appears to show an imbalance.

There is an opportunity to add other tree parameters to the TAT model that includes risk factors to assets for trees, regardless of health and structural issues. A large body of work (much of it conducted by PG&E) employs LiDAR metrics, such as overstrike distance, fall pathways to assets, tree position slope to alignment, and canopy exposure to wind. A focus on these metrics have been demonstrated to be key identifiers of risk (to strike an asset), associated with all trees, including green trees. Further, these parameters can be calculated and applied without increasing field inspection duties (Reference: PG&E Tree Risk Score Back Testing Results). Adding LiDAR metrics is a proven way to speed EVM program operational velocity, automate and standardize assessments, and include green trees into the TAT model. That said, it is not trivial and warrants a master plan for EVM adoption. The benefit PG&E enjoys is that PG&E invented, operationalized, and maintains the largest LiDAR VM program in North America.

Recommendation 4: Harmonize Outage and Ignition (O&I) data with TAT data parameters. Complete all O&I data fields during investigations. To the best extent possible, perform a retroactive TAT analysis on future O&I trees. Where possible, associate the O&I tree with a LiDAR tree segmentation ID.

Recommendation 5: Increase green tree abatement rates for trees with no obvious defects. To identify green tree risk (to strike an asset), consider scored abatements that add LiDAR metrics for overstrike distance, fall pathways to assets, tree position slope to alignment, and canopy exposure to wind.

2.8 EVM “Clear” Effectiveness Evaluation

This effort compares ignitions in EVM Clear and Not-Clear circuit segments. From September 15, 2009, to June 6, 2021, 259 ignitions occurred, 32 were manually reviewed, and potentially 11 of these occurred on EVM Clear circuit segments.

Methods

The EVM Clear effectiveness analysis was conducted utilizing the following three PG&E enterprise datasets to determine the occurrence of ignitions on segments after they had passed work verification (EVM Clear). Three input datasets were utilized for the analysis:

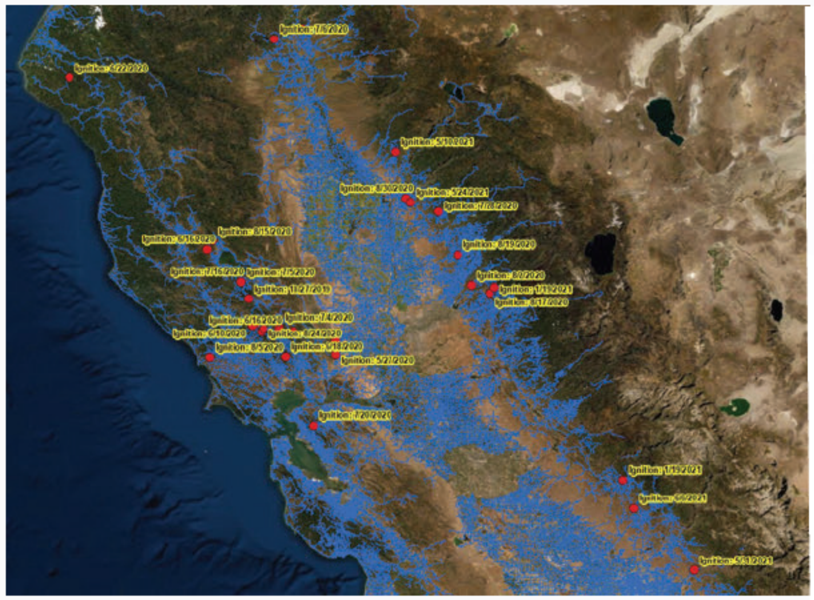
- IGNITIONS DATABASE
- EVM CLEAR SEGMENTS
- EDGIS CIRCUITS

The Ignitions Database was joined to the Outage Database for additional information, but there were ignition records that did not have a corresponding outage record. All ignitions that occurred during the timeframe of analysis contained location information. The EDGIS Circuits data included many asset-related fields but did not contain the same unique circuit segment identifiers as are present in the EVM Clear Segments dataset.

The EVM Clear Segments were mapped with the goal of cross-referencing with ignition locations. The EVM Clear Segments data consisted of attributes for circuit name, unique segment identifier, work verification status, and work verified date. Figure 2.27 illustrates the locations of ignitions considered for analysis and shows the features provided in the EVM Clear database. A significant portion of the Work Verification Status and Date fields are "NULL," indicating that they have not been through the EVM Clear procedure yet.

Temporally, data were included from the first date of any segment passing EVM Clear inspection to the most current ignition available in received datasets. The date range for included EVM Clear Segments was September 15, 2019, to June 6, 2021, and the Ignitions Database was subset to this range as well. This temporal subset resulted in 259 ignitions remaining for analysis.

From the 259 ignitions remaining after the temporal subset, only those within 500 meters of any circuit segment designated as passing EVM Clear inspection were selected for further analysis as an ignition that may have occurred on an EVM Clear Segment. The following steps were employed to spatially identify ignitions relative to EVM Clear Segments:



UNIQUE_SEGMENT_ID	CIRCUITNAME	WORK_VERIFICATION_STATUS	WORK_VERIFIED_DATE
CIL_AK116-L22_9803	LUCERNE 1106	<Null>	<Null>
CIL_AK117-D07_9804	LUCERNE 1106	<Null>	<Null>
CIL_AK116-L12_9805	LUCERNE 1106	<Null>	<Null>
CIL_AK116-L12_9806	LUCERNE 1106	<Null>	<Null>
CIL_AK116-L17_9807	LUCERNE 1106	<Null>	<Null>
CIL_AK116-L17_9808	LUCERNE 1106	<Null>	<Null>
CIL_AK116-L12_9809	LUCERNE 1106	<Null>	<Null>
CIP_AV116-D01_364894	BRUNSWICK 1106	<Null>	<Null>
CIP_AV116-D01_364895	BRUNSWICK 1106	<Null>	<Null>
CIP_AV116-D01_364896	BRUNSWICK 1106	<Null>	<Null>
CIP_AV116-D01_364897	BRUNSWICK 1106	<Null>	<Null>
CIP_AW116-A10_397318	BRUNSWICK 1106	Work Verification Pass	11/29/2019 12:16:00 PM
CIP_BE125-O04_613577	OAKHURST 1101	Work Verification Pass	7/31/2021 11:25:00 AM
CIP_AY118-I14_472215	APPLE HILL 2102	<Null>	<Null>
CIP_AW116-A04_398864	BRUNSWICK 1106	Work Verification Pass	6/4/2020 6:01:00 PM
CIP_AW116-A04_398865	BRUNSWICK 1106	Work Verification Pass	6/4/2020 6:00:00 PM
CIE_AN107-K09_1763297	STILLWATER 1102	Work Verification Pass	7/31/2021 11:38:00 AM

Figure 2.27. EDGIS Circuit Segment Locations and Manually Reviewed Ignitions Illustrate the Locations of Ignitions Considered for Analysis and Show the Features Provided in the EVM Clear Database

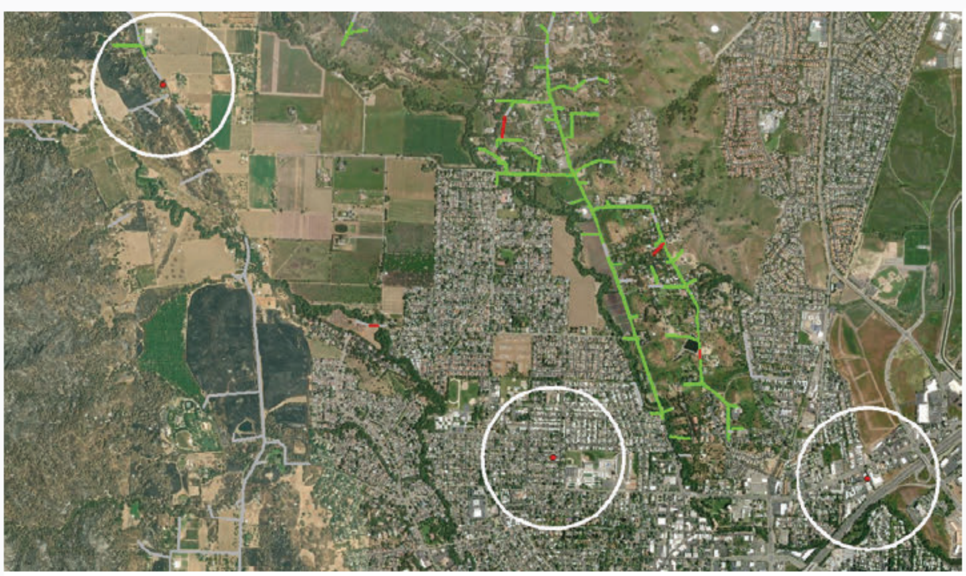
- Assume that any ignition not within 500 meters of inspected EVM Clear Segments would not reasonably be associated with those segments. The 500-meter threshold was determined empirically by inspecting and analyzing the Ignitions Database, EVM Clear Segments, and EDGIS Circuit datasets to assess the potential impact of significant positional error and uncertainty in each dataset.

- If any ignition was further than 500 meters from an EVM Clear Segment, it was unlikely to be associated with that segment and would be difficult to assess even if it were.
- This spatial subset reduced the dataset to 32 ignitions (from the previous 259 ignitions).

Figure 2.28 illustrates the 500-meter buffer around ignition record locations and offsets to circuit segment locations in the EVM Clear dataset. Due to the offsets, a manual review was further conducted for each of the 32 ignitions to determine which of these ignitions may have potentially occurred on circuit segments after they had passed EVM Clear status inspection. The following key methods were employed during the manual inspection process:

- Consideration was given to positional uncertainty and error amongst the three geospatial datasets to identify the most likely circuit segment associated with each ignition.
- Challenges included positional discrepancies and error between the EVM Clear dataset and the EDGIS dataset, as well as general uncertainty associated with ignition location accuracy (Figure 2.29 - page 42).
- For any ignition assessed to be potentially associated with an EVM Clear segment after it was inspected, the unique segment identifier was appended to the ignition record to facilitate any additional follow-on analysis or research with additional datasets or reports.
- For each of the ignitions reviewed, a confidence level (i.e., low, medium, or high) was noted to represent a general level of certainty regarding the ignition/circuit segment association. Additionally, a brief comment was included to describe the general scenario and clarifying information that may be pertinent to further analysis.

Figure 2.28. Map of Spatial Join with EDGIS Segments and Ignition Locations with 500-Meter Buffer



Results

In summary, from September 15, 2019, to June 6, 2021, there were 259 ignitions recorded in the PG&E Ignition Database. Of the 32 ignitions that were manually reviewed, 11 were determined to have been potentially associated with an EVM Clear Circuit Segment after it had been inspected.

Figure 2.29. Map of Spatial Offsets with EVM Clear Segments (Green and Gray), EDGIS Segments (Yellow), and Ignition Location (Red)

Count	EVM Clear Effectiveness
11 Ignitions	4.2% of ignitions possibly occurred on EVM clear circuit segments following inspection.
248 Ignitions	95.8% of ignitions possibly occurred on circuit segments which had not been worked and inspected as EVM clear.
259 Ignitions Total	100% of All Ignitions that occurred between 9/15/2019 to 6/6/2021

Given the positional uncertainties with associating the three datasets; Ignitions Database, EVM Clear Segments, and EDGIS Circuits, a confidence level was applied to the manual selection of the 11 ignitions that possibly occurred on EVM Clear Circuits following inspection to describe the general level of confidence regarding the ignition to EVM Circuit matching. The percentages of each confidence category are shown in Figure 2.30.

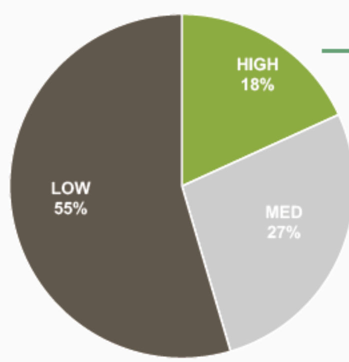


Figure 2.30. Confidence Level of Location/Position Manually Inspected for 11 Ignitions.

Discussion

This analysis only underscores the need to have O&I data recorded with accurate positions. And, it is equally important to use the accurately positioned circuit digital twin vectors to represent EVM segments. These types of analysis can become automated and routine and far less subjective. This is merely a restatement of Recommendation 2.

3. FUTURE CONSIDERATIONS FOR IMPROVING THE TREE ASSESSMENT TOOL (TAT)

3.1 Ecoregion Delineated Regional Species Fire Risk Rating[3]

The Regional Species Fire Risk Rating (RSFRR) is an important TAT scoring component that aggregates a metric for legacy vegetation-caused outages and ignitions by species across each of the six PG&E administrative regions. PG&E designed the RSFRR parameter specifically to address root and trunk failure events occurring during fire season months (i.e., May through November). It is recommended that aggregation should instead use ecoregions using the same legacy data and algorithm.

What is an Ecoregion?

The Environmental Protection Agency (EPA) has identified and categorized ecoregions (i.e., spatially defined zones where ecosystem characteristics are generally homogenous) at various spatial scales throughout North America. The EPA's ecoregion delineations incorporate vegetation, climate, land use, wildlife, hydrology, geology, landforms, and soils to define ecoregions at four spatial scales increasing in detail from Level I to Level IV (Omernik and Griffith, 2014). Ecoregions provide a spatial framework that is more meaningful from an environmental geospatial perspective by facilitating the aggregation of historical vegetation-caused outages and ignitions into zones defined by characteristics with increased relevance to wildfire risk.

Methodology

The RSFRR parameter provides a species-specific index that characterizes the wildfire risk throughout PG&E's service territory. The RSFRR, as currently implemented in the EVM TAT model, is a scored parameter based on the species-specific frequency of historical trunk- and root-failure-caused outages and ignitions (with additional weight applied to ignitions) as the proportion of the total tree species population (Figure 3.1). In other words, a tree species associated with more outages and ignitions than that species' proportion of the overall tree population would be considered to represent a greater likelihood of causing outages and ignitions and thus assigned a higher RSFRR value. Higher RSFRR values represent a greater likelihood of causing outages and ignitions.

Figure 3.1. Regional Species Fire Risk Rating Calculation

$$\frac{\text{\% regional root and trunk outages caused by species}}{\text{species \% of total regional tree population}} + 1.5\,X\;\frac{\text{\% regional root and trunk ignitions caused by species}}{\text{species \% of total regional tree population}}$$

[3]See Appendix D: Ecoregion Analysis for greater detail.

Currently, RSFRR values are spatially aggregated and calculated within each of PG&E's six administrative regions (i.e., Bay, Central Coast, Central Valley, North Coast, North Valley, and Sierra regions) to derive a unique RSFRR for each species. Reference species composition (i.e., the relative percentage of the total tree population represented by each species in each region) was calculated using PG&E's routine vegetation work history management database to serve as an estimate of the overall tree species population. PG&E used the 2016 – 2017 vegetation inspection cycle to estimate the reference species composition as a "snapshot" of the tree population. The regional focus was intended to help capture species-specific geographic trends that may be related to environmental, anthropogenic, and/or asset-related variables throughout PG&E's distribution service territory.

The RSFRR parameter is incorporated into the environment score component of the EVM TAT model and has a weak relationship to abatement outcomes (see Section 2.1 TAT Abatement Decision Tree). The RSFRR values for each species and region combination are classified into four classes, with each being assigned a numeric score value ranging from 5 to 36 and then added to the other environmental scoring parameters (which are also all weak or negligible in affecting abatement outcomes). Only 20% of abatements come from the scored parameters, and RSFRR is a weak parameter in a weak category, as the model is current deployed.

Two primary opportunities for potential improvement of the RSFRR calculation and implementation are as follows:

1. Enhancing the spatial aggregation defining the regional component of the RSFRR using the EPA's Level III Ecoregions (as opposed to PG&E's administrative regions)
2. Increasing the robustness of the reference species composition analysis by incorporating multiple vegetation management annual inspection cycles to assess the sensitivity of selecting any single annual inspection cycle and provide a larger dataset from which to determine the regional tree species composition

Level III Ecoregions were assessed to provide the most meaningful balance between level of detail and the number of regions used for RSFRR analysis, such that the regions are not so small as to result in very low counts of outages and ignitions per species in each region. PG&E's distribution service territory intersects nine of the EPA Level III Ecoregions, and HFTD Tier 3 and Tier 2 areas intersect five of those ecoregions that contain historical outages and ignitions: 1) Cascades; 2) Central California Foothills and Coastal Mountains; 3) Coast Range; 4) Klamath Mountains/California High North Coast Range; and 5) Sierra Nevada (Figure 3.2) (page 45).

The temporal sensitivity associated with using a single, annual vegetation management inspection cycle was

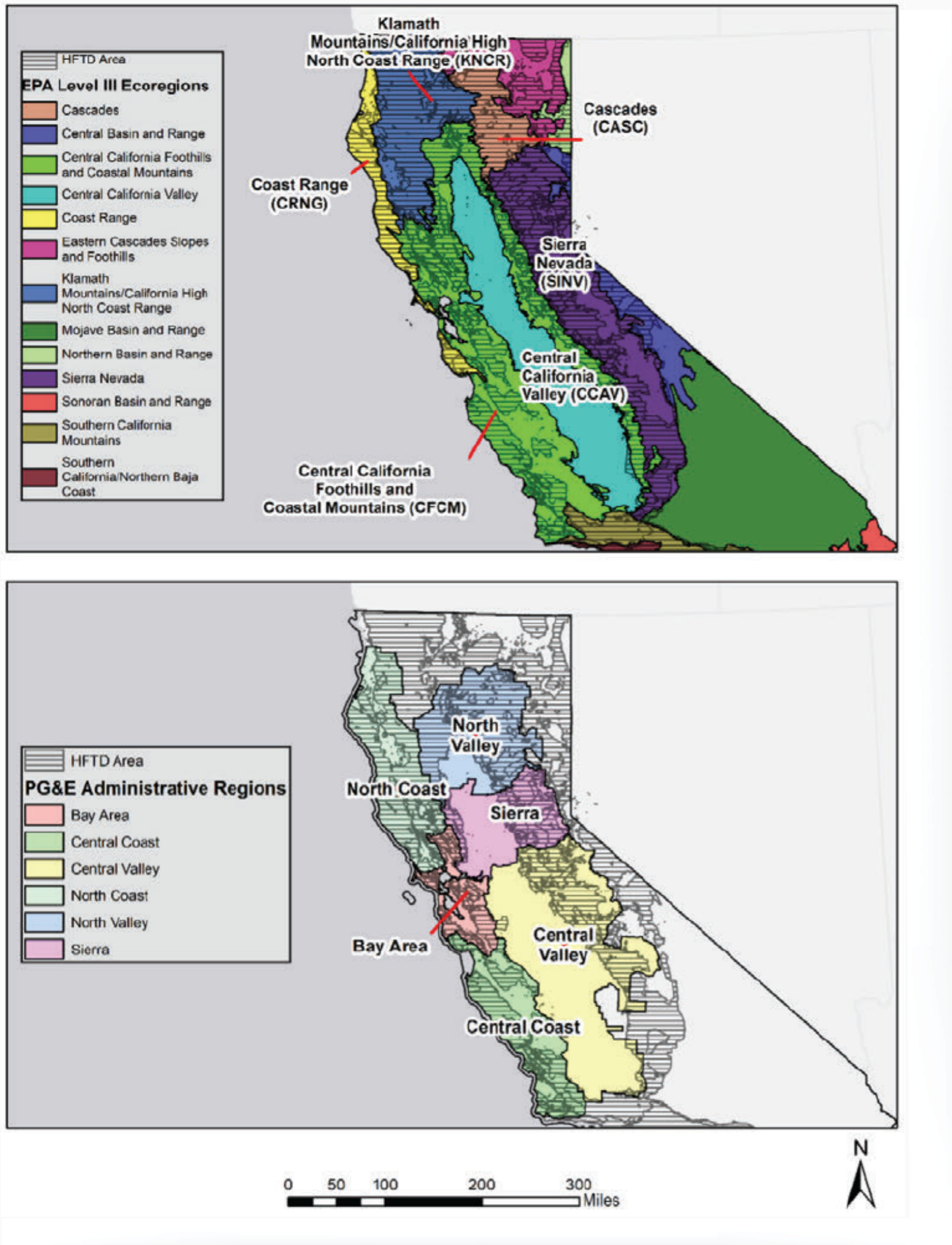


Figure 3.2. Overview Map Depicting EPA Level III Ecoregions (top panel) and PG&E Administrative Regions (bottom panel), with CPUC HFTD Areas Indicated by Horizontal Black Hatching

assessed by increasing the time-frame of analysis to 2013 – 2020 (the maximum number of available inspection cycles deemed useable from the distribution routine work history database). This subset of the distribution routine work history database consisted of approximately 38 million records and formed the basis of the multi-year, ecoregion-based species composition calculations.

The primary PG&E datasets used to enhance the RSFRR parameters were: 1) historical PG&E distribution O&I database, 2) PG&E distribution routine vegetation management work history database, and 3) EVM TAT inspection records database. Initial data filtering and cleaning steps omitted unusable or obviously erroneous data (where possible), spatially and temporally constrained the datasets to the relevant areas and periods of interest (e.g., HFTD areas and fire season months), and maintained consistency with the existing RSFRR methodology to provide a meaningful comparison. The overall temporal range of the historical outage and ignition data, after the described filtering, was from October 2007 through June 2021 and consisted of approximately 4,717 tree failures caused by root or trunk failure mechanisms. The routine work history database was similarly filtered, except no fire season temporal filtering was performed as this dataset is used to estimate the regional tree species composition. A mean species composition of the seven annual inspection cycles was calculated. With the reference species compositions estimated, the historical outages and ignitions caused by root and trunk failures were analyzed in each ecoregion.

The total numbers of outages and ignitions per ecoregion were summed, and the species-specific outage and ignition counts per ecoregion were divided by these regional totals to determine the percentages of outages and ignitions in each ecoregion. Significant species are those responsible for greater than 1% of the outages or ignitions in a particular ecoregion, consistent with the existing RSFRR methodology.

Results

The boxplots in Figure 3.3(A)-(F) show the RSFRR values for significant species in each of the five ecoregions, as well as the overall HFTD aggregate (i.e., treating the entire HFTD as one single region). The sensitivity of annual inspection cycle variations (reference species composition, i.e., denominator of the algorithm) creates each boxplot range (25th to 75th percentile). This variability is introduced by the annual inspection cycle process/database, as the species composition (of trees) is likely changing interannually. Regardless, using multiple annual inspection cycles increases analysis robustness.

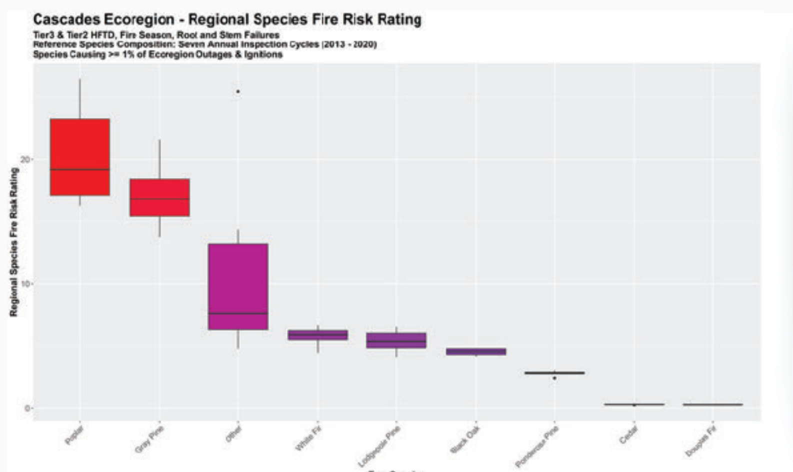


Figure 3.3. (A) RSFRR CASCADES Ecoregion Results

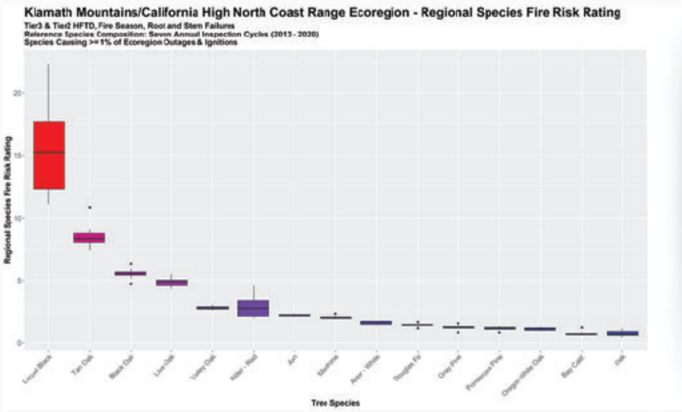


Figure 3.3. (B) RSFRR KLAMATH Ecoregion Results

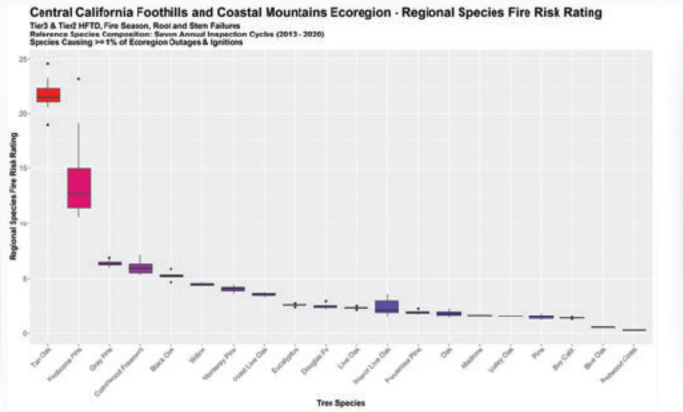


Figure 3.3. (C) RSFRR CENTRAL FOOTHILLS Ecoregion Results

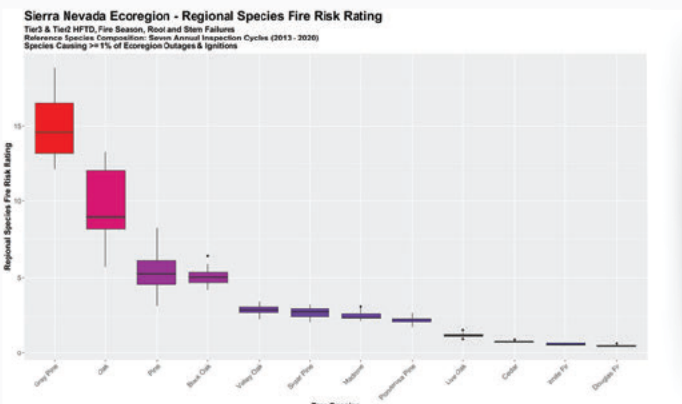


Figure 3.3. (D) RSFRR SIERRA NEVADA Ecoregion Results

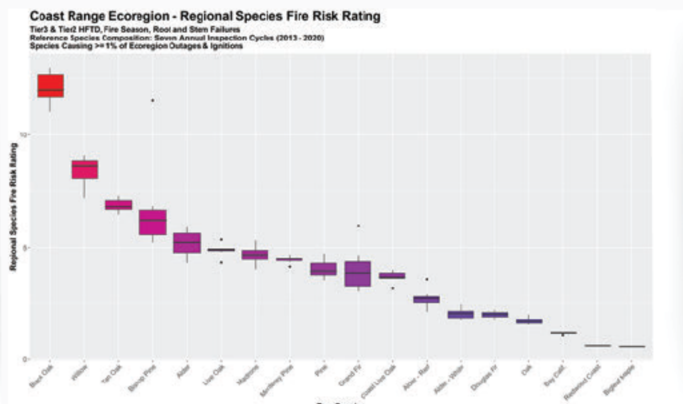


Figure 3.3. (E) RSFRR COAST RANGE Ecoregion Results

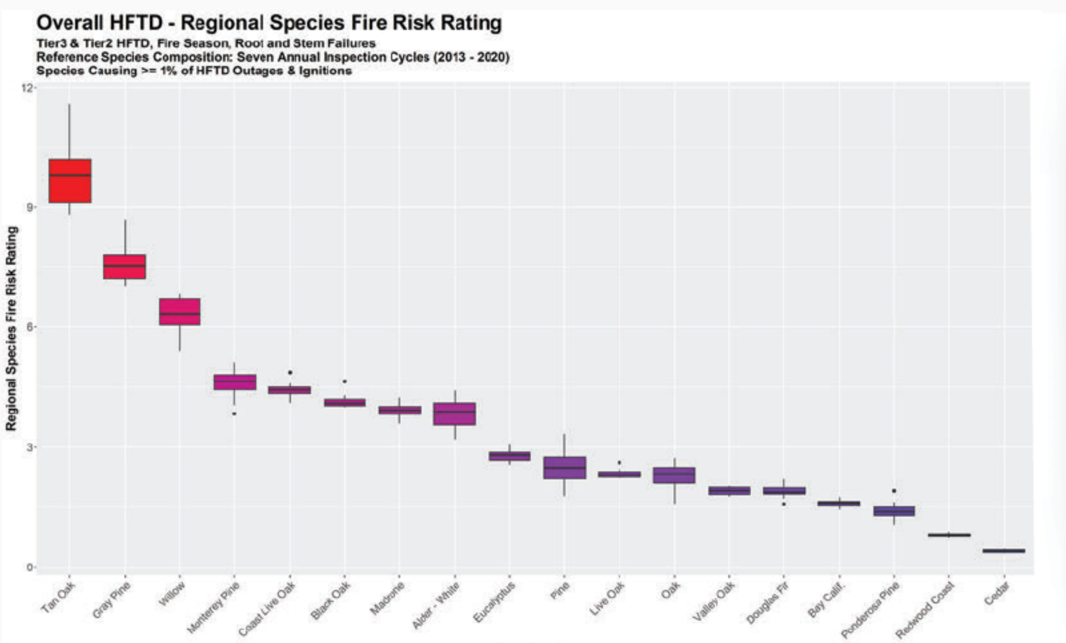


Figure 3.3. (F) RSFRR OVERALL HFTD Ecoregion Results

There are differences in TAT abatements that manifest from the ecoregion aggregation compared to the currently used PG&E administrative region aggregations. That said, these abatement differences are small in net effect when employing the TAT methodology (see Figure 3.4).

These results provide the opportunity to employ Recommendation 3: Track TAT abatement species compositions and compare to outage and ignition species distributions. Note potential over-/under-abatements. Over time, this can serve as a programmatic KPI.

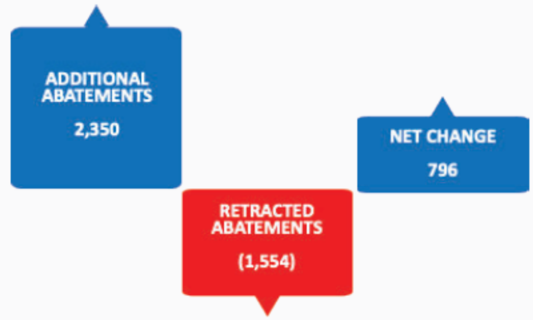


Figure 3.4. Resulting Abatement Changes Resulting from Ecoregion RSFFR for Entire HFTD

When considering abatement changes induced by ecoregion RSFFR, species variability becomes evident. The total number of abatement changes by species is shown in Figure 3.5(A). What is more informative is how these changes compare to the total abatement species composition (e.g., the percentage change in abatement species population), as shown in Figure 3.5(B). While the net effect is only 0.6%, some species have increased abatement populations of 6-9% (Ponderosa Pine, Coastal Live Oak, Eucalyptus, Interior Live Oak, and Sugar Pine. Notable reduction in abatement species population -6-8% are Gray Pine, Monterey Cypress, and Poplar.

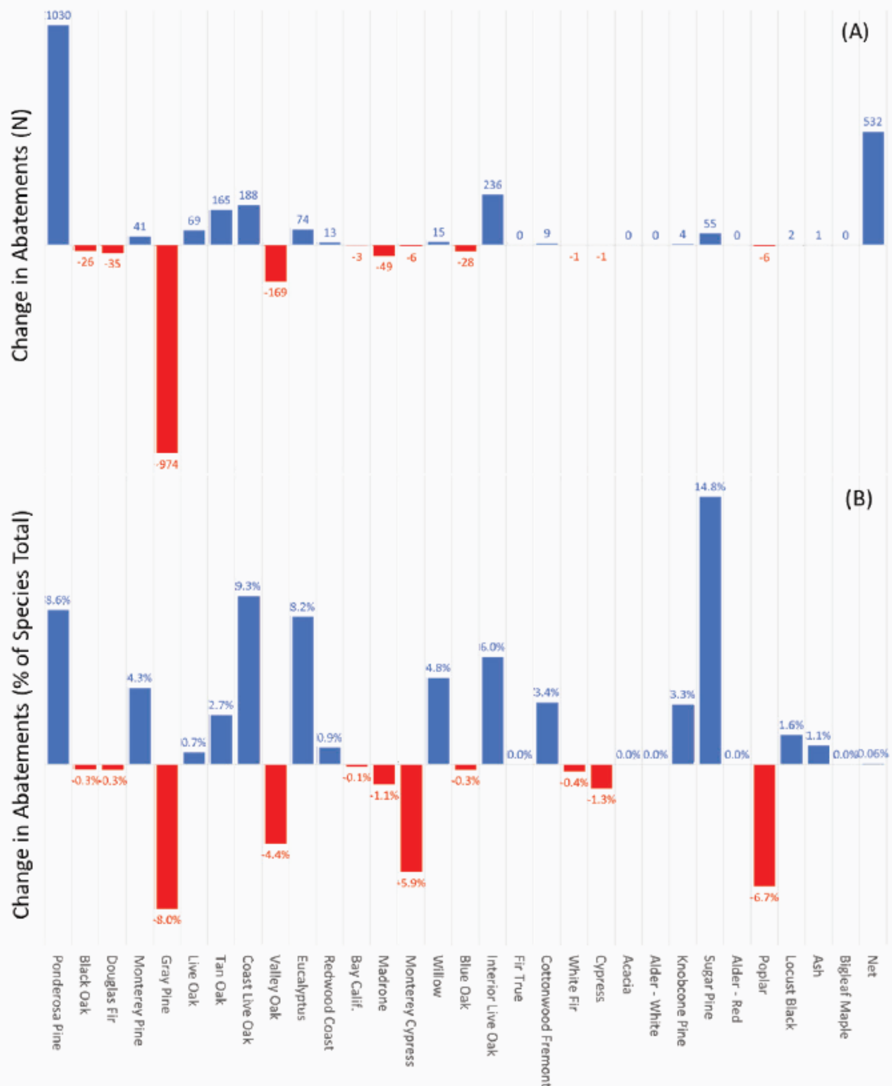


Figure 3.5. Resulting Abatement Changes by Tree Species (for Top 95th Percentile of Outage Species) Resulting from Ecoregion RSFFR for Entire HFTD

To determine for which species the ecoregion RSFFR aligns better (and worse) to O&I species than the current model, the differences (deltas) between the TAT abatement and outage (fall-in) tree species proportions were calculated (Figure 3.6). An additional calculation yields the differences in these deltas as:

Measure of Movement from Outage Species Proportions

$$ABS(\text{Abatement Rate}_{\text{Ecoregion RSFFR}} - \text{Outage Rate}) - (\text{Abatement Rate}_{\text{Current RSFFR}} - \text{Outage Rate}) = \pm 0.5\%$$

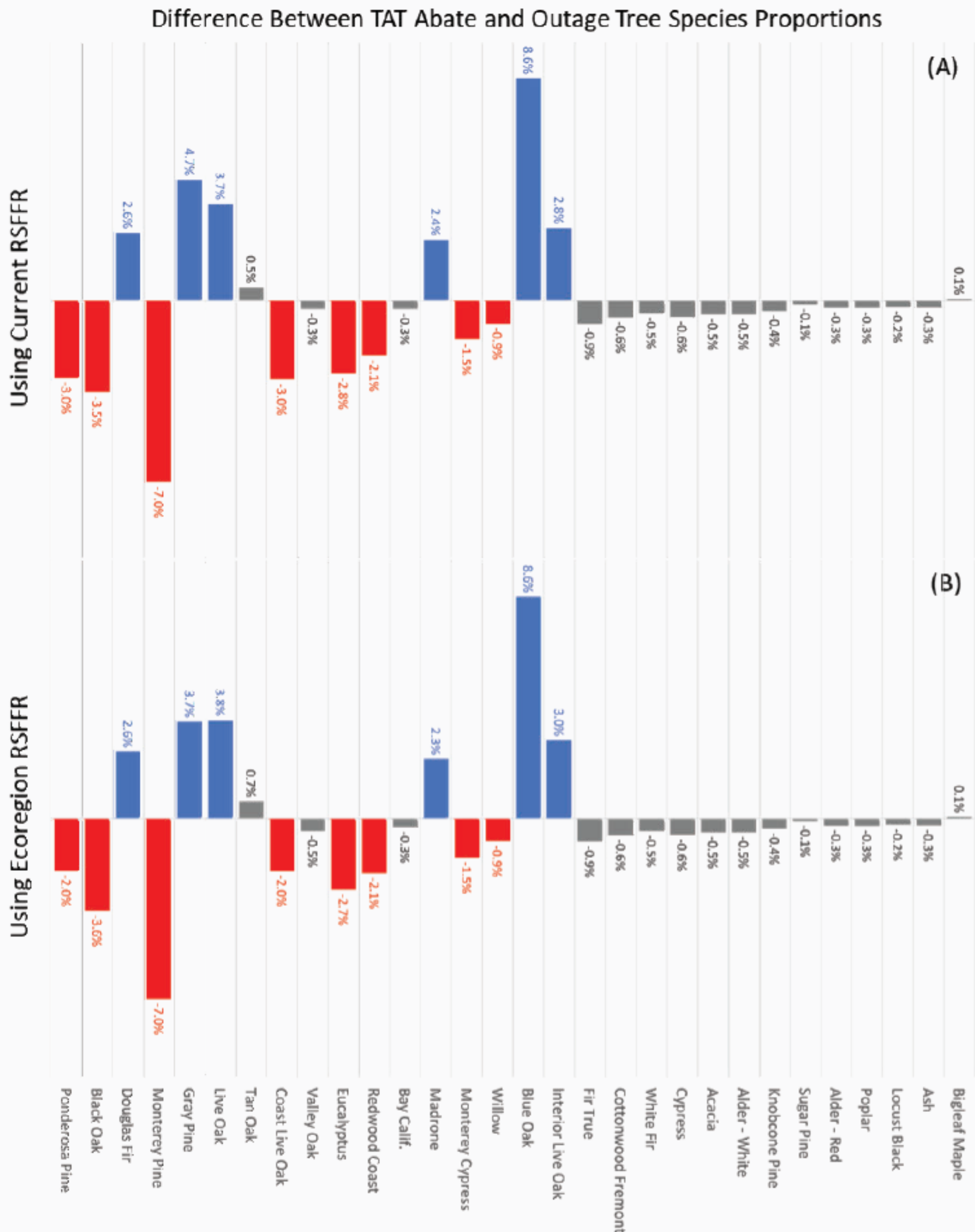


Figure 3.6.
TAT Abatement Tree Species Proportions Compared to Outage Tree Proportions Using (A) Current RSFFR and (B) Ecoregion RSFFR

This sets a threshold that essentially determines which TAT abatement species moved closer to the outage species population (-0.5%). In this case, it was found that three species (noted in Blue below) showed greater alignment with O&I species outage ranks. Just as important, no abatement tree species diverged from the outage species populations above this threshold (0.5%). Using this metric, it can be said that three major TAT abated species improved alignment with O&I species using ecoregion RSFFR, while no TAT abatement species degraded (or diverged above the threshold, the largest being interior live oak, at 0.2%).

Top 95th Percentile Outage (Fall-In) Species as Proportion of Total Respective Populations (%)

	TAT Abatement Rank & Proportion		
Outage Rank & Proportion	**Using Current RSFFR**	**Using Ecoregion RSFFR**	**Measure of Movement from Outage Species Proportions**
1. Ponderosa Pine (14.41%)	1. Douglas Fir (12.17%)	1. Ponderosa Pine (12.40%)	1. Ponderosa Pine (-0.98%)
2. Black Oak (12.96%)	2. Gray Pine (11.60%)	2. Douglas Fir (12.13%)	2. Black Oak (0.02%)
3. Douglas Fir (9.54%)	3. Ponderosa Pine (11.43%)	3. Gray Pine (10.67%)	3. Douglas Fir (-0.03%)
4. Monterey Pine (7.93%)	4. Blue Oak (9.76%)	4. Live Oak (9.74%)	4. Monterey Pine (-0.04%)
5. Gray Pine (6.92%)	5. Live Oak (9.67%)	5. Blue Oak (9.74%)	5. Gray Pine (-0.92%)
6. Live Oak (5.93%)	6. Black Oak (9.43%)	6. Black Oak (9.41%)	6. Live Oak (0.07%)
7. Tan Oak (5.18%)	7. Tan Oak (5.70%)	7. Tan Oak (5.86%)	7. Tan Oak (0.16%)
8. Coast Live Oak (4.11%)	8. Madrone (4.25%)	8. Madrone (4.20%)	8. Coast Live Oak (-1.03%)
9. Valley Oak (4.00%)	9. Interior Live Oak (3.76%)	9. Interior Live Oak (3.98%)	9. Valley Oak (0.16%)
10. Eucalyptus (3.67%)	10. Valley Oak (3.67%)	10. Valley Oak (3.51%)	10. Eucalyptus (-0.07%)
11. Redwood Coast (3.43%)	11. Bay Calif. (2.72%)	11. Bay Calif. (2.72%)	11. Redwood Coast (-0.01%)
12. Bay Calif. (3.05%)	12. Redwood Coast (1.30%)	12. Coast Live Oak (2.09%)	12. Bay Calif. (0.00%)
13. Madrone (1.90%)	13. Coast Live Oak (1.06%)	13. Redwood Coast (1.32%)	13. Madrone (-0.05%)
14. Monterey Cypress (1.59%)	14. Monterey Pine (0.92%)	14. Monterey Pine (0.95%)	14. Monterey Cypress (0.01%)
15. Willow (1.18%)	15. Eucalyptus (0.86%)	15. Eucalyptus (0.93%)	15. Willow (-0.01%)
16. Blue Oak (1.15%)	16. Bigleaf Maple (0.40%)	16. Sugar Pine (0.40%)	16. Blue Oak (-0.03%)
17. Interior Live Oak (0.95%)	17. Sugar Pine (0.35%)	17. Bigleaf Maple (0.40%)	17. Interior Live Oak (0.22%)
18. Fir True (0.90%)	18. Willow (0.30%)	18. Willow (0.31%)	18. Fir True (0.00%)
19. Cottonwood Fremont (0.89%)	19. Cottonwood Fremont (0.25%)	19. Cottonwood Fremont (0.26%)	19. Cottonwood Fremont (-0.01%)
20. White Fir (0.73%)	20. White Fir (0.25%)	20. White Fir (0.25%)	20. White Fir (0.00%)
21. Cypress (0.70%)	21. Locust Black (0.12%)	21. Knobcone Pine (0.12%)	21. Cypress (0.00%)
22. Acacia (0.61%)	22. Knobcone Pine (0.11%)	22. Locust Black (0.12%)	22. Acacia (0.00%)
23. Alder - White (0.54%)	23. Monterey Cypress (0.10%)	23. Alder - Red (0.10%)	23. Alder - White (0.00%)
24. Knobcone Pine (0.51%)	24. Alder - Red (0.10%)	24. Monterey Cypress (0.09%)	24. Knobcone Pine (0.00%)
25. Sugar Pine (0.50%)	25. Ash (0.09%)	25. Ash (0.09%)	25. Sugar Pine (-0.05%)
26. Alder - Red (0.37%)	26. Acacia (0.08%)	26. Acacia (0.08%)	26. Alder - Red (0.00%)
27. Poplar (0.36%)	27. Poplar (0.08%)	27. Poplar (0.08%)	27. Poplar (0.01%)
28. Locust Black (0.35%)	28. Cypress (0.07%)	28. Cypress (0.07%)	28. Locust Black (0.00%)
29. Ash (0.35%)	29. Fir True (0.02%)	29. Fir True (0.02%)	29. Ash (0.00%)
30. Bigleaf Maple (0.33%)	30. Alder - White (0.02%)	30. Alder - White (0.02%)	30. Bigleaf Maple (0.00%)

Discussion

The ecosystem RSFFR model had a small net effect on TAT abatements but more closely aligns three major tree species abatement rates when compared to historical outage fall-in proportions, namely, Ponderosa Pine, Gray Pine and Coast Live Oak. Further, there was de minimis effect to the other TAT abatement species, meaning that those abatement rates did not change significantly. It has been demonstrated that updating the ecoregion RSFFR can be done annually using data records that span multiple years. Finally, Recommendation 3 was employed to measure TAT abatement rates against legacy O&I species to determine over-/under-abatement patterns by species.

Recommendation 6: Use EPA Level III Ecoregions to aggregate Regional Species Fire Risk Rating scores. Use multiple years of data to determine population counts. Update annually.

3.2 Wind Risk Scoring Using an Event-Driven Model (or Similar Risk Model)[4]

See Appendix E: Wind Model Development for the complete analysis.

Section 2.1 TAT Abatement Decision Tree discusses the finding that the wind risk score is statistically insignificant and has a negligible effect in creating TAT abatement outcomes. The data used for wind scoring lack dynamic range to assign the upper range of the wind score, with 99.6% of TAT records receiving the lowest "slight" wind score, 0.4% receiving a "moderate" wind score, and no trees assigned a "severe" score[5]. With virtually all trees receiving the same "slight" score (Figure 3.7), the wind score effectively dilutes the other environment parameters, in addition to rendering the wind score effect negligible in tree abatement decisioning. A different wind dataset and approach is warranted in the TAT. This section describes the methodology for evaluating wind conditions and historical O&I events. It also includes discussion of the modeling methodologies used in the analysis: the Simple Wind Score Model and the Comprehensive Wind Score Model. Results and discussion are also provided.

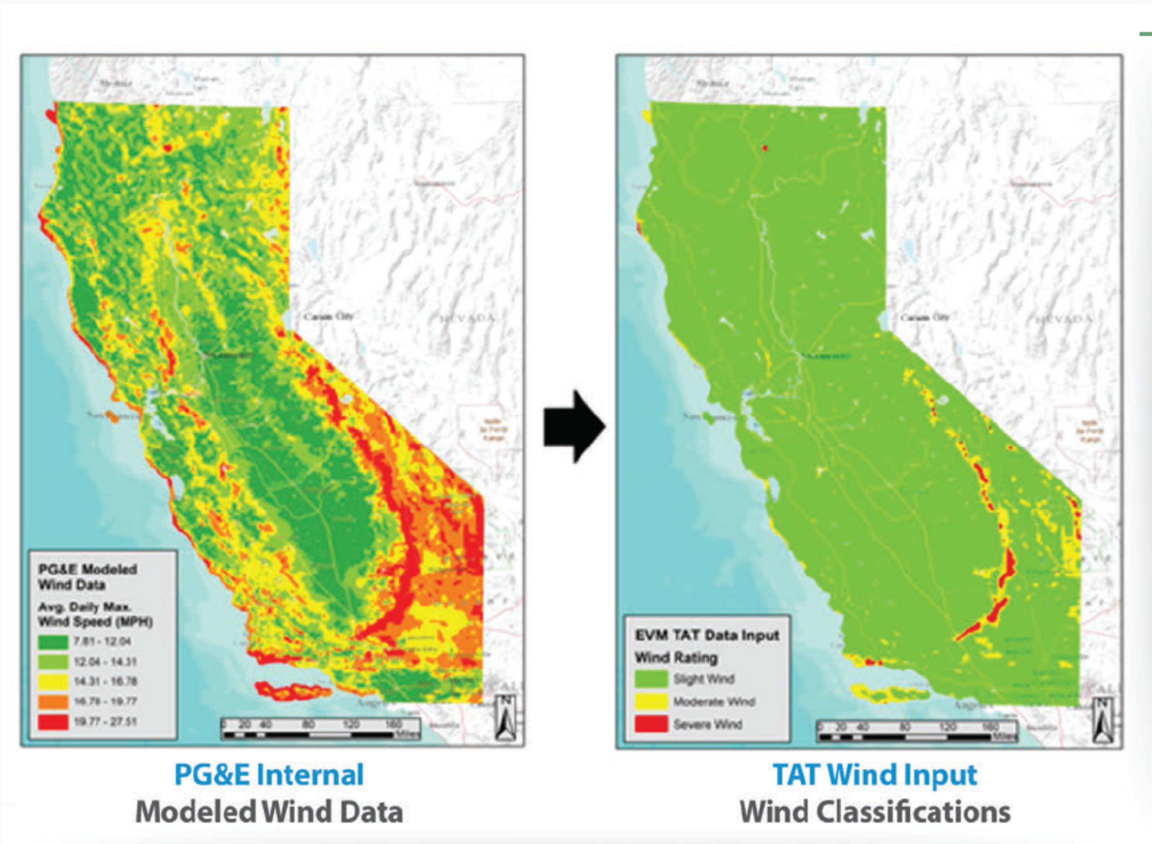


Figure 3.7. Data Currently Used (Right) for Wind Classification and TAT Scoring (Note that the Vast Majority is Classified as "Slight Wind" in Green)

[4] See Appendix E: Wind Model Development for greater detail.

[5] Wind score values of "slight," "moderate," and "severe" refer to the ordinal wind risk scores used in PG&E's original EVM TAT model. With respect to modeled average daily maximum wind speeds from May – November 2006 – 2019: "slight" = wind speed within less than one standard deviation of the average daily maximum wind speed; "moderate" = wind speed between one and two standard deviations of the average daily maximum wind speed; "severe" = wind speed greater than two standard deviations from the average daily maximum wind speed. Relevant details may be viewed in PG&E's "Vegetation Tree Assessment Tool Development and Application" document.

Methodology: Evaluation of Wind and Vegetation-caused O&I Events

The TAT ultimately needs a wind score parameter to capture the actual risk of wind for vegetation-caused outages. Outage and ignition data were categorized into two separate groups: Wildfire Season and Non-Wildfire Season. The total number of events per day were plotted as shown in Figure 3.8. Non-wildfire season days are shown in gray, whereas wildfire season days are shown in orange and red. From the figure, spikes are noted as days that had a higher number of vegetation-caused O&I events. High numbers of occurrence days are hypothesized to occur on high wind days and can therefore be potentially indicative of wind speeds causing increasing tree failures. A sensitivity analysis was conducted to identify a wind event threshold of 59 events per day to distinguish between high and low wind event dates (Group 1 ≥ 59 O&I event/day threshold, Group 2 < than 59 O&I event/day threshold).

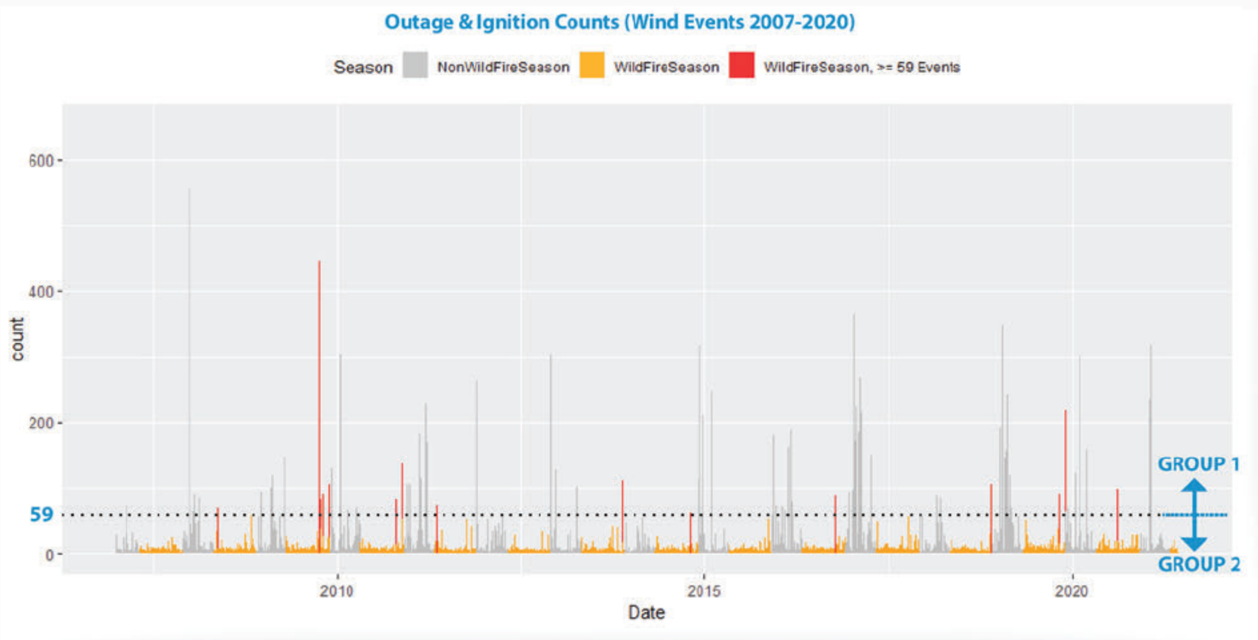


Figure 3.8. Outage Events: Total Number of Outage and Ignition per Day from 2007 to 2020: Group 1 is ≥ than Threshold of 59 O&I Events per Day (Group 2 is < than 59 O&I events per day)

The median of daily maximum wind speed was calculated for these two groups. The difference between two medians is plotted in Figure 3.9(A) (page 53). The higher the difference value, the bigger separation between two groups with maximum value at 59 tree failure events per day, with minimal differences after a threshold of 20. The distribution of daily maximum wind speed for all the days (wildfire season only) for groups 1 and 2 show separation in Figure 3.9(B) (page 53).

As an example, data from October 12-13, 2009 (in a wildfire month), illustrate the spatial correlation between the wind data and the O&I events (Figure 3.10). October 12th has calm winds and only 5 outages. October 13, 2009, experienced higher wind speeds (shown as red in Figure 3.10), corresponding to 446 events that occurred that date.

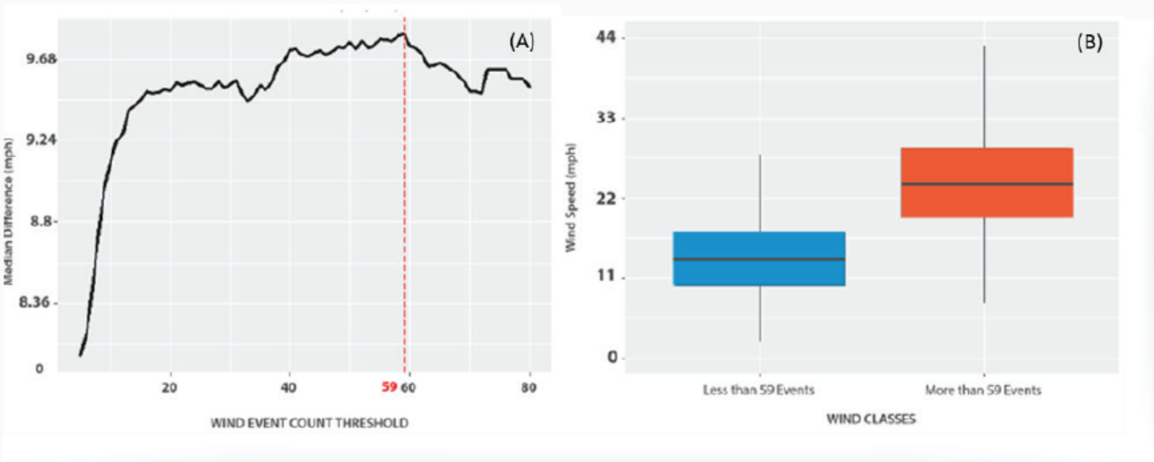


Figure 3.9. (A) Median Difference Between Group 1 and Group 2 and (B) Wind Speed Distribution within Respective Groups

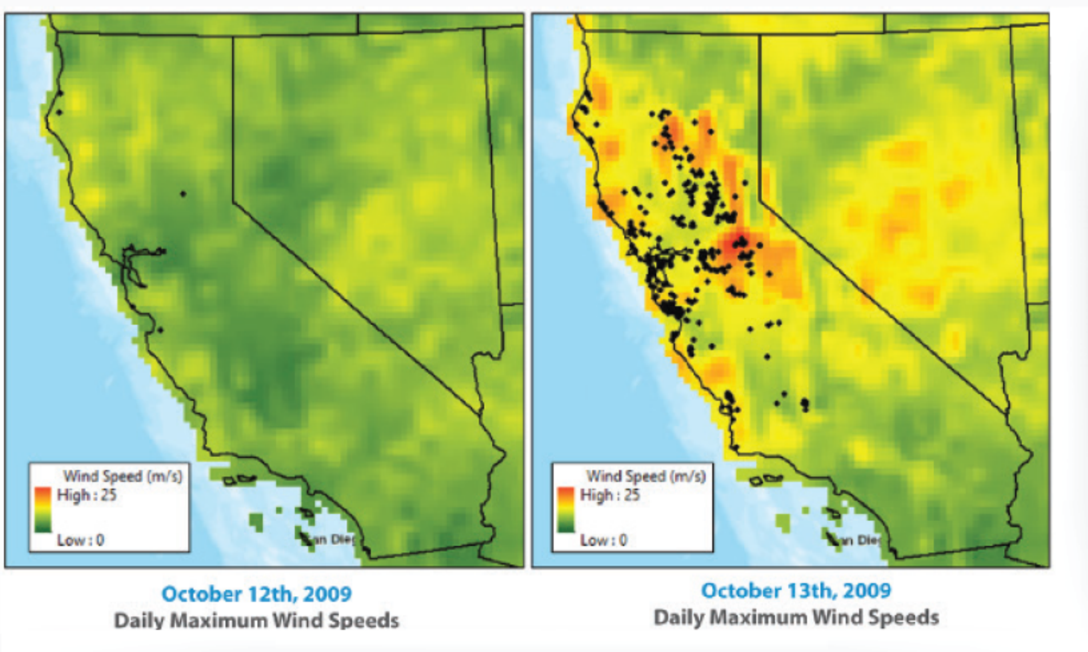


Figure 3.10. (Left) October 12, 2009, Experienced 5 vegetation-caused O&I Events, and (Right) October 13, 2009, Experienced 446 vegetation-caused O&I Events

Additional investigation was conducted on the reported TAT vegetation parameters associated with the O&I data for all dates in Group 1 (with greater than 59 events). The vegetation-associated parameters include Terrain, Tree Species, Ignition vs. Outage, Tree Age, Soil Condition, Tree Health, Tree Condition, Outside Tree Root Condition, Main Cause, Interior Tree Rot Condition, and Height:DBH. It was determined that reported failed vegetation for these O&I events were mostly healthy, live trees without a visible presence of root rot or other significant defects. Failure causes were predominantly related to branch or trunk failures with a high percentage of failed trees located on hillsides. These conditions suggest that the current TAT Boolean values and weighted parameters would likely not have resulted in abatement of these failure trees.

Methodology: Simple Wind Score Model

All fire season days with outage/ignition events greater than 59 from the O&I data are found within the North American Land Data Assimilation System (NLDAS) wind dataset. More weight is given to the days with higher likelihood of wind-caused outage/ignitions, and the weighted average of those high-wind event days daily maximum wind speeds is taken with the weights being the number of outage/ignitions for that day. A final wind event model presents wind scores (1) to communicate the regions of higher wind risk and (2) to estimate how the new wind condition scores would have affected the TAT's abatement records (see Figure 3.11). Note that the weighted average daily maximum wind speeds were normalized to range from 0 – 9 to facilitate a direct comparison and be consistent with the existing weight given to wind in the current TAT.

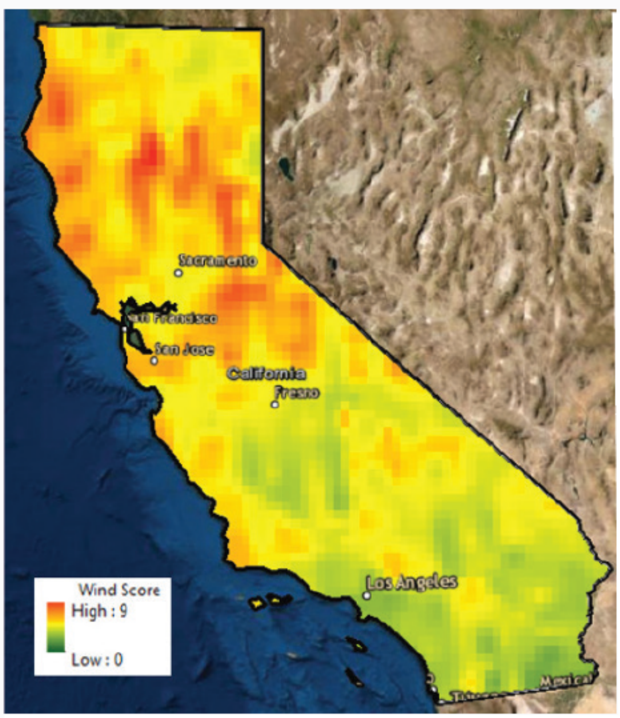


Figure 3.11. Raster Map for Wind Scores Using the Simple Wind Score Model

Methodology: Comprehensive Wind Score Model

Each of the model components of the Comprehensive Wind Score Model was weighted before being combined into a final score. The three models used for this analysis are as follows:

- **Model 1:** Percent tree failures caused by strong wind
- **Model 2:** Maximum of daily maximum wind speed for the days above threshold
- **Model 3:** Probability of occurrence for the days above threshold

Model 1: Percent tree failures caused by strong wind: O&I data were used to identify tree failures likely caused by strong winds by searching for key words such as "Strong Wind," "Windy," "High Wind," in the free-text comment field named "cReason," in which inspectors often enter a brief written description of the tree failure event and note relevant environmental conditions such as high winds, saturated soils from recent precipitation events, and so on. All failure trees, both wind-related and otherwise, were aggregated to a spatial resolution consistent with the NLDAS wind dataset (Figure 3.12).

The formula used to calculate the score of the Model 1 was:

$$\text{Percent of Failure Trees} = \frac{\text{Total Number of Failure Trees Caused by Strong Winds (Trunk \& Root Failure Only)}}{\text{Total Number of Failure Trees}}$$

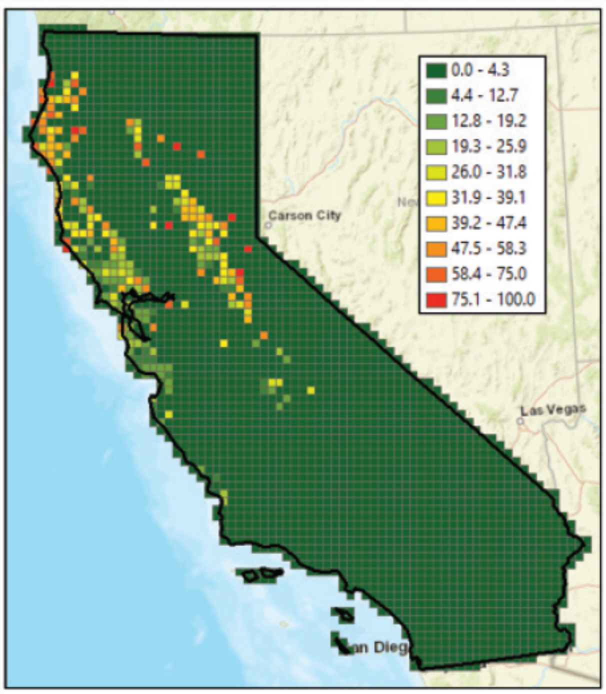


Figure 3.12. Model 1: Raster Map for Wind Scores as Percent of Tree Failure Caused by Strong Wind

The score ranges from zero to 100%, where 100% represent that all failure trees are caused by wind. No value is assigned to any grid cell with fewer than five failure trees due to uncertainty in O&I spatial inaccuracy. The objective of Model 1 is to identify areas that are particularly prone to wind-related tree root and stem failures during the fire season, based on legacy failures.

Model 2: Maximum of daily maximum wind speed for the days above threshold. Failure trees were further filtered to include only root and trunk failures and constrained to the fire season only (i.e., May – November).). Wind-related tree failure population locations were used to extract wind speeds from the NLDAS dataset using the date of the tree failure to compile the maximum daily wind speeds. The threshold was defined as the average of the daily maximum wind speed of the tree failure population and is shown in Figure 3.13 (next page), with the threshold value of 9.5 meters per second (m/s) (this value was used to separate high and low wind zones). High wind zone is the class that will potentially cause the majority of trees to fail. The score of Model 2 is calculated by taking the maximum of above-threshold wind speeds at the pixel/grid level. The normalized score ranges from 0 to 100% and is shown in Figure 3.14 (page 56).

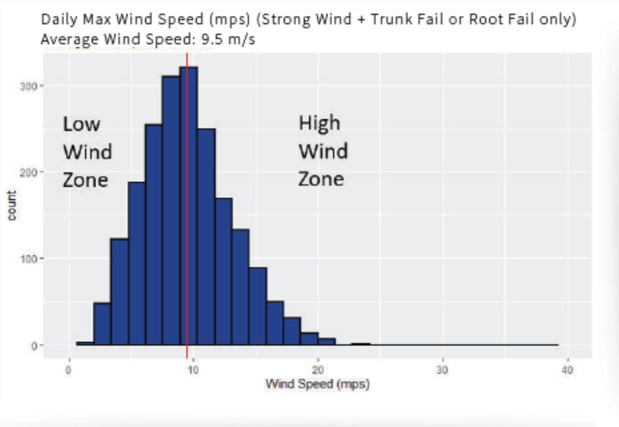


Figure 3.13. Wind Speed Distribution of Tree Failure Caused by Strong Wind

Note: Winds speeds shown in Fig 3.13 histogram are represented in meters per second (mps or {m/s)}. Conversion to miles per hour (mph) is as follows: 1 mps = 2.24 mph. The average wind speed of 9.5 m/s = 21.28 mph.

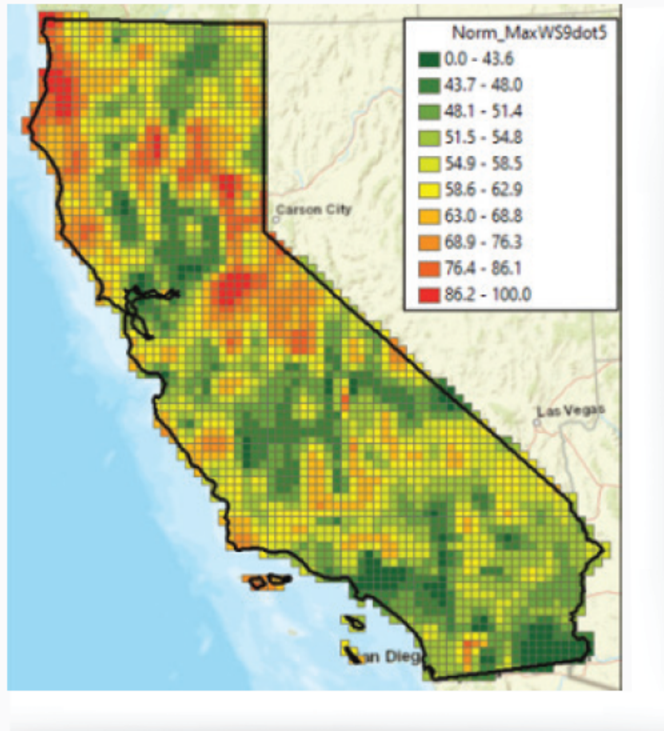


Figure 3.14. Model 2: Maximum of Daily Maximum for Days Above Threshold

Model 3: Probability of occurrence for the days above threshold. The analysis evaluates the daily maximum wind speed rasters to compare values to the threshold calculated earlier from the outage and ignition database. The score of Model 3 is the ratio between the total count of days greater than or equal to the threshold and total days in the fire season (Figure 3.15).

$$\text{Score} = \frac{\textit{Total Days Equal or Above the Threshold}}{\textit{Total Days}} \times 100\%$$

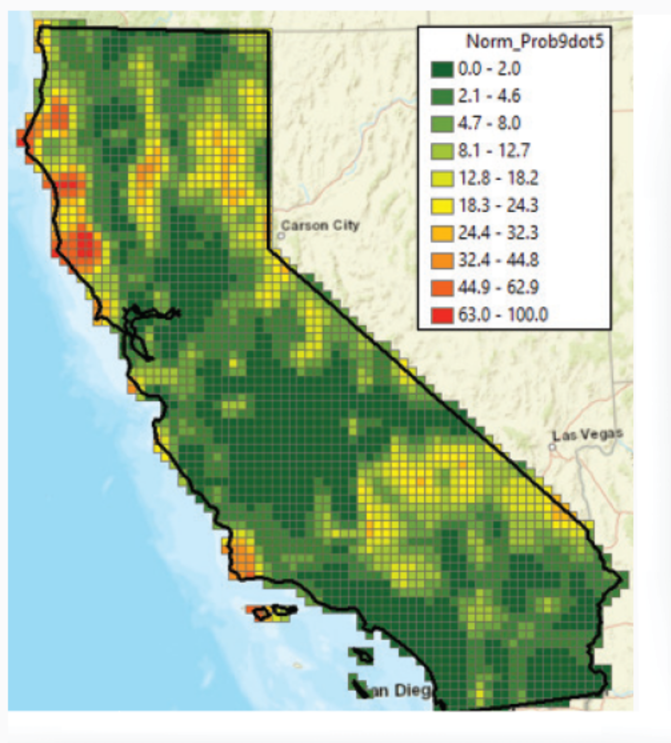


Figure 3.15. Model 3: Probability of Occurrence for the Days Above Threshold

Final Comprehensive Wind Score Model: The final score is calculated by weighting Model 1 by 50%, and Models 2 and 3 each by 25%. The final score was then scaled to 0-9 to match the current wind score range of the TAT model. The result is shown in Figure 3.16.

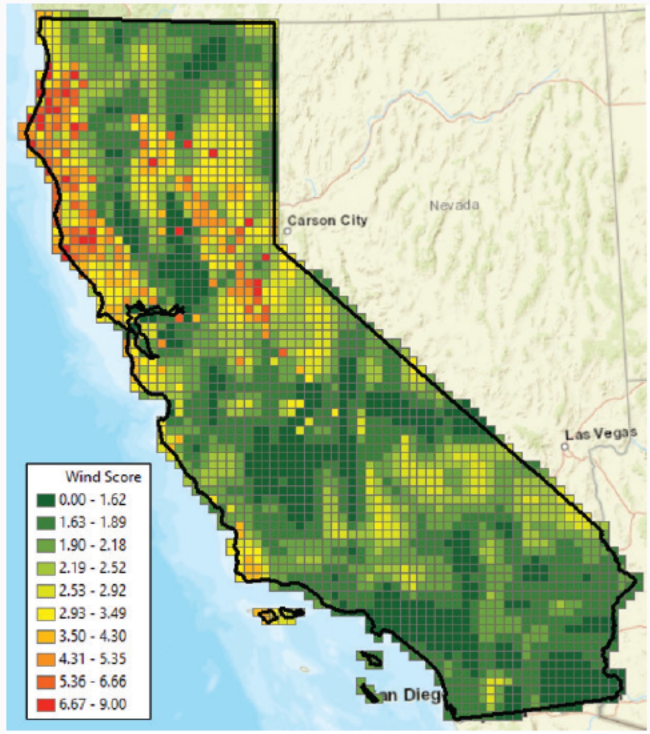


Figure 3.16. Raster Map for Wind Scores Using the Comprehensive Wind Score Model

Results

Recall that the wind risk parameter is one of ten parameters used in the scored abatement part of the TAT. Taking these two alternative models, we calculated the new abatements that would occur if either model were employed in lieu of the existing method.

	SCORED OUTCOMES		Δ FROM CURRENT SCORED OUTCOMES	
	Abate	Do Not Abate	New Abatement	Retracted Abatement
Current Model	20,763	430,070		
Simple Wind Score	28,132	422,701	7,414	(45)
Comprehensive Wind	25,074	425,759	4,351	(40)

Discussion

Both wind score models are data-driven approaches that have rational basis for implementation. The "Simple Wind Score Model" nets more abatements, and thus may be more conservative. Regardless, either model is an improvement over the current wind scoring method. PG&E meteorology data is also recommended as an additional source of wind data, as it has better resolution and is currently used throughout PG&E for PSPS and other risk modeling.

Recommendation 7: Replace existing wind model scoring methods with a wind event-driven representation that captures where wind-driven outages and ignitions are more likely, using either model proposed. The "Simple Wind Score Model" will result in more net abatements and may be more conservative. PG&E meteorology data should also be considered as the data have higher temporal and spatial resolution and are used across several important PG&E programs.

3.3 Height to DBH Ratio as a Scored Parameter for Selected Species

Tree height to diameter-at-breast height ratios (H:DBH) have been used to understand and predict susceptibility to windthrow and storm damage and are proposed as a new parameter for addition to the EVM TAT. The tree height to diameter ratio refers to the ratio derived by a tree's height divided by the diameter-at-breast height of its trunk (Figure 3.17), with both measurements being in the same units.

Trees with higher H:DBH may be more prone to failure in response to wind and gravitational forces (e.g., snow loading) acting on the tree. H:DBH is most associated with stem breakage failures, as opposed to uprooting, which is more a result of root and soil conditions (Wonn and O'Hara, 2001). H:DBH is an important individual tree characteristic that affects susceptibility to stem breakage while a tree's overall likelihood of root or trunk failure in response to external forces is a complex interaction between individual tree characteristics and species, stand level characteristics, soil conditions, topographic exposure characteristics, and meteorological conditions (Stathers, Rollerson, and Mitchell, 1994). For any individual tree, the H:DBH can be quickly and accurately assessed during an EVM TAT inspection.

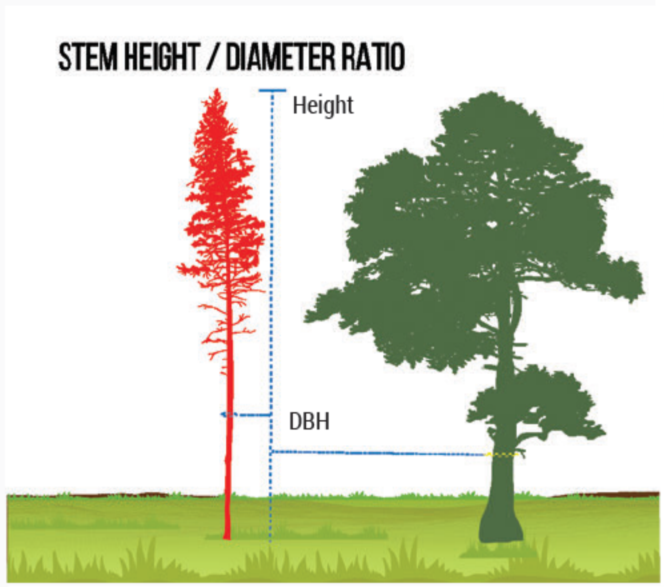


Figure 3.17. Stem Height/Diameter Ratio Conceptualization

Methodology

H:DBH using O&I trunk failure trees was compared to the standing trees recorded in the routine work history and EVM TAT inspection record databases. A single year of the routine work history database (2019 inspection cycle) was used to prevent the duplication of trees. This analysis was performed on an overall tree species population level (limited to trees with >2" DBH and >15' height).

Results

The summary statistics comparing H:DBH of standing trees to failure trees, by failure mechanism, are shown in Figure 3.18 (page 59). The tree failure types with the highest H:DBH are the set of trunk failure trees, indicating that these results are generally in agreement with the behavior expected based on the findings of Stathers et al. (1994) and Wonn and O'Hara (2001). These results were found to be statistically significant.[6]

Dataset	Count	First Quartile	Median	Mean	Third Quartile
O&I Trunk Failures	13,813	34.38	36.92	40.45	51.43
O&I Root/Trunk Failures	25,316	25.38	36.92	40.01	50
O&I Branch/Root/Trunk Failures	43,581	23.33	33.1	36.38	45.45
Standing Trees	4,718,769	20.45	30	35.88	45

Figure 3.18. H:DBH Summary Statistics of Standing Trees Compared to Failure Trees (Note that Trunk Failures Have the Highest Values)

Species-specific comparisons used tree species with at least 20 stem failures in the historical O&I database. Species found to be statistically significant are shown in Figure 3.19, where positive values indicate that the stem failure trees have a greater H:DBH compared to the standing trees of that species. Figure 3.20 (next page) presents using Jeffrey Pine as an example of how data are analyzed for H:DBH using failure and standing trees.

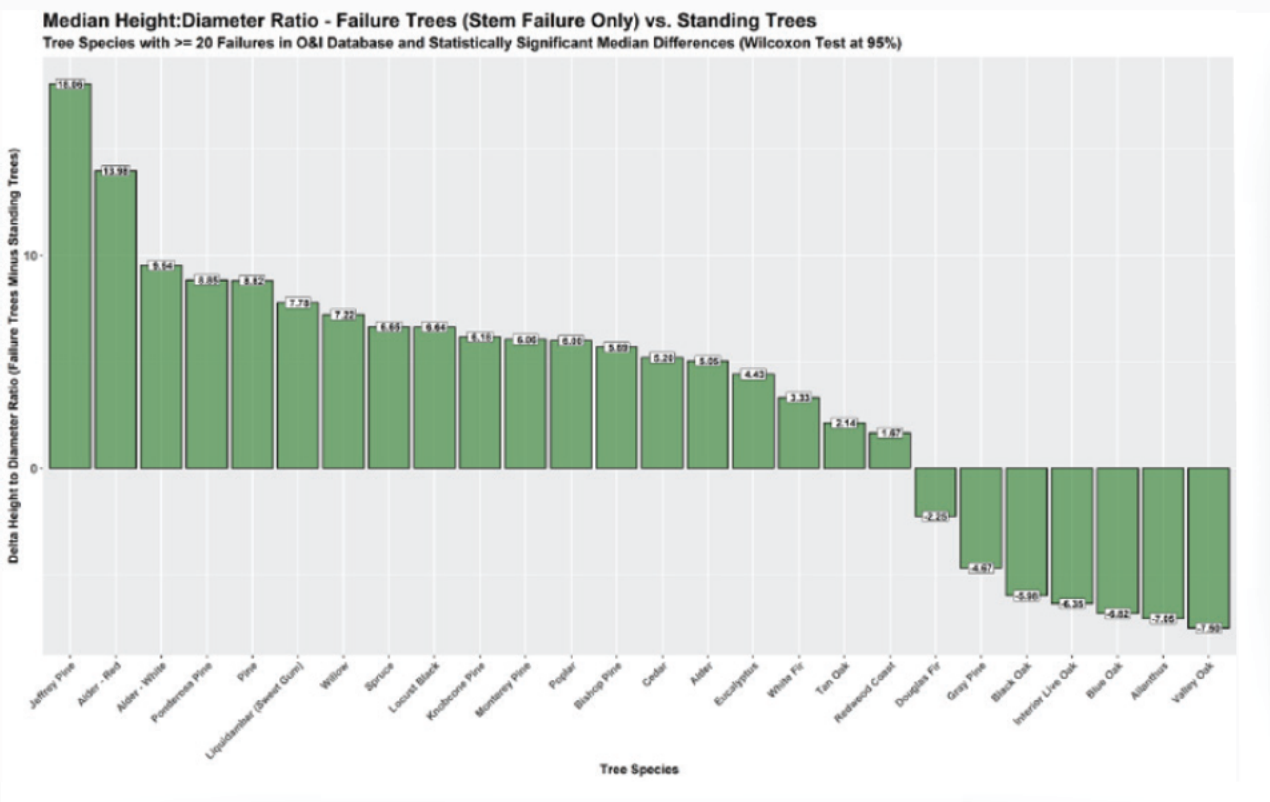


Figure 3.19. Difference Between H:DBH for Failure Trees and Standing Trees (Positive Values Indicate Higher H:DBH for Failure Trees than Standing Trees)

[6] *Using the Wilcoxon rank-sum test*

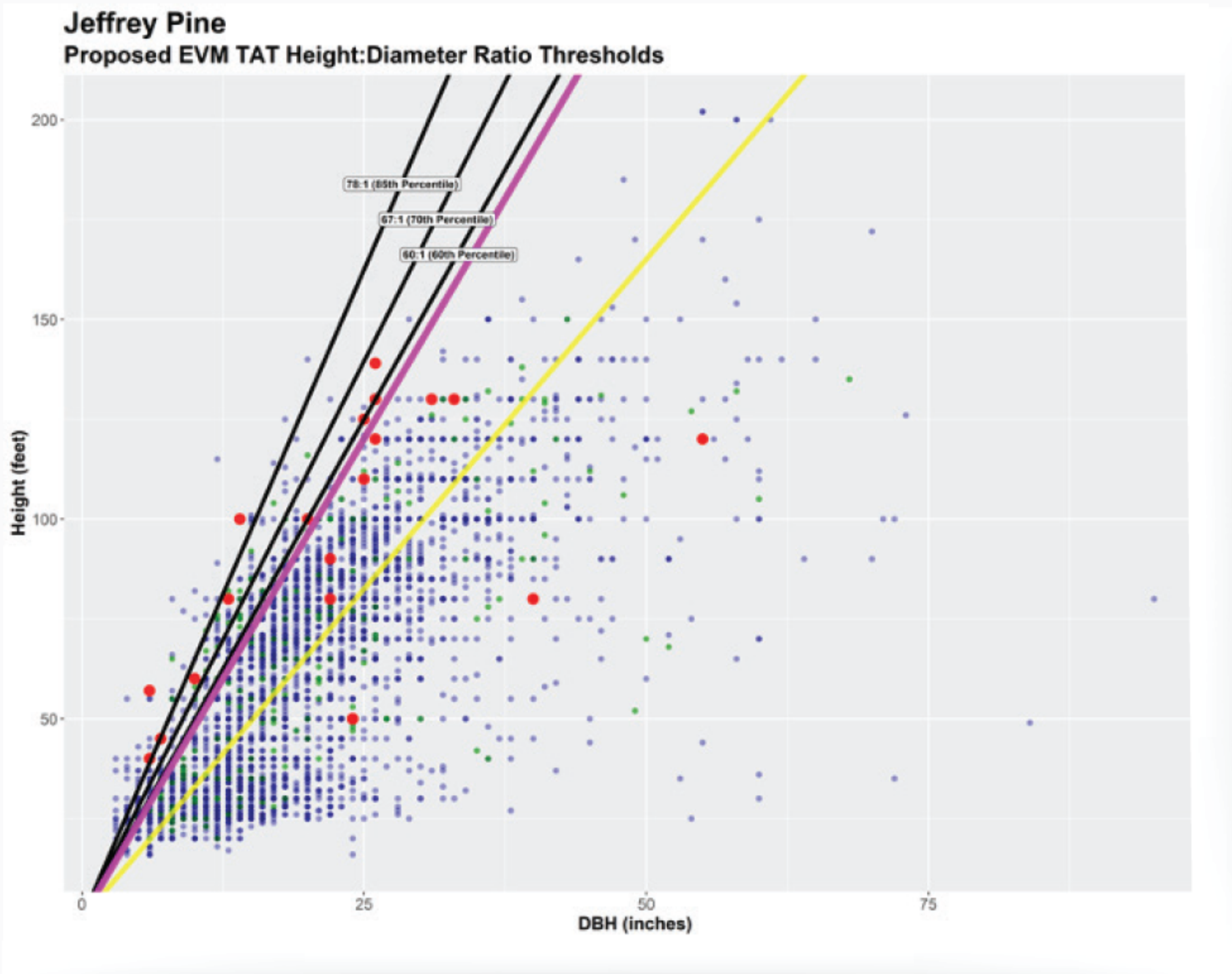


Figure 3.20.
Example: Jeffrey Pine Species-Specific Plots Showing the Relationship of H:DBH Between Stem Failures and Standing Trees

Species were selected for which stem failure trees had statistically significant higher H:DBH as compared to standing trees. The 85th, 70th, and 60th percentiles were selected to represent the high, medium, and low classes of H:DBH scoring, respectively (Table 3.1 - page 61). Species-specific plots showing the relationship of H:DBH between stem failures and standing trees are presented in Appendix F: H:DBH Model Development.

TREE SPECIES	COUNT (STEM FAILURE TREES)	COUNT (STANDING TREES)	85TH PERCENTILE HEIGHT:DBH ("High" Class)	70TH PERCENTILE HEIGHT:DBH ("Med" Class)	60TH PERCENTILE HEIGHT:DBH ("Low" Class)	DELTA: HEIGHT:DBH (Median Stem Failure Minus Median Standing Trees)
Jeffrey Pine	20	3608	78	67	60	18.06
Alder - Red	96	12423	75	65	60	13.98
Alder - White	53	10915	53	48	46	9.54
Ponderosa Pine	1591	272851	80	65	60	8.85
Pine	286	51440	61	48	43	8.82
Liquid Amber	56	35170	49	44	40	7.78
Willow	170	78324	60	44	38	7.22
Spruce	69	10313	69	53	58	6.65
Locust Black	39	18151	60	50	41	6.64
Knobcone Pine	62	3597	68	60	51	6.18
Monterey Pine	544	71133	46	39	36	6.06
Poplar	65	11870	60	49	43	6
Bishop Pine	131	131	60	48	45	5.69
Cedar	615	615	60	51	47	5.2
Alder	91	11903	67	52	49	5.05
Eucalyptus	411	58374	51	40	36	4.43
White Fir	159	32597	74	60	60	3.33
Tan Oak	1452	90530	68	57	51	2.14
Redwood - Coast	861	247908	55	44	40	1.67

Table 3.1. Proposed Height to Diameter Ratio Thresholds Derived from Species-Specific Percentiles of Historical Stem Failure Trees (Note: These are Only Trees with Positive Correlation)

To add species-specific H:DBH thresholds to the EVM TAT, the scoring algorithm needs adjustment to accommodate this new parameter. In this case, H:DBH scores were selected and assigned high (10), medium (7), and low (5) class values to the tree species with statistically significant positive H:DBH failure tendencies (listed in Table 3.1). Scored results increased abatements by 3,845 trees (Table 3.2).

	SCORED OUTCOMES		Δ FROM CURRENT SCORED OUTCOMES	
	Abate	Do Not Abate	New Abatement	Retracted Abatement
Current Model	20,725	429,099		
Add H: DBH Parameter	24,570	425,254	3,845	(0)

Table 3.2. H:DBH Scored Parameter Abatement Results (If Added to TAT Scored Abatement as Described in this Section) Note: Trees with missing height and/or DBH values could not be included.

Discussion

Adding H:DBH for selected species is supported by the literature (Stathers et al. [1994], Wonn and O'Hara [2001]) and is simple, given that these data are already collected in TAT inspections. This parameter has the potential to bring in "green trees" without obvious defects, which are known to be underrepresented in TAT abatement outcomes. The proposed scoring for H:DBH increased abatements by 3,845 trees; however, these scoring weights can be modified to increase or decrease abatements, if warranted.

Recommendation 8: Add H:DBH as a scored parameter for selected species.

3.4 Climate Data to Evaluate Trends in TAT Recorded Dead Trees

Environmental parameters are those that have ecological and weather connectivity and may affect tree growth, stress, health, or failure. In this study phase, Formation's objective was to utilize external data to identify correlates as potential predictors for tree mortality. Three environmental parameters were assessed: precipitation, evaporation, and standard precipitation index.

Precipitation Trend Data

Precipitation data used in this analysis were acquired from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) monthly, yearly, and single-event gridded data products of mean temperature and precipitation, max/min temperatures, and dewpoints (Figure 3.21). In-situ point measurements are ingested into the PRISM statistical mapping system. The PRISM products use a weighted regression scheme to account for complex climate regimes associated with orography, rain shadows, temperature inversions, slope aspect, coastal proximity, and other factors. PRISM includes the USDA's official climatological data and monthly data are available at 4-km resolution. The PG&E meteorological database has a 2-km resolution and 1-hour temporal resolution dating back ~30 years, but was not available for this effort.

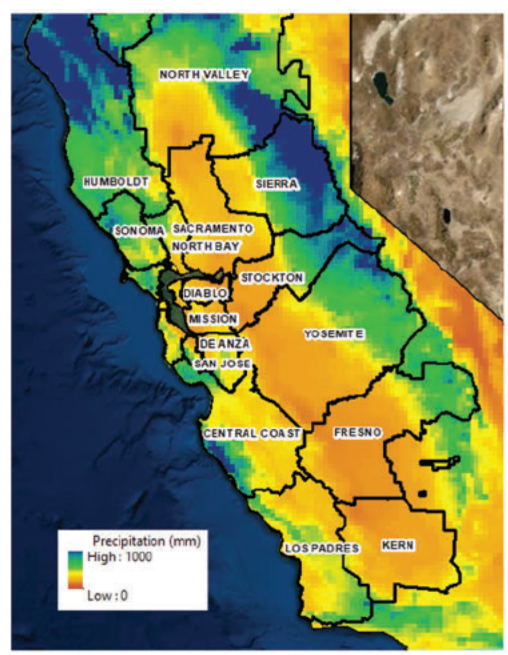


Figure 3.21. Northern California Map with PG&E Divisions, Annual Precipitation for Year 2020

Actual Evapotranspiration (ETa) Trend Data

Evapotranspiration (ETa) is the sum of evaporation from the land surface plus transpiration from plants/trees. Evaporation occurs when water changes to vapor on soil surfaces. Transpiration refers to the water lost through the leaves of plants. The California ETa dataset is a statewide model developed by Formation Environmental using remote sensing Surface Energy Balance (SEB) algorithms to estimate actual evapotranspiration. Climate data, including solar radiation, relative humidity, air pressure, and wind speed from California Irrigation Management Information System (CIMIS) stations, are used as inputs to the model. ETa is a good indicator of tree mortality and the water stress of vegetation. For example, a dying tree will have lower ETa compared to a healthy tree. Formation's ETa framework provides historical ETa data up to 30 years. Formation modeled the actual evapotranspiration at the daily time scale and aggregated the daily values to monthly and yearly data (Figure 3.22).

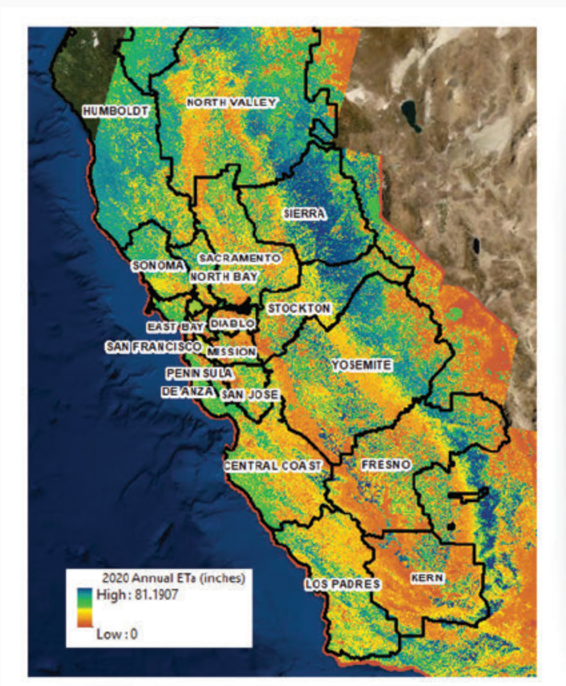


Figure 3.22. Northern California Map with PG&E Divisions, 2020 Annual ETa Values

ETa has ecological and weather connectivity and affects tree growth or stress condition. To evaluate the ETa condition for each year, a long-term trend (2004 to 2020) was calculated and a Z-Score method was used to compare results to a "normal" or average value over a period.

$$Z\text{-}Score = \frac{(x - \mu)}{\sigma}$$

μ = mean of yearly Evapotranspiration from 2004 to 2020
σ = standard deviation of yearly Evapotranspiration from 2004 to 2020

A Z-Score informs where the value lies on a normal distribution curve (zero means that the value is exactly at the long-term average whereas a Z-Score of +3 means the value is three standard deviations above the average).

Standard Precipitation Index (SPI) Trend Calculation

The SPI is based on precipitation and PET (Potential ET) combines sensitivity related to evaporation. It is calculated at a monthly time step as:

Standard Precipitation Index = Precipitation (P) – Evapotranspiration (ET)

Methodology

The TAT database contains an inventory of dead trees (N=25,543) and alive trees (N=614,958) that are accurately located and identified to the species level. This creates a unique opportunity to test these two populations against environmental trends to determine causation and correlation. Data were derived by sampling the environmental data described in this section (annual precipitation, Eta, and SPI) at the location of each alive or dead TAT tree record.

Two tree locations (Figure 3.23) were selected, illustrating long-term ETa Z-Score trends at both locations to demonstrate how ETa Z-Scores may vary throughout the PG&E service territory. In both locations, negative Z-Scores dominate in the seven-year period from 2014-2020. In Location 1, five of seven years have negative Z-Score ETa, with the two recent years 2019-2020 having positive ETa Z-Scores. Location 2 has negative Z-Score ETa for the entire seven-year period. The charts reflect that vegetation at both locations are more photosynthetically stressed; however, Location 1 shows some ETa recovery.

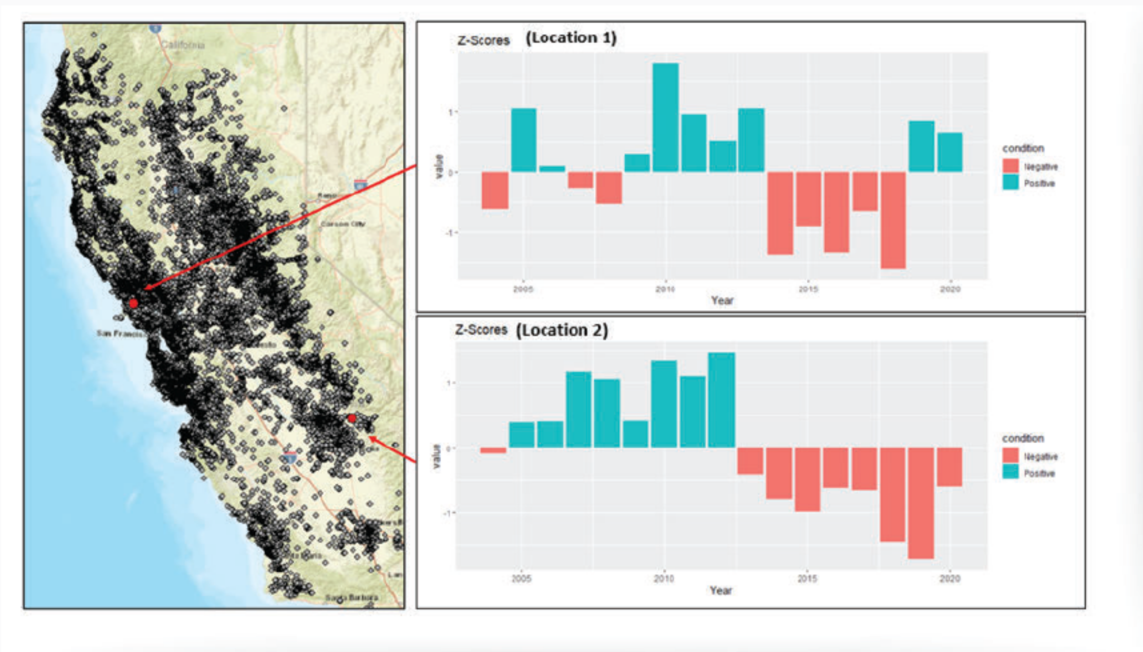


Figure 3.23. Z-Scores from 2004–2020 for Two Different Tree Locations (Red Points) (Black Points are Outage and Ignition Events)

The preceding six yearly trends of precipitation, ETa, Z-Scores, and SPI were tested using the two TAT populations of alive and dead trees.[7] Note that precipitation, ETa, and SPI trends for each alive and dead tree population were not tested by species. Hence, the alive and dead populations are aggregates of all species.

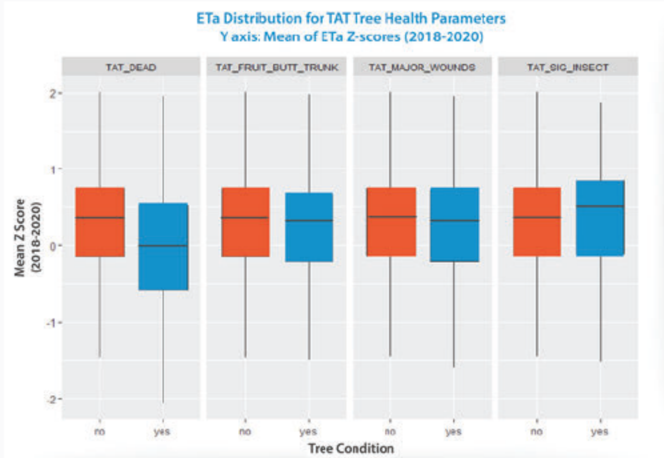
[7] *Using the Mann-Whitney U test and Vargha & Delaney A measure as statistical tests*

Results

Negligible relationships were found between the precipitation and SPI yearly trends for TAT alive and dead trees, regardless of yearly trend duration. ETa has a small relationship with previous one-year values when comparing dead and alive trees, with the remailing annual trends having negligible relationships (Table 3.3 and Figure 3.24).

Trend	Precipitation	Standard Precipitation Index	Evapotranspiration
Previous 1 Year	Negligible	-	Small
Previous 2 Year	Negligible	Negligible	Negligible
Previous 3 Year	Negligible	Negligible	Negligible
Previous 4 Year	Negligible	Negligible	Negligible
Previous 5 Year	Negligible	Negligible	Negligible
Previous 6 Year	Negligible	-	Negligible

— Table 3.3. Test for Effect Size for Environmental Parameters Trends of Tree Mortality



— Figure 3.24. Mean ETa Z-Score Distribution for Four Tree Health Parameters (2018-2020)

Discussion

The TAT data offer a rich opportunity to study cause-and-effect relationships for tree health and mortality. This large (and growing) database accurately geolocates trees, better than any other PG&E database employed in this study. While cursory analysis found only a weak relationship for ETa comparing dead vs. alive trees, it is believed that future (more robust) investigations can gain deeper insights and explore causal factors and become a stress index for PG&E tree threats. The following future next steps are recommended:

1. Utilize the PG&E meteorology data. These data offer better temporal and spatial resolution and span 30+ years. They are continuously updated and are the best source of climate data for this application.
2. All the data are in place to create a stress index model for factors affecting PG&E tree health and mortality. Take a dual track:
    a. **Multivariate Analysis:** Explore the combinations of meteorological processes that cause tree mortality. Perhaps evaluating any one parameter individually misses the inter-relatedness and complexity of prevailing environmental trends related to tree health/mortality.

    b. **Machine Learning:** Use the TAT tree health/mortality records and PG&E meteorology data for training a convoluted neural network or similar ML. The model(s) will not be too difficult to deploy and often find non-linear complex relationships.

3. Make models recursive. Both the TAT database and PG&E meteorology data are updating in time-series. Future validation and training data are being collected every year forward. Essentially, these models can be deployed and constantly learning beyond existing data presented in this report, as they will be repopulated with additional incoming TAT and meteorological data.

4. Incorporate species-specific drought response physiology. The PG&E service territory covers a wide geographic extent with many different tree species occurring throughout varying landscapes and climatic conditions. Considering species-specific drought tolerance, including hydraulic safety margins and resistance to xylem embolism, in combination with time series ETa and other climatological data will facilitate an increased ability to understand and predict drought-induced tree mortality. These analyses could be updated on a rolling basis to continuously estimate which areas of the PG&E service territory may be most susceptible to experiencing widespread drought-induced tree mortality in the near future (Blackman et al., 2019).

Recommendation 9: Create a species-specific stress index model for PG&E tree health and mortality. Employ the PG&E climate database and external environmental models to evaluate temperature, precipitation, evapotranspiration, and other environmental trends to evaluate relationships affecting TAT trees health and mortality. Consider both multivariate parameterized analysis and machine learning. Develop a framework that is recursive, and constantly learning/training from incoming new data.

4. SUMMARY OF RECOMMENDATIONS

Recommendation 1: Implement a rule set, harmonized with O&I procedures, for TAT to record at species level, with only specified genus allowed as aggregates. Adopt definitions presented in the OEIS Geographic Information Systems Data Standard, *DRAFT* Version 2.2 in Section 3.4.3 Ignition (Feature Class), Page 71.

Recommendation 2: Outage and/or ignition investigations should record accurate (dual-phase GPS) positions and be assigned to an EVM circuit segment that correlates to geo-rectified and spatially conflated PG&E EDGIS digital twin vector data. Similar to PG&E Transmission VM, where possible, associate the O&I tree with a LiDAR tree segmentation ID to further improve tree locational accuracy, and future tracking.

Recommendation 3: Track TAT abatement species compositions and compare to outage and ignition species distributions. Note potential over-/under-abatements. Over time, this can serve as a programmatic KPI.

Recommendation 4: Harmonize Outage and Ignition (O&I) data with TAT data parameters.

- Fill out all O&I data fields.
- To the best extent possible, perform a retroactive TAT analysis on future O&I trees.
- Where possible, associate the O&I tree with a LiDAR tree segmentation ID.

Recommendation 5: Increase green tree abatement rates for trees with no obvious defects. Consider scored abatements that add LiDAR metrics for overstrike distance, fall pathways to assets, tree position slope to alignment, and canopy exposure to wind.

Recommendation 6: Use EPA Level III Ecoregions to aggregate Regional Species Fire Risk Rating scores. Use multiple years of data. Update annually.

Recommendation 7: Replace existing wind model scoring methods with a wind-event-driven representation that captures where wind-driven outages and ignitions are more likely, using either model proposed. The "Simple Wind Score Model" will result in more net abatements and may be more conservative. PG&E meteorology data should also be considered as the data have higher temporal and spatial resolution and are used across several important PG&E programs.

Recommendation 8: Add H:DBH as a scored parameter for selected species.

Recommendation 9: Create a species-specific stress index model for PG&E tree health and mortality. Employ the PG&E climate database and external environmental models to evaluate temperature, precipitation, evapotranspiration, and other environmental trends to evaluate relationships affecting TAT trees health and mortality. Consider both multivariate parameterized analysis and machine learning. Develop a framework that is recursive, and constantly learning/training from incoming new data.

APPENDICES

Appendix A: Data Descriptions

The Formation Environmental team began Phase 1 at the Project Kickoff meeting on May 27, 2021, at which time preliminary research questions were presented to stakeholders (pending receipt and review of PG&E enterprise databases that were the basis of the project analysis). From May 27 - September 30, 2021, Formation received PG&E provided databases in tabular and/or geospatial format to undergo analysis. Some data including the full VM Work History & LiDAR data were delivered after the Phase 1 Report. Figure A1 illustrates the temporal domain, as well as the size of each database.

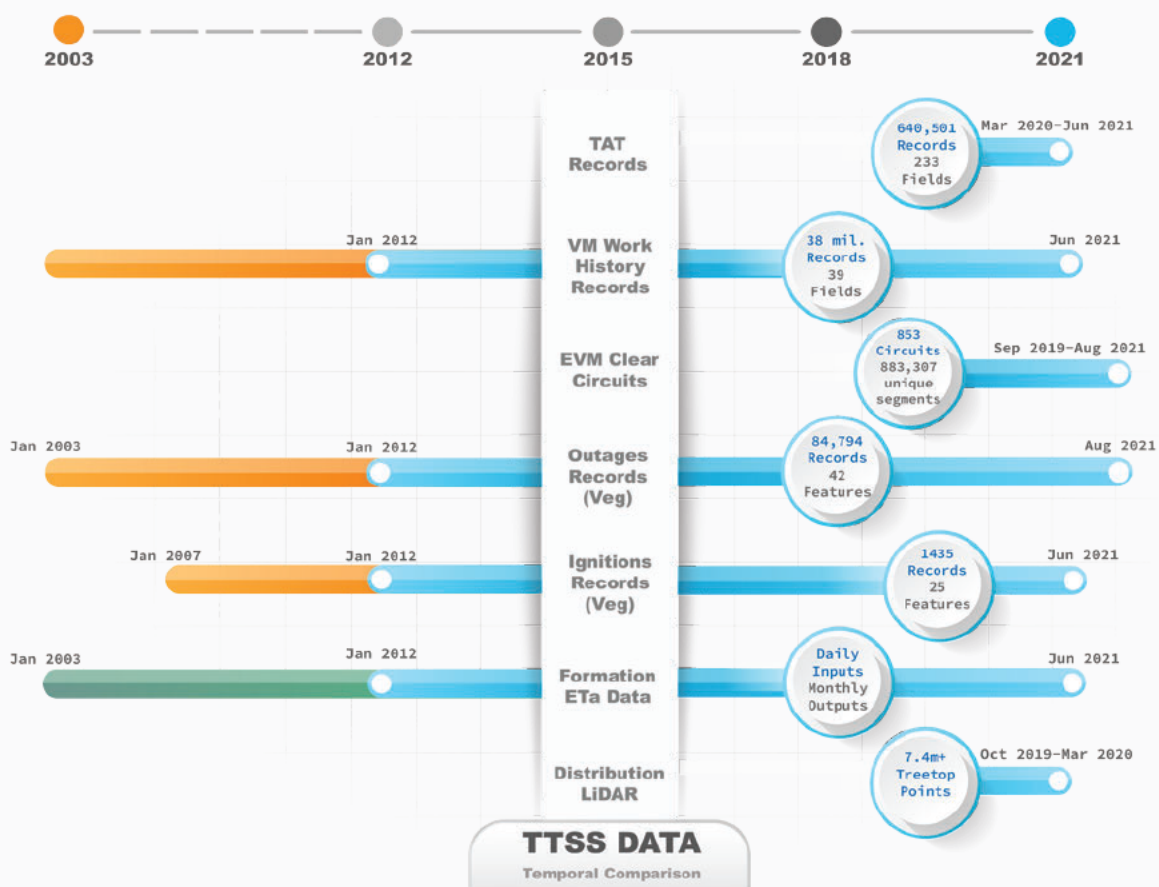


FIGURE A1. TTSS Data Temporal Comparison

The illustration also shows the Formation Evapotranspiration (ETa) data, a proprietary statewide framework developed by Formation Environmental to evaluate water stress in correlation with TAT environmental parameters. These data are suggested because Formation identified ETa as a strong correlate for tree failure in the previously conducted PG&E Transmission Back Testing project (2020-2021).

TREE ASSESSMENT TOOL (TAT) RECORD SUMMARY

NUMBER OF RECORDS: 640,501

NUMBER OF FIELDS: 233 (40 PLANNED FOR ANALYSIS)

DATE RANGE: MARCH 2020-JUNE 2021

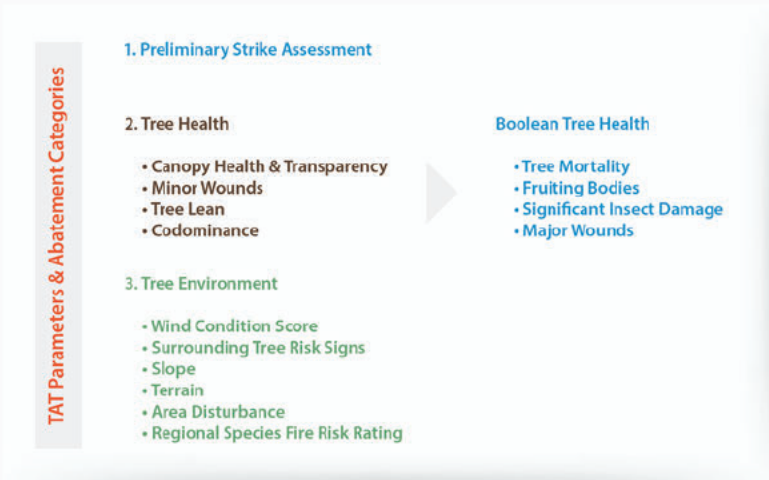


FIGURE A2. TAT Parameters Grouped by Categories

TAT PARAMETERS & CATEGOREIES (Figure 3)

1. PRELIMINARY STRIKE ASSESSMENT

-Boolean (Y/N) Decision for Abate based on overstrike, fall path, tree lean (>25 deg)

2. TREE HEALTH

-Boolean (Y/N) Decision for Abate based on Tree Dead, Fruiting Bodies Present, Major Wounds, Significant Insect Attack

- The overall tree health score is computed via the following linear combination:

- "TreeHealth" = Canopy Health + Lean + Codominance + Minor Wounds
  (Note: underlying weighting based on categorical selection)
- Within the TAT database, the score and rating are given by the variables TAT_TREE_HEALTH_SCR and the TAT_TREE_HEALTH_RTG.

3. TREE ENVIRONMENT

-In addition, the Tree Environment score and rating are calculated as such:

- "TreeEnvironment" = Slope + Terrain + Surrounding Tree Risk + Wind Condition + Area Disturbance + Regional Species Fire Risk Rating. (Note: underlying weighting based on categorical selection)
- RSFRR = (% outages per species in a region)/(Species % of total population in a region) + 1.5*(%Ignitions per species in a region)/(Species % of total population in a region)

The purpose of the TAT Records data intake and review is to

- Identify attributes described in the white paper and data dictionary within the TAT database records
- For each attribute, understand the nominal rating and corresponding score of each parameter
- Understand how the Tree Health and Tree Environment score are calculated
- Understand how the attributes available in the historical outage and ignition databases relate to the EVM TAT framework and abatement decisions

Attributes in the EVM TAT Model

The attributes included in the TAT are divided into three sections which consist of binary and ordinal parameters describing a tree's health, surrounding environment, and likelihood of striking a distribution asset in the event of a root or stem failure. Much of this section references the PG&E TAT White Paper (Appendix).

1. The first section is a preliminary strike assessment that supersedes other TAT parameters if assessments related to strike potential, fall path opportunity, or significant tree lean fail (Boolean Y/N criteria).

2. The second set of attributes are associated with tree health; these attributes are:

- **Canopy Health and Transparency**
  - Measures the amount of light that shines through the live portion of a tree's crown as a percent of total light that would be visible if the light were unblocked.
  - Rationale: Crown health and dieback branches are indicative of overall tree health.
- **Minor Wounds**
  - Location of wounds and decay.
  - No Wounds: No wounds larger than 3" wide, 12" long, and 0.75" deep found on the tree or scaffold.
  - Upper Wounds: Minor wounds found on the upper half of the tree or scaffold.
  - Lower Wounds: Minor wounds found on the lower half of the tree or scaffold.
  - Rationale: Minor wounds can cause structural instability and be indicative of other tree health issues which may correspond to a greater likelihood of stem or root failure.
- **Tree Lean**
  - Trees that do not grow perfectly upright are often considered predisposed to failure and trees which lean towards distribution assets are considered more likely to fall towards the asset in the event of a root or stem failure. This variable quantifies tree lean towards (greater than 5°), parallel to (or less than 5°), or away from facilities (greater than 5°) and distinguishes coniferous from deciduous trees by

assigning a higher score to coniferous trees which are leaning towards assets.

- Rationale: Trees that do not grow perfectly upright are often considered predisposed to failure; Per PRC 4293 California utilities must address tree lean through abatement if it represents a potential threat to electric assets. An international tree failure database found that 10% of root failures and 7% of all reported trunk failures were related to pre-failure lean.

- **Codominance**
  - Two or more main stems that are about the same diameter and emerge from the same location on the main trunk.
  - Rationale: Many co-dominant stems feature bark that grows into the union between the stems, causing a weak V-shaped branch union. Trees with co-dominant stems and included bark have an increased propensity for failure.

3. The third set consists of attributes associated with tree environment; these attributes are:

- **Wind Condition Score**
  - Wind condition score is derived from PG&E meteorology modelling of daily maximum wind speeds from May through November from 2006 – 2018 at 3 km by 3 km spatial resolution and the ordinal wind score is based on standard deviations from the historical average.
  - Moderate to severe winds can impact healthy trees.
  - Rationale: Wind alone does not typically cause root or stem failure in healthy trees, but it can accelerate failure for trees in poor tree health/environment.
- **Surrounding Tree Risk Signs**
  - General health of surrounding trees or span.
  - Rationale: Indicates general health problem with an area or span, also creates a trigger to look back at Tree Health attributes with greater scrutiny if issue appears to be widespread.
- **Slope**
  - Slope is a categorical variable which characterizes the steepness of slope of the ground which the tree is located.
  - Slope categories are less than 15%, 15 – 45%, and greater than 45%.
  - Rationale: Potential destabilizing effect of vegetation on slope stability documented in several studies.

- **Terrain**

  - The terrain environment in which the tree is located. Terrain categories include plains, valleys, creeks, or hillsides.

  - Rationale: Datasets indicate certain terrain types are more likely to have tree failures; TAT criteria simplified to try and eliminate subjectivity; supported by SME experience.

- **Area Disturbance**

  - Unusual activity that impacts tree density such as logging or construction.

  - Rationale: Post tree removal increases frequency of landslides. SMEs, field experience and research indicate mass tree removal or site disturbance can increase the frequency of landslides.

TAT Record Correspondence

TREE HEALTH

1. Canopy Health and Transparency – The categorical variable associated with this attribute is TAT_CROWN_HEALTH. The possible values are:

   a. CROWN_LT20: Crown less than 20% transparent.

   b. CROWN_20_60: Crown 20% to 60% transparent and/or 4 or less dieback branches.

   c. CROWN_GT60: Crown greater than 60% transparent and/or 4 or more dieback branches.

For TAT_CROWN_HEALTH_SCR, the above categories are given values 0, 10 and 15.

2. Minor Wounds – The categorical variable associated with this attribute is TAT_LOCATION_WOUND. The possible values are:

   a. NO_WOUND

   b. UPPER_WOUND

   c. LOWER_WOUND

For TAT_LOCATION_WOUNDS_SCR, the above categories are given values 0, 10 and 15.

3. Tree Lean – The categorical variable associated with this attribute is TAT_LEAN. The possible values are:

   a. TREE_TOWARD_5: Tree leaning AWAY from facilities (>5°).

   b. TREE_AWAY_5: Minor tree lean (<5°) or parallel lean.

   c. TREE_LESS_5: Tree leaning TOWARDS facilities (>5°).

The variable TAT_LEAN_SCR requires information on if the tree is a conifer. The given values are {12(Conifer), 8(Not Conifer}, -12 and 0.

4. Codominance – The categorical variable associated with this attribute is TAT_CODOMINANCE. The possible values are:

   a. Codominance
   b. No Codominance

The variable TAT_CODOMINANCE_SCR are given values 10 and 0.

TREE ENVIRONMENT

5. Wind Condition – The categorical variable associated with this attribute is TAT_WIND_COND. The possible values are called from an external database and have ultimate values:

   a. SLIGHTWIND - is determined by having a wind speed less than or within one standard deviation of the average maximum wind speed.
   b. MODERATEWIND - within two standard deviations above the average maximum wind speed.
   c. SEVEREWIND - greater than two standard deviations above the average maximum wind speed.

The variable TAT_WIND_SCR is given values 0, 3 and 9.

6. Surrounding Tree Risk Signs – The categorical variable associated with this attribute is TAT_SURR_RISK. The possible categories and corresponding values are:

   a. NO TREES - NONE
   b. ONE TO FOUR TREES - 1TO4
   c. MORE THAN FOUR TREES - MORETHAN4

The variable TAT_SURR_RISK_SCR is given values of 0, 3 and 9.

7. Slope – The categorical variable associated with this attribute is TAT_SLOPE. The categories with corresponding values are:

   a. LESS than 15-degree slope - LESS15
   b. 15-45 degree slope - 15TO45
   c. Greater than 45-degree slope - GREATER45

The variable TAT_SLOPE_SCR is given values 0, 3 and 6.

8. Terrain – The categorical variable associated with this attribute is TAT_TERRAIN. The possible values are:
    a. FLAT
    b. VALLEY
    c. CREEK
    d. HILLSIDE

The variable TAT_TERRAIN_SCR is given values 0, 2, 4 and 6.

9. Area Disturbance – The variable associated with this attribute is TAT_DISTURBANCE. The possible values are:
    a. NO DISTURBANCE - NONE
    b. LOW TO MODERATE (20% or less tree change) - LOWMOD
    c. HIGH TO VERY HIGH (more than 20% tree change) - HIGHTOVH

The variable TAT_DISTURBANCE_SCR is given values 0, 8 and 15.

10. Regional Species Fire Risk Rating – derived from analysis of the historical outage and ignition frequency of individual tree species with respect to their estimated percentage of the overall tree species population. The variable associated with this attribute is TAT_REGION_RISK_RATING.

Tree Abatement

The abatement decision for an individual tree is based on not only the combination of the summed tree health and tree environment scores, but also includes the following logic which is derived from the Boolean variables included in the preliminary strike assessment and tree health sections:

If BLOCKED == 'yes':	Do not abate
Else if STRIKE == 'no':	Not a strike tree
Else if (SEVERE == 'Away from facilities') and (BLOCKED == 'no'):	Do not abate
Else if (SEVERE == 'Toward facilities') and (Blocked == 'no'):	Abate
Else if (Dead == 'yes'):	Abate
Else if (FRUIT_BUTT_TRUNK == 'yes'):	Abate
Else if (MAJOR_WOUNDS == 'yes'):	Abate
Else if (SIG_INSECT == 'yes'):	Abate
Else if (MATRIX == 'Do Not Abate'):	Do not abate
Else if (MATRIX == 'Abate'):	Abate

The above variables correspond to the following Boolean parameters included in the preliminary strike assessment and tree health sections:

TAT_BLOCKED - Is the tree completely blocked from falling toward facilities

TAT_STRIKE – Is the tree tall enough to strike the facilities

TAT_SEVERE – Is the tree leaning(severely) > 25 degrees

TAT_DEAD – Is the tree dead or clearly dying

TAT_FRUIT_BUTT_TRUNK – Are there fruiting bodies on butt or trunk?

TAT_MAJOR_WOUNDS – Are there major wounds on the roots, butt or trunk (larger than 4” wide and 24” long and 0.75” deep)

TAT_SIG_INSECT – Are there significant insect attacks to the butt or trunk?

Using the tree health and environment scores, the following logic is used to calculate an abatement matrix:

If:

(Health_Score >= 27) and (Env_Score <= 10) ----> Abate

(Health_Score >= 27) and (10 < Env_Score <= 20) ----> Abate

(Health_Score >= 20) and (20 < Env_Score <= 35) ----> Abate

(Health_Score >= 15) and (Env_Score > 35) ----> Abate

Else:

Do not abate

Summary of TAT Records - by Species

- 175 Different Species
- 98% of Records Associated w/ Top 50 Species

Figure A3 illustrates a tree graph of the Top 50 species represented in the TAT records database. Of those, Douglas Fir represents 14.9% of the TAT species, Blue Oak is recorded in 13% of records and Ponderosa Pine is recorded in 12.2% of the records. In Formation's initial assessment of the TAT data related to species, we noted that some of the fields are duplicated but show as separate categories due to the introduction of additional characters (comma). Prior to analysis, these fields will be evaluated and cleaned to ensure species composition is correctly characterized.

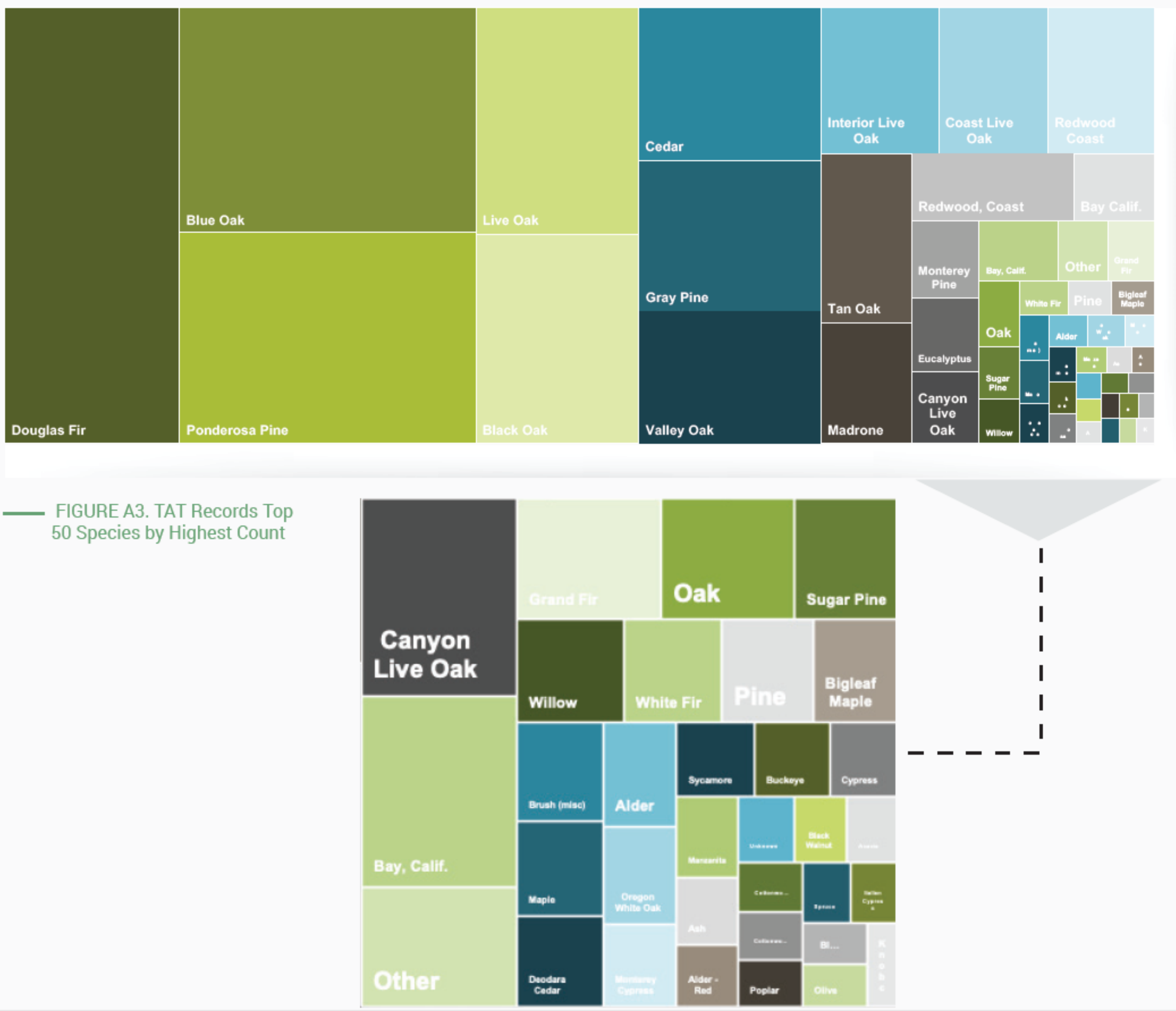


FIGURE A3. TAT Records Top 50 Species by Highest Count

FORMATION ENVIRONMENTAL

Summary of TAT Records - by Circuits

- 187 Total Circuits
- Top 50 Circuits represent 79% of TAT Records

Figure A4 illustrates the Top 50 circuits represented in the TAT records database. There are 187 total circuits with 79% of TAT records associated with the top 50 circuits. The blue graph represents the % of trees recommended for abatement (by circuit) in the TAT records. This initial review does not reveal a strong relationship in number of records to the number of trees recommended for abatement.

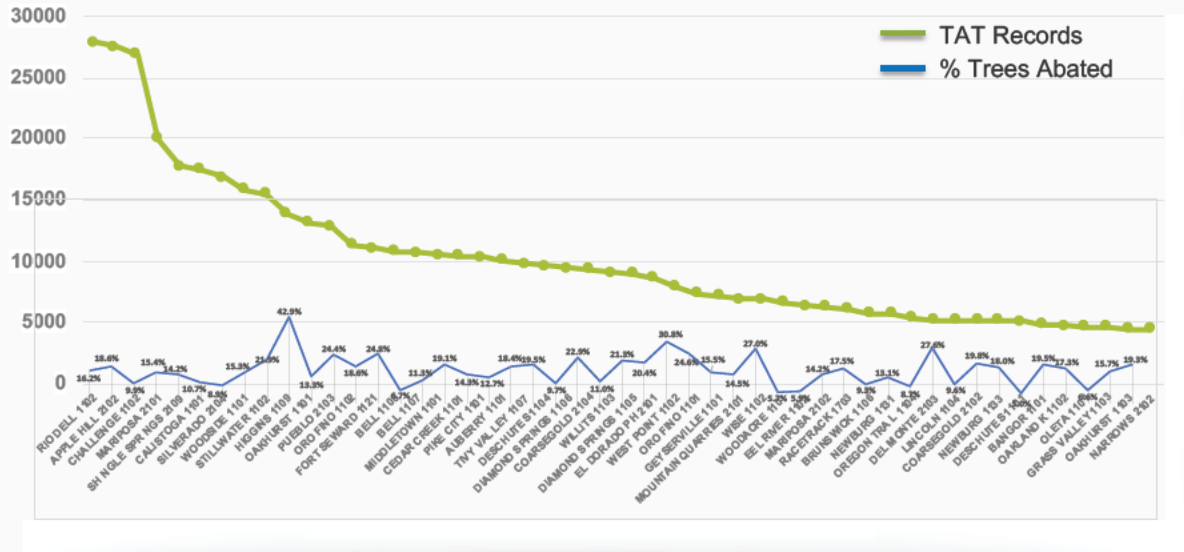


FIGURE A4. TAT Records Top 50 Circuits

Summary of TAT Records - by PG&E Region

Figure A5 illustrates the geographic distribution of the TAT records database by PG&E administrative and operational regions. The highest number of TAT records were in the Sierra Region representing 27.8% of total TAT records. Central Valley and North Coast Regions contained 18.8% and 18% of total TAT records, respectively.

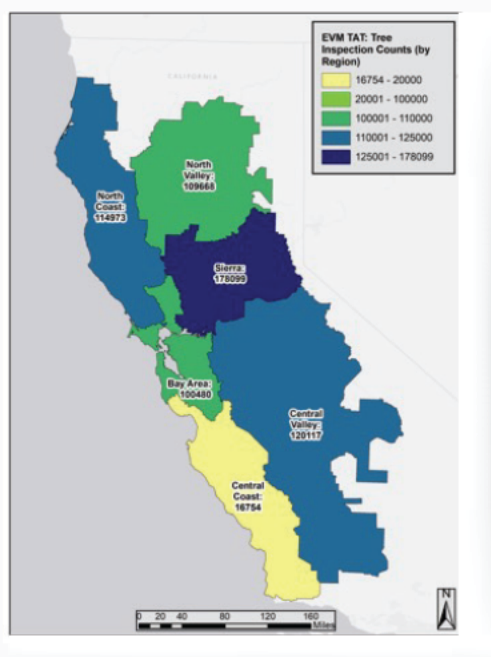


FIGURE A5. TAT Records by PG&E Administrative Region

Summary of TAT Records - by PG&E Administrative Divisions

Figure A6.a illustrates the geographic distribution of the TAT records database by PG&E administrative and operational divisions. The highest number of TAT records were in the Sierra Division with 27.7% of total TAT records. Figure A6.b is a corresponding geographic division map illustrating the number of EVM TAT records with % of TAT records that resulted in an abate decision. Kern Division shows the highest percentage of records with an abate outcome, a result of a low number of total TAT records comparative to other divisions.

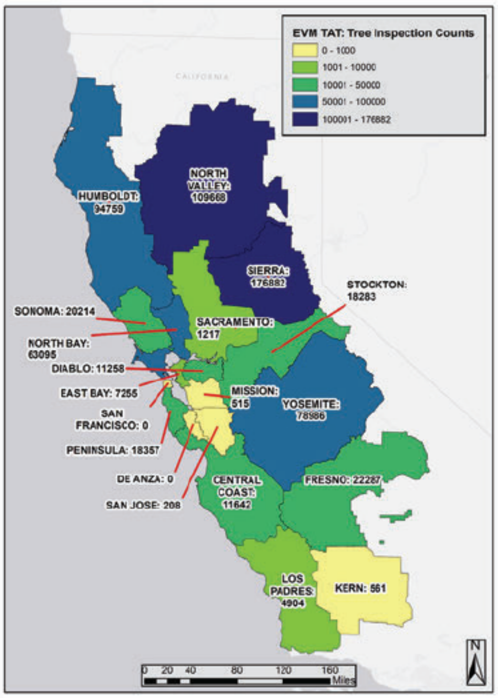


FIGURE A6.A. TAT Records by PG&E Divisions

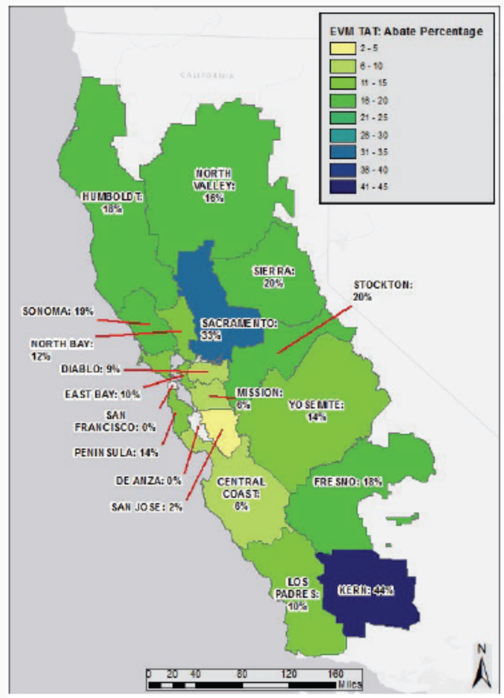


FIGURE A6.B. TAT Records Abate Percentage

Summary of TAT Records - by HFTD

- Tier 3 = 41% of TAT Records
- Tier 2 = 57% of TAT Records
- Tier 0 = 1.5% of TAT Records

Figure A7 illustrates the geographic locations of CPUC HFTD T3 and T2. 57% of TAT Records were collected in Tier 2 and 41% in Tier 3.

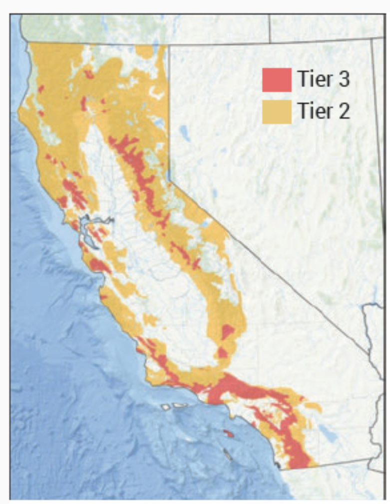


FIGURE A7. CPUC High Fire Threat Districts

WORK HISTORY RECORDS

NUMBER OF RECORDS: ~38 MILLION
NUMBER OF FIELDS: 39
DATE RANGE: JANUARY 2012-JUNE 2021

This dataset represents significant information that will allow, at minimum to utilize this dataset as a representation of the total population of trees when studying species composition. The date range for this data goes back further than January 2012, however in interviews with subject matter expert, this team was advised that there may be inconsistency with data collection and/or GPS coordinates for records predating January 2012. The TAT uses these data to calculate tree distributions used in the regional fire risk rating scores.

EVM CLEAR CIRCUIT GIS LAYER

NUMBER OF UNIQUE CIRCUITS: 853
NUMBER OF SEGMENTS: 883,307
DATE RANGE: SEPTEMBER 2019-JUNE 2021
NOTE: COMPRISING 28,060 CIRCUIT MILES, OF WHICH 4,973 CIRCUIT MILES ARE EVM CLEAR

The EVM Clear database includes work verification status records for circuit segments where EVM inspections and work were conducted. Table A1 shows circuit segment counts by work verification status (at date of receipt of data). Figure A8 illustrates the work verification status by HFTD zone. The spatial accuracy of the EVM Clear dataset is poor with respect to actual circuit locations.

Count	EVM Work Verification Status	% of Data
189,068	Work Verification Pass	21%
7,411	Work Verification Fail	<1%
1,157	Ready for Work Verification	<1%
685,671	Blank	78%

TABLE A1. EVM Work Verification by Status

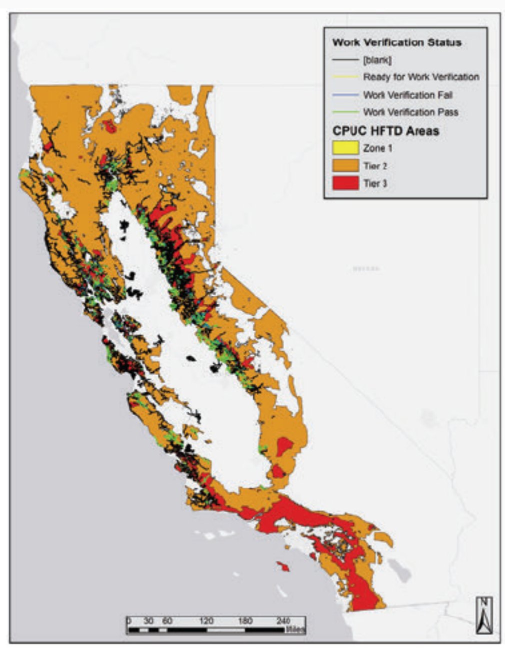


FIGURE A8. EVM Work Verification by HFTD

PG&E DISTRIBUTION OUTAGE RECORDS

NUMBER OF RECORDS: 84,794
NUMBER OF FEATURES: 42
DATE RANGE: 2003-2021

The outage database consists of records of historical distribution vegetation-caused outages. This data is necessary to conduct any back testing and/or evaluation of how well the TAT algorithm would perform on those trees that caused outages. The outage data does not contain the same features / attributes as the TAT database. However, some variables can be used to extract information which mirrors some of it. The list below shows which outage features can be mapped to compare TAT features. Note: not all records have location information.

Outage Features		TAT Features
cTreeHealth	→	Canopy Transparency
cDefects, cCause	→	Fruiting Trunk, Major Wounds, Insect Infestation, Minor Wounds
nHeight, nDistance	→	Strike Tree
bTreeDead	→	Dead
cTreeLean	→	Lean
cSpecies	→	Regional Species Fire Risk Rating
cTerrain	→	Terrain

PG&E DISTRIBUTION IGNITION RECORDS

NUMBER OF RECORDS: 1435
NUMBER OF FEATURES: 25
DATE RANGE: January 2, 2007 to June 6, 2021

The ignition database consists of records of historical distribution vegetation-caused outages that also caused an ignition. These records were joined / referenced to corresponding outage records to back test EVM Clear Effectiveness and as a comparison for TAT abatements, trends associated with species, wind, or other potential parameters. The fields to be used include as join / references include Division, Circuit, Date, Latitude, and Longitude.

Additional attributes utilized in analysis include the following features

- Size (Acres), Size (Range), Cause, Line Type, Species, DBH, Height

DISTRIBUTION LIDAR DATA

NUMBER OF RECORDS: 7,448,381 Treetop points

FEATURES OF INTEREST: Vegetation Segmentation

DATE RANGE: October 2019 to March 2020

A set of derivative vector products produced from an airborne LiDAR dataset were provided by PG&E and consisted of several feature classes related to distribution assets and vegetation in the vicinity. The LiDAR data was collected throughout primarily the Tier3 and Tier2 HFTD area between October 2019 and March 2020. This LiDAR dataset was used to create spatially accurate digital twins of electrical assets (conductors, poles, etc.). The asset data included feature classes representing distribution poles and spans, each of which included attributes such as unique circuit and asset identifiers, location (i.e., latitude, longitude, and elevation) descriptive circuit information (e.g., circuit name, voltage, etc.) and administrative region designation. Also included was a feature class dataset representing the estimated locations of treetop points as derived from a vegetation segmentation and analysis of the airborne LiDAR data. The treetop points feature class included many of the same administrative and asset-related attributes which were included with the spans and poles, as well as a number of attributes describing the trees themselves, such as tree height, radial distance to wire, overstrike and presence of overhanging branches. There were approximately 7,448,381 treetop points in this feature class. Although this LiDAR dataset was received at the very end of the analytical stage of this project (late December 2021) an thus unable to be meaningfully included in this study, the LiDAR derivative products appear to be well organized upon a brief initial review and these derivative products, in addition to the LiDAR point clouds themselves, could provide a substantial benefit to future analysis by enabling the detailed study of parameters such as overstrike, surface and topographic exposure, slope and aspect to wire, fall path quantification, and the potential opportunity to detect and classify failure trees in the LiDAR point cloud to facilitate further analysis and machine learning techniques (Figure A9 a&b).

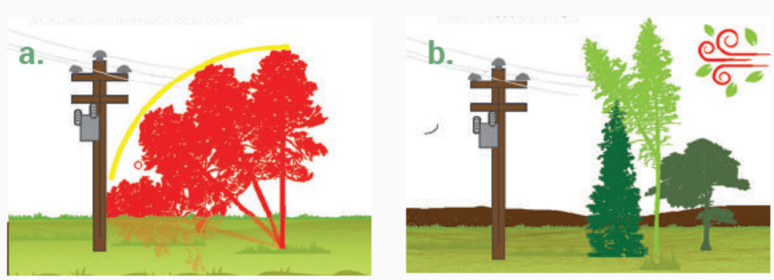


FIGURE A9 a&b: Illustrations showing potential LiDAR application to evaluate a. overstrike distance and b. tree height and topographic exposure

FORMATION ENVIRONMENTAL ETa FRAMEWORK (External to PG&E)

DATA SOURCE: FORMATION ENVIRONMENTAL
GEOGRAPHIC COVERAGE: STATEWIDE
SPATIAL RESOLUTION: 30 METERS
TEMPORAL RESOLUTION: 16-DAY TIME SERIES INTERVALS
DATE RANGE: JANUARY 2007-DECEMBER 2021

Actual Evapotranspiration (ETa) dataset is a California state-wide model developed by Formation Environmental using remote sensing Surface Energy Balance (SEB) algorithms. Evapotranspiration is the sum of evaporation from the land surface plus transpiration from plants/trees. This framework was initially developed for the State of California Department of Water Resources to analyze the impact of drought conditions associated with consumptive water use and water allocation programs. Formation applies its ETa framework in the analysis of many vegetation-related projects because it is a good indicator of tree mortality and water stress of vegetation. For example, a dying tree will have lower ETa compared to a healthy tree. Figure A10 illustrates CalETa statewide framework with varying ETa values from year 2011. Formation's ETa framework provides historical ETa data for 35 years (at 16-day time-series intervals), allowing the team to evaluate this parameter in coordination with PG&E's TAT data from 2007-2021.

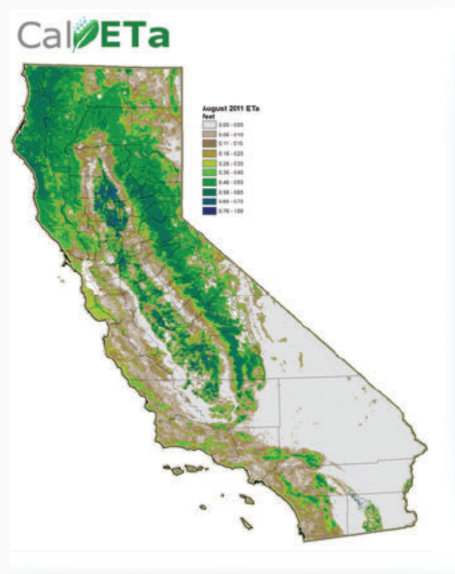


FIGURE A10. ETa Map Year 2011

Reference: https://www.formationenvironmental.com/products/caleta.php

NORTH AMERICAN LAND DATA ASSIMILATION SYSTEM (External to PG&E)

DATA SOURCE: NOAA / NASA COLLABORATIVE
GEOGRAPHIC COVERAGE: NORTH AMERICA
TEMPORAL RESOLUTION: HOURLY TIMESTEP
DATE RANGE: JANUARY 1979 TO PRESENT

North American Land Data Assimilation System Phase 2 (NLDAS-2) wind dataset is used to explore the correlation between wind and Outage and Ignition datasets. NLDAS is a collaboration project among several groups:

- NOAA/NCEP's Environmental Modeling Center (EMC)
- NASA/GSFC's Hydrological Sciences Laboratory
- Princeton University
- the University of Washington
- NOAA/NWS Office of Hydrological Development (OHD)
- NOAA/NCEP Climate Prediction Center (CPC)

NLDAS is constructed using quality-controlled, and spatially and temporally consistent, land-surface model (LSM) datasets from the best available ground and space-based observations. NLDAS is currently running operationally in near real-time on a 1/8th-degree grid with an hourly timestep over central North America (25-53 North). Retrospective hourly/monthly NLDAS datasets extend back to January 1979. Reference: https://ldas.gsfc.nasa.gov/nldas/v2/forcing

NATIONAL ELEVATION DATASET (External to PG&E)

DATA SOURCE: US GEOLOGICAL SURVEY
GEOGRAPHIC COVERAGE: NORTH AMERICA
RESOLUTION: 10 METERS
DATE RANGE: UPDATED BIMONTHLY

The National Elevation Dataset (NED) was developed by the US Geological Survey (USGS). The NED is a seamless mosaic of best-available elevation data. The 7.5-minute elevation data for the conterminous United States are the primary initial source data. One of the effects of the NED processing steps is a much-improved base of elevation data for calculating slope and hydrologic derivatives. Artifact removal greatly improves the quality of the slope, shaded-relief, and synthetic drainage information that can be derived from the elevation data. Geospatial elevation data are used by the scientific and resource management communities for global change research, hydrologic modeling, resource monitoring, mapping, and visualization applications. Reference: https://gdg.sc.egov.usda.gov/Catalog/ProductDescription/NED.html

Appendix B: TAT Parameter Validation with External Data

Terrain & Slope Comparison to National Elevation Dataset

The TAT tool is used by field personnel to evaluate the conditions of each tree and its surrounding environment. This includes assessment and categorization of terrain type and the degree of slope. Assessments and category assignment decisions are made by visually inspecting these conditions, approximating the slope and assigning the corresponding category representing a range. The goal of this analysis is to compare the terrain and slope category assignments in the Tree Assessment Tool (TAT) database with a quantitative dataset to assess for consistency and relative accuracy of the input values for each TAT record. The external comparative dataset, the Statewide National Elevation Dataset (NED) was utilized to compare the data collected using the TAT tool.

Two parameters collected using the TAT that are related to terrain are SLOPE and TERRAIN. For the TERRAIN parameter, the values are categorized into “CREEK”, “FLAT”, “HILLSIDE” and “VALLEY” (TABLE B1). For the SLOPE parameter, the values are categorized into three groups with ranges representing the degree of slope at the location of the tree; Less than 15°, 15° to 45°, and greater than 45° (TABLE B2). The total number of records in the TAT database is 640,501, although 189,613 records are NULL or empty for these categories, therefore this comparative analysis was conducted on 450,888 records. A geographic distribution of the TAT Categories by Slope are show in FIGURE B1.

TAT_TERRAIN Categories	TAT RECORDS (Count & Percentage of Total)
Creek	18,403 (4.1%)
Flat	181,140 (40%)
Hillside	210,401 (47%)
Valley	40,944 (9.1%)

TABLE B1: TAT SLOPE Categories & Record Counts

TAT_SLOPE Categories	TAT RECORDS (Count & Percentage of Total)
Less 15	320,414 (71%)
15 to 45	116,930 (26%)
Greater 45	13,544 (3.0%)

TABLE B2. TAT SLOPE Categories & Record Counts

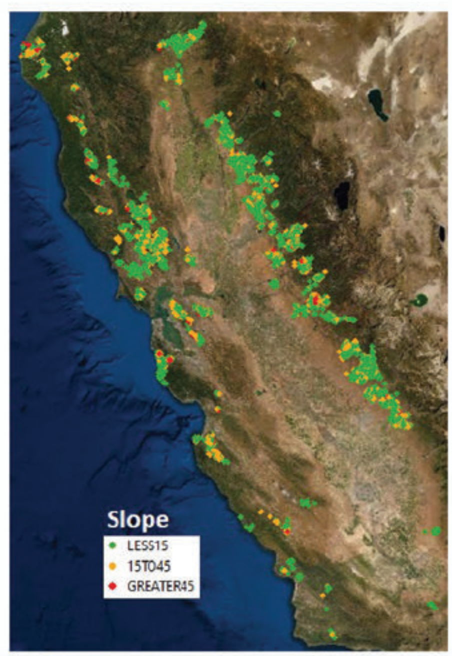


FIGURE B1. Geographic Distribution of Slope Categories from TAT Records

To compare the terrain and slope categories from the TAT records, the NED values are matched to TAT locations (Lat/Lon) and extracted for comparison. FIGURE B2 is a box and whiskers plot illustrating the breakdown of NED slope values for each slope class and each terrain category. The median of the NED Slope distributions is generally increasing along with the assigned slope class in the TAT database, particularly with the Hillside terrain class. This illustrates that the slope classes assigned by TAT inspectors on the ground generally correspond to slope values derived from the NED. While the spatial resolution, variation in positional accuracy, and elapsed time between the acquisition of the NED and the EVM TAT records make a numeric comparison between NED slope values and inspector-estimated slope values, the fact that the slope values from each data source show general agreement in their trend direction is indicative of these slope values being assessed with generally good accuracy and consistency by the TAT inspectors.

To determine if the data distributions are statistically different among the three slope classes, a t-test must be performed. However, before the t-test, a statistical test was conducted to determine the normality of the data.

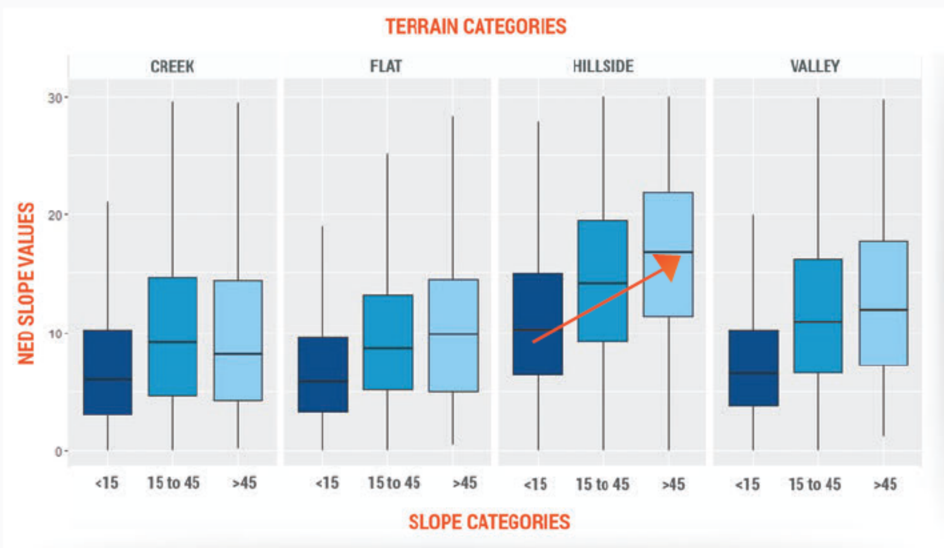


FIGURE B2. NED Values Matched to TAT Terrain & Slope Categories

The Anderson–Darling model was applied to test below normality. This model is a statistical test to determine whether a given sample of data is drawn from a given probability distribution. It is a modification of the Kolmogorov-Smirnov (K-S) test and gives more weight to the tails than does the K-S test. The Anderson-Darling test makes use of the specific distribution in calculating critical values. This has the advantage of allowing a more sensitive test and the disadvantage that critical values must be calculated for each distribution. It is one of the most powerful statistical tools for detecting most departures from normality. If the p-value of the test is greater than the significance level 0.05, the distribution of the data are not significantly different from a normal distribution. In other words, one can assume normality. The p-values, histogram and q-plots are shown below. Figures B3-6 illustrates that all the p-values are less than 0.05, implying that all data distributions are not normal.

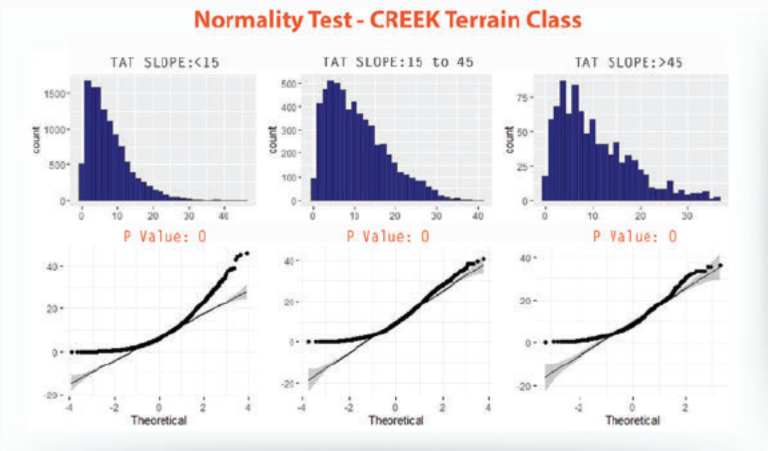


FIGURE B3.
TAT Slope Categories
Normality Test
CREEK Terrain Class

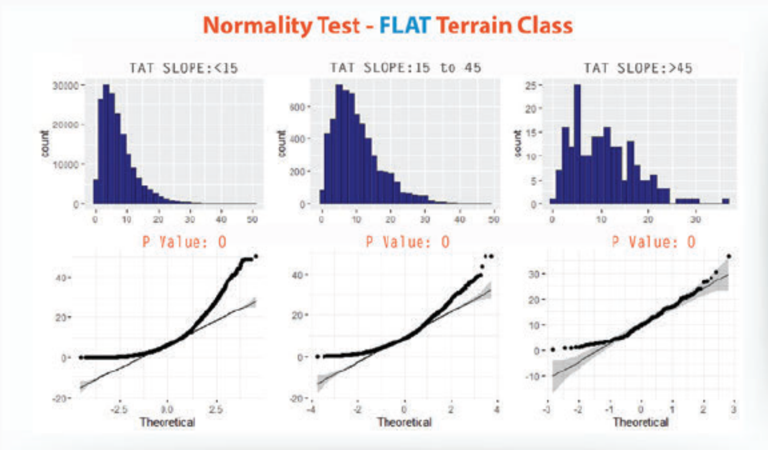


FIGURE B4.
TAT Slope Categories
Normality Test
FLAT Terrain Class

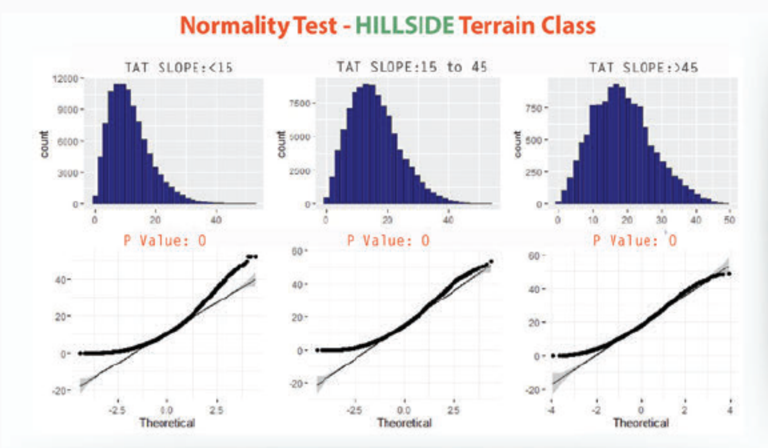


FIGURE B5.
TAT Slope Categories
Normality Test
HILLSIDE Terrain Class

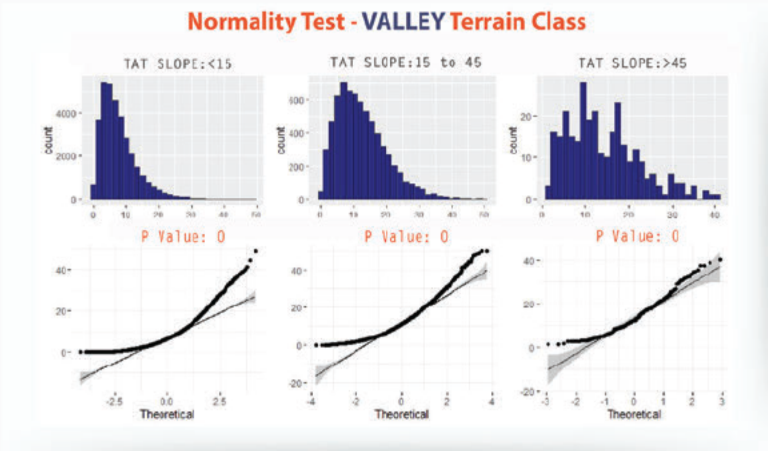


FIGURE B6.
TAT Slope Categories
Normality Test
VALLEY Terrain Class

The results of the normality test illustrate that the data are not normally distributed. Therefore, a non-parametric unpaired two-samples test - Wilcoxon rank sum test was used instead of the traditional t-test. It is also known as the Mann-Whitney test. This test was used to compare the NED slope data for three slope categories alternatively to determine whether their medians are statistically significant from each other. Table B3 shows the p-values for each comparison by the terrain categories.

SLOPE COMPARISONS	TERRAIN CLASSES: CREEK	FLAT	HILLSIDE	VALLEY
<15 vs. 15to45	0.000	0.000	0.000	0.000
15to45 vs. >45	0.082	0.198	0.000	0.001
<15 vs. >45	0.000	0.000	0.000	0.000

TABLE B3. Wilcoxon rank sum test comparing TAT slope values to NED slope values

Except for the comparisons among the moderate and steepest slopes, specifically at the creek and flat terrains, all other p-values are less than 0.05. Consequently, it is reasonable to conclude that all data distributions except the moderate and steepest slope categories ("15° to 45°" vs. "greater than 45°" slope value) are statistically significantly different from each other.

Additional tests were conducted utilizing two Formation datasets, Slope Length & Steepness Factor (SL-Factor) and Topographic Wetness Index (TWI). These tests produced similar results, supporting the accuracy and consistency of Slope & Terrain categorization assignments by inspectors utilizing the Tree Assessment Tool.

Further evaluation of the TAT counts in the Slope & Terrain classifications illustrated that the greatest number of abated trees were located on hillsides with 15° to 45° degrees slopes (Figure B7).

FIGURE B7. TAT Abated Trees by Slope & Terrain Classes.

To determine the importance of slope & terrain for abatement decisions, Formation evaluated failed trees from the outage and ignition databases. The outage database contains the field "cTerrain" that includes 5 primary classes of terrain (Creek, Ridge, Plain, Valley, Hillside), as well as 2 additional categories representing "OTHER" and "NULL". Figure B8 illustrates that the highest occurrence of failed vegetation associated with outages were reported to have occurred on hillsides, which corresponds to the greatest number of TAT abated trees on hillsides.

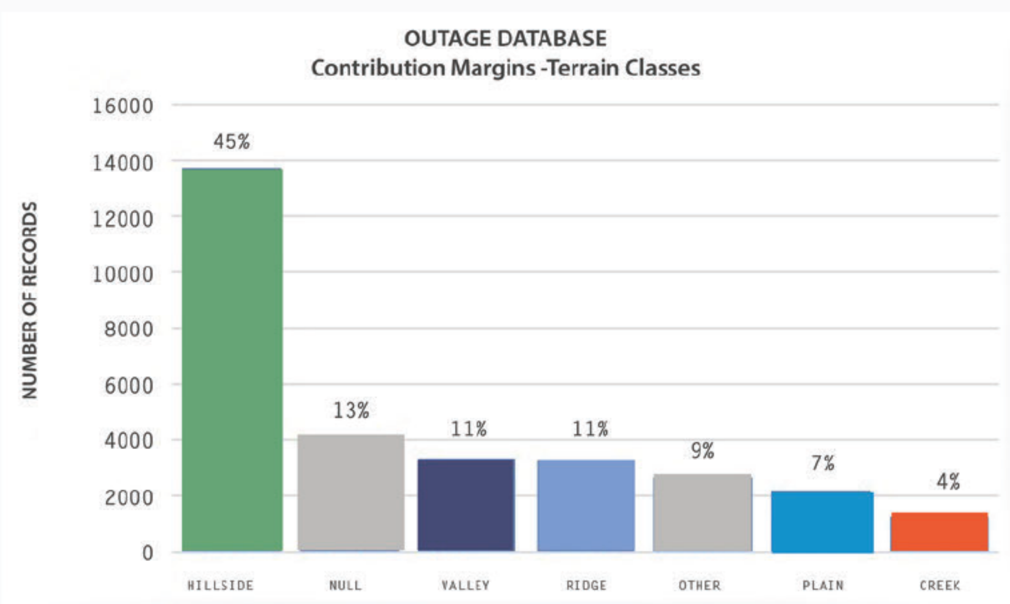


FIGURE B8. Percent contributions of vegetation-caused outages by terrain classes

The NED comparative analysis validated accuracy and consistency of the TAT values entered for the degree of slope at each tree location. However, the effect of the slope and terrain parameters on abatement outcomes were found to be negligible. To assist with determining whether the slope parameter should be revised to have a greater impact, The outage and ignition databases were further evaluated with regard to contribution margins of slope and terrain categories of vegetation-caused failure trees. There are a total of 51,455 records with lat/lon values allowing for geospatial reference. Of those, records, 30,284 occurred in HFTD (T2 & T3). The slope class statistics in Figure B9apply to HFTDs only.

Slope categories in the outage database utilize a lookup table with A, B, C, D corresponding to degrees of slope <5°, 5-15°, 15-45°, and >45°, respectively. A number of records had "NULL" fields for these parameters.

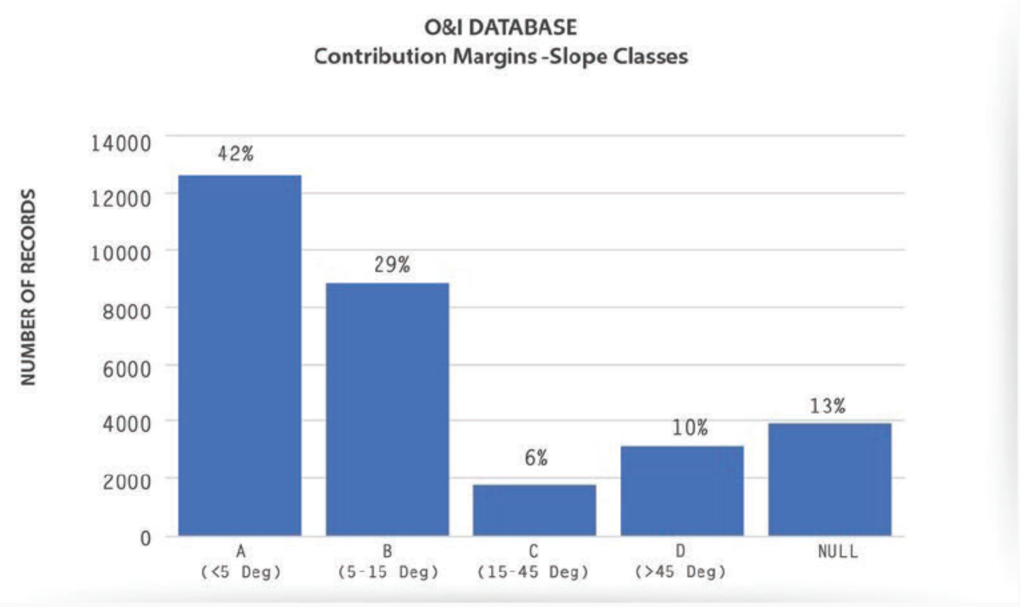


FIGURE B9. Percent contributions of vegetation-caused outages by slope classes

Approximately 71% of outages and ignitions occurred on slope classes A and B, with slopes less than 15°. While steeper ground slopes represent a greater risk of instability in response to saturated soil or other disturbances, it is unclear how important terrain slope is with respect to predicting the likelihood that any individual tree will fail. Further analysis with additional datasets may provide additional insight into this question, but the current assessment of slope significance is inconclusive and supports the relatively low weighting currently assigned to terrain slope in the TAT.

Appendix C: TAT Species and Genus Compositions

While many of the TAT records are recorded to the tree species level, some are recorded to the Genus level. Below is a summary of all of the tree naming TAT records. Note, in this case "aggregates" are considered species that are recorded only at the Genus level.

Summary of TAT Genus Aggregates

Genus	Common Name	N	Aggregated by Genus	Distinct Genus & species
Abies	Fir	5,804	3%	97%
Acacia	Acacia	904	75%	25%
Acer	Maple	1,648	44%	56%
Alnus	Alder	2,477	62%	38%
Cupressus	Cypress	2,827	37%	63%
Eucalyptus	Eucalyptus	6,938	89%	11%
Ficus	Ficus	52	8%	92%
Fraxinus	Ash	902	93%	7%
Juglans	Walnut	1,283	33%	67%
Pinus	Pine	125,176	2%	98%
Populus	Poplar	2,481	24%	76%
Quercus	Oak	255,334	1%	99%
Salix	Willow	2,299	97%	3%
Ulmus	Elm	370	65%	35%

Abies		TAT Records (N)				Percent of Genus Total			
TAT Description	Genus & species	Abate	Do Not Abate	Not a Strike Tree	Total	Abate	Do Not Abate	Not a Strike Tree	Total
Fir (True)	Abies	16	155	4	175	3%	3%	2%	3%
Fir, White	Abies concolor	262	1,719	62	2,043	43%	34%	32%	35%
Fir, Grand	Abies grandis	331	3,070	130	3,531	54%	61%	66%	61%
Fir, Red	Abies magnifica	-	55	-	55	0%	1%	0%	1%
	Total	609	4,999	196	5,804	100%	100%	100%	100%
	Aggregated by Genus Only	16	155	4	175	3%	3%	2%	3%
	Distinct Genus & species	593	4,844	192	5,629	97%	97%	98%	97%

Acacia		TAT Records (N)				Percent of Genus Total			
TAT Description	Genus & species	Abate	Do Not Abate	Not a Strike Tree	Total	Abate	Do Not Abate	Not a Strike Tree	Total
Acacia	Acacia	84	501	96	681	79%	74%	82%	75%
Acacia, Blackwood	Acacia melanoxylon	23	179	21	223	21%	26%	18%	25%
	Total	107	680	117	904	100%	100%	100%	100%
	Aggregated by Genus	84	501	96	681	79%	74%	82%	75%
	Distinct Genus species	23	179	21	223	21%	26%	18%	25%

Acer

TAT Description	Genus & species	TAT Records (N) Abate	Do Not Abate	Not a Strike Tree	Total	Percent of Genus Total Abate	Do Not Abate	Not a Strike Tree	Total
Maple	Acer	248	1,272	128	1,648	35%	47%	41%	44%
Maple, Bigleaf	Acer macrophyllum	421	1,195	158	1,774	59%	44%	51%	48%
Maple, Silver	Acer saccharinum	16	152	9	177	2%	6%	3%	5%
Box-Elder	Acer negundo	24	77	16	117	3%	3%	5%	3%
	Total	709	2,696	311	3,716	100%	100%	100%	100%
	Aggregated by Genus	248	1,272	128	1,648	35%	47%	41%	44%
	Distinct Genus species	461	1,424	183	2,068	65%	53%	59%	56%

Alnus

TAT Description	Genus & species	TAT Records (N) Abate	Do Not Abate	Not a Strike Tree	Total	Percent of Genus Total Abate	Do Not Abate	Not a Strike Tree	Total
Alder	Alnus	237	1,135	166	1,538	66%	60%	69%	62%
Alder, Red	Alnus rubra	102	605	51	758	28%	32%	21%	31%
Alder, White	Alnus rhombifolia	21	137	23	181	6%	7%	10%	7%
	Total	360	1,877	240	2,477	100%	100%	100%	100%
	Aggregated by Genus	237	1,135	166	1,538	66%	60%	69%	62%
	Distinct Genus & species	123	742	74	939	34%	40%	31%	38%

Cupressus

TAT Description	Genus & species	TAT Records (N) Abate	Do Not Abate	Not a Strike Tree	Total	Percent of Genus Total Abate	Do Not Abate	Not a Strike Tree	Total
Cypress	Cupressus	76	873	86	1,035	38%	36%	50%	37%
Italian Cypress	Cupressus sempervirens	21	502	60	583	11%	20%	35%	21%
Cypress, Monterey	Cupressus macrocarpa	101	1,081	27	1,209	51%	44%	16%	43%
	Total	198	2,456	173	2,827	100%	100%	100%	100%
	Aggregated by Genus	76	873	86	1,035	38%	36%	50%	37%
	Distinct Genus & species	122	1,583	87	1,792	62%	64%	50%	63%

Eucalyptus

TAT Description	Genus & species	TAT Records (N) Abate	Do Not Abate	Not a Strike Tree	Total	Percent of Genus Total Abate	Do Not Abate	Not a Strike Tree	Total
Eucalyptus	Eucalyptus	800	5,159	243	6,202	88%	90%	79%	89%
Gum, Blue	Eucalyptus globulus	65	428	55	548	7%	7%	18%	8%
Gum, Red	Eucalyptus camaldulensis	28	41	-	69	3%	1%	0%	1%
Gum, Red-flowering	Eucalyptus ficifolia	-	2	-	2	0%	0%	0%	0%
Gum, Silver Dollar	Eucalyptus polyanthemos	7	41	8	56	1%	1%	3%	1%
Ironbark, Red	Eucalyptus sideroxylon	5	53	3	61	1%	1%	1%	1%
	Total	905	5,724	309	6,938	100%	100%	100%	100%
	Aggregated by Genus	800	5,159	243	6,202	88%	90%	79%	89%
	Distinct Genus & species	105	565	66	736	12%	10%	21%	11%

Ficus

TAT Description	Genus & species	TAT Records (N) Abate	Do Not Abate	Not a Strike Tree	Total	Percent of Genus Total Abate	Do Not Abate	Not a Strike Tree	Total
Ficus	Ficus	-	3	1	4	0%	11%	5%	8%
Fig	Ficus carica	4	24	20	48	100%	89%	95%	92%
	Total	4	27	21	52	100%	100%	100%	100%
	Aggregated by Genus	-	3	1	4	0%	11%	5%	8%
	Distinct Genus & species	4	24	20	48	100%	89%	95%	92%

Fraxinus		TAT Records (N)				Percent of Genus Total			
TAT Description	Genus & species	Abate	Do Not Abate	Not a Strike Tree	Total	Abate	Do Not Abate	Not a Strike Tree	Total
Ash	Fraxinus	94	643	101	838	89%	94%	93%	93%
Ash, Evergreen	Fraxinus uhdei	3	10	5	18	3%	1%	5%	2%
Ash, Modesto	Fraxinus velutina Modesto	9	29	3	41	8%	4%	3%	5%
Ash, Raywood	Fraxinus oxycarpa Raywod	-	5	-	5	0%	1%	0%	1%
	Total	106	687	109	902	100%	100%	100%	100%
	Aggregated by Genus	94	643	101	838	89%	94%	93%	93%
	Distinct Genus & species	12	44	8	64	11%	6%	7%	7%

Juglans		TAT Records (N)				Percent of Genus Total			
TAT Description	Genus & species	Abate	Do Not Abate	Not a Strike Tree	Total	Abate	Do Not Abate	Not a Strike Tree	Total
Walnut	Juglans	36	331	55	422	26%	34%	34%	33%
Walnut, English	Juglans regia	17	121	28	166	12%	12%	17%	13%
Walnut, Black	Juglans californica	86	531	78	695	62%	54%	48%	54%
	Total	139	983	161	1,283	100%	100%	100%	100%
	Aggregated by Genus	36	331	55	422	26%	34%	34%	33%
	Distinct Genus & species	103	652	106	861	74%	66%	66%	67%

Pinus		TAT Records (N)				Percent of Genus Total			
TAT Description	Genus & species	Abate	Do Not Abate	Not a Strike Tree	Total	Abate	Do Not Abate	Not a Strike Tree	Total
Pine	Pinus	295	1,454	148	1,897	1%	2%	2%	2%
Pine, Knobcone	Pinus attenuata	120	370	44	534	0%	0%	1%	0%
Pine, Canary Island	Pinus canariensis	4	32	1	37	0%	0%	0%	0%
Pine, Lodgepole	Pinus contorta latifolia	40	50	3	93	0%	0%	0%	0%
Pine, Aleppo	Pinus halepensis	40	251	22	313	0%	0%	0%	0%
Pine, Jeffery	Pinus jeffreyi	20	163	16	199	0%	0%	0%	0%
Pine, Sugar	Pinus lambertiana	371	2,036	129	2,536	1%	2%	2%	2%
Pine, Bishop	Pinus muricata	9	80	9	98	0%	0%	0%	0%
Pine, Italian Stone	Pinus pinea	37	161	20	218	0%	0%	0%	0%
Pine, Ponderosa	Pinus ponderosa	12,033	62,535	3,490	78,058	46%	68%	52%	62%
Pine, Monterey	Pinus radiata	964	5,525	136	6,625	4%	6%	2%	5%
Pine, Gray	Pinus sabiniana	12,212	19,687	2,669	34,568	47%	21%	40%	28%
	Total	26,145	92,344	6,687	125,176	100%	100%	100%	100%
	Aggregated by Genus	295	1,454	148	1,897	1%	2%	2%	2%
	Distinct Genus & species	25,850	90,890	6,539	123,279	99%	98%	98%	98%

Populus		TAT Records (N)				Percent of Genus Total			
TAT Description	Genus & species	Abate	Do Not Abate	Not a Strike Tree	Total	Abate	Do Not Abate	Not a Strike Tree	Total
Poplar	Populus	89	457	57	603	19%	25%	32%	24%
Poplar, Lombardy	Populus nigra talica	12	38	5	55	3%	2%	3%	2%
Cottonwood, Black	Populus trichocarpa	114	400	41	555	24%	22%	23%	22%
Cottonwood, Freemont	Populus fremontii	261	930	77	1,268	55%	51%	43%	51%
	Total	476	1,825	180	2,481	100%	100%	100%	100%
	Aggregated by Genus	89	457	57	603	19%	25%	32%	24%
	Distinct Genus & species	387	1,368	123	1,878	81%	75%	68%	76%

Quercus		TAT Records (N)				Percent of Genus Total			
TAT Description	Genus & species	Abate	Do Not Abate	Not a Strike Tree	Total	Abate	Do Not Abate	Not a Strike Tree	Total
Oak	Quercus	827	2,125	297	3,249	2%	1%	1%	1%
Oak, Live (Canyon or Interior)	Quercus chrysolepis or Q. wislezenii	10,187	29,570	6,233	45,990	24%	16%	27%	18%
Oak, Coast Live	Quercus agrifolia	2,015	16,597	1,285	19,897	5%	9%	6%	8%
Oak, Canyon Live	Quercus chrysolepis	1,118	4,510	565	6,193	3%	2%	2%	2%
Oak, Blue	Quercus douglasii	10,281	66,741	6,393	83,415	24%	35%	28%	33%
Oak, Oregon White	Quercus garryana	264	1,086	102	1,452	1%	1%	0%	1%
Oak, Holly	Quercus ilex	32	89	2	123	0%	0%	0%	0%
Oak, Black	Quercus kelloggii	9,933	29,572	3,370	42,875	23%	16%	15%	17%
Oak, Valley	Quercus lobata	3,885	23,838	2,374	30,097	9%	13%	10%	12%
Oak, Oracle	Quercus morehus	116	315	31	462	0%	0%	0%	0%
Oak, Pin	Quercus palustris	1	32	8	41	0%	0%	0%	0%
Oak, English	Quercus robur	8	50	-	58	0%	0%	0%	0%
Oak, Red Northern	Quercus rubra	23	60	8	91	0%	0%	0%	0%
Oak, Cork	Quercus suber	1	22	4	27	0%	0%	0%	0%
Oak, Interior Live	Quercus wislizenii	3,960	15,258	2,146	21,364	9%	8%	9%	8%
	Total	42,651	189,865	22,818	255,334	100%	100%	100%	100%
	Aggregated by Genus	827	2,125	297	3,249	2%	1%	1%	1%
	Distinct Genus & species	41,824	187,740	22,521	252,085	98%	99%	99%	99%

Salix		TAT Records (N)				Percent of Genus Total			
TAT Description	Genus & species	Abate	Do Not Abate	Not a Strike Tree	Total	Abate	Do Not Abate	Not a Strike Tree	Total
Willow	Salix	312	1,515	401	2,228	99%	97%	96%	97%
Willow, Weeping	Salix babylonica	4	50	17	71	1%	3%	4%	3%
	Total	316	1,565	418	2,299	100%	100%	100%	100%
	Aggregated by Genus	312	1,515	401	2,228	99%	97%	96%	97%
	Distinct Genus & species	4	50	17	71	1%	3%	4%	3%

Ulmus		TAT Records (N)				Percent of Genus Total			
TAT Description	Genus & species	Abate	Do Not Abate	Not a Strike Tree	Total	Abate	Do Not Abate	Not a Strike Tree	Total
Elm	Ulmus	29	186	25	240	91%	61%	76%	65%
Elm American	Ulmus americana	3	43	1	47	9%	14%	3%	13%
Elm, Chinese	Ulmus parvifolia	-	76	7	83	0%	25%	21%	22%
	Total	32	305	33	370	100%	100%	100%	100%
	Aggregated by Genus	29	186	25	240	91%	61%	76%	65%
	Distinct Genus & species	3	119	8	130	9%	39%	24%	35%

No Aggregates: Genus sp.		TAT Records (N)				Percent of Genus Total			
TAT Description	Genus & species	Abate	Do Not Abate	Not a Strike Tree	Total	Abate	Do Not Abate	Not a Strike Tree	Total
Buckeye	Aesculus sp.	140	784	200	1,124	12%	70%	18%	100%
Century Plant	Agave americana	2	6	15	23	9%	26%	65%	100%
Ailanthus	Ailanthus altissima	49	249	146	444	11%	56%	33%	100%
Monkey Puzzle	Araucaria araucana	3	3	-	6	50%	50%	0%	100%
Norfolk Island Pine	Araucaria heterophylla	-	8	-	8	0%	100%	0%	100%
Madrone	Arbutus menziesii	4,477	8,254	978	13,709	33%	60%	7%	100%
Bottlebrush	Callistemon sp.	6	9	1	16	38%	56%	6%	100%
Cedar, Incense	Calocedrus decurrens	4,393	28,062	2,185	34,640	13%	81%	6%	100%
Pecan	Carya illinoensis	14	85	5	104	13%	82%	5%	100%
Chestnut	Castanea dentata	5	41	1	47	11%	87%	2%	100%
Atlas, Cedar	Cedrus atlantica	19	142	4	165	12%	86%	2%	100%
Deodara, Cedar	Cedrus deodara	45	1,437	90	1,572	3%	91%	6%	100%
Carob	Ceratonia siliqua	-	2	-	2	0%	100%	0%	100%
Redbud	Cercis occidentalis	5	35	18	58	9%	60%	31%	100%
Camphor	Cinnamomum camphora	7	41	6	54	13%	76%	11%	100%
Willow, Australian	Geijera parviflora	2	3	2	7	29%	43%	29%	100%
Ginkgo	Ginkgo biloba	-	8	-	8	0%	100%	0%	100%
Oak, Silk	Grevillea robusta	5	52	2	59	8%	88%	3%	100%
Toyon	Heteromeles arbutifolia	6	95	24	125	5%	76%	19%	100%
Hickory	Hicoria ovata	1	35	-	36	3%	97%	0%	100%
Laurel Grecian	Laurus nobilis	6	15	2	23	26%	65%	9%	100%
Oak, Tan	Lithocarpus densiflorus	6,003	12,130	1,048	19,181	31%	63%	5%	100%
Tulip Tree	Liriodendron tulipifera	3	32	2	37	8%	86%	5%	100%
Apple	Malus pumila	19	88	32	139	14%	63%	23%	100%
Chinaberry	Melia azedarach	3	21	5	29	10%	72%	17%	100%
Redwood, Dawn	Metasequoia glyptostroboides	9	265	14	288	3%	92%	5%	100%
Myrtle, Pacific Wax	Myrica californica	2	14	-	16	13%	88%	0%	100%
Oleander	Nerium oleander	-	67	3	70	0%	96%	4%	100%
Olive	Olea europaea	17	435	90	542	3%	80%	17%	100%
Palo Verde	Parkinsonia aculeata	1	-	-	1	100%	0%	0%	100%
Avocado	Persea americana	2	12	6	20	10%	60%	30%	100%
Almond	Prunus dulcis	7	51	3	61	11%	84%	5%	100%
Fir, Douglas	Pseudotsuga menziesii	12,812	79,417	3,075	95,304	13%	83%	3%	100%
Cascara	Rhamnus purshiana	5	13	7	25	20%	52%	28%	100%
Locust, Black	Robinia pseudoacacia	122	325	65	512	24%	63%	13%	100%
Tallow, Chinese	Sapium sebiferum	2	22	2	26	8%	85%	8%	100%
Redwood, Coast	Sequoia sempervirens	1,374	30,912	603	32,889	4%	94%	2%	100%
Sequoia, Giant	Sequoiadendron giganteum	18	498	24	540	3%	92%	4%	100%
Palm-Queen	Syagrus romanzoffianum	-	25	-	25	0%	100%	0%	100%
Eugenia	Syzygium paniculatum	-	4	-	4	0%	100%	0%	100%

FORMATION ENVIRONMENTAL

No Aggregates: Genus Only		TAT Records (N)				Percent of Genus Total			
TAT Description	Genus	Abate	Do Not Abate	Not a Strike Tree	Total	Abate	Do Not Abate	Not a Strike Tree	Total
Manzanita	Arctostaphylos	121	705	180	1,006	12%	70%	18%	100%
Bamboo	Bamboo	8	30	6	44	18%	68%	14%	100%
Birch	Betula	25	294	24	343	7%	86%	7%	100%
Chinquapin	Castanopsis	15	12	-	27	56%	44%	0%	100%
Casuarina	Casuarina	-	13	5	18	0%	72%	28%	100%
Catalpa	Catalpa	13	59	15	87	15%	68%	17%	100%
Ceanothus	Ceanothus	20	63	23	106	19%	59%	22%	100%
Hackberry	Celtis	1	13	12	26	4%	50%	46%	100%
Dogwood	Cornus	4	105	17	126	3%	83%	13%	100%
Hawthorn	Crataegus	1	19	9	29	3%	66%	31%	100%
Beech	Fagus	5	7	6	18	28%	39%	33%	100%
Juniper	Juniperus	22	315	43	380	6%	83%	11%	100%
Koelreuteria	Koelreuteria	-	1	1	2	0%	50%	50%	100%
Myrtle, Crape	Lagerstroemia	2	43	3	48	4%	90%	6%	100%
Privet	Ligustrum	14	424	69	507	3%	84%	14%	100%
Liquid Amber (Sweet Gum)	Liquidambar	31	815	68	914	3%	89%	7%	100%
Magnolia	Magnolia	1	66	7	74	1%	89%	9%	100%
Mulberry	Morus	21	265	80	366	6%	72%	22%	100%
Myoporum	Myoporum	-	4	-	4	0%	100%	0%	100%
Palm	Palm	2	108	9	119	2%	91%	8%	100%
Palm-Date	Phoenix	-	15	-	15	0%	100%	0%	100%
Photinia	Photinia	2	27	7	36	6%	75%	19%	100%
Spruce	Picea	34	531	22	587	6%	90%	4%	100%
Pistache	Pistacia	5	113	22	140	4%	81%	16%	100%
Pittosporum	Pittosporum	3	47	6	56	5%	84%	11%	100%
Sycamore	Platanus	188	944	39	1,171	16%	81%	3%	100%
Mesquite	Prosopis	-	2	-	2	0%	100%	0%	100%
Apricot	Prunus	1	2	3	6	17%	33%	50%	100%
Cherry	Prunus	21	254	57	332	6%	77%	17%	100%
Peach	Prunus	1	14	-	15	7%	93%	0%	100%
Plum	Prunus	23	347	86	456	5%	76%	19%	100%
Pomegranate	Punica	2	11	-	13	15%	85%	0%	100%
Podocarpus	Punica	-	6	-	6	0%	100%	0%	100%
Pear	Pyrus	19	338	54	411	5%	82%	13%	100%
Elderberry	Sambucus	5	27	9	41	12%	66%	22%	100%
Pepper Tree	Schinus	5	90	4	99	5%	91%	4%	100%
Tamarisk	Tamarix	-	5	-	5	0%	100%	0%	100%
Linden	Tilia	-	9	1	10	0%	90%	10%	100%
Hemlock	Tsuga	-	10	-	10	0%	100%	0%	100%
Palm-Fan	Washingtonia	1	67	8	76	1%	88%	11%	100%
Yucca	Yucca	-	11	-	11	0%	100%	0%	100%
Zelkova	Zelkova	1	9	2	12	8%	75%	17%	100%

General Aggregates		TAT Records (N)				Percent of Total			
TAT Description	Genus	Abate	Do Not Abate	Not a Strike Tree	Total	Abate	Do Not Abate	Not a Strike Tree	Total
Brush (misc)	None	202	577	943	1,722	12%	34%	55%	100%
Other	None	313	1,319	2,103	3,735	8%	35%	56%	100%
Unknown	None	93	471	175	739	13%	64%	24%	100%
Vine	None	9	20	12	41	22%	49%	29%	100%
Fruit Tree	None	39	354	66	459	8%	77%	14%	100%
Citrus	None	-	23	2	25	0%	92%	8%	100%

Duplicate Name for 2 Species		TAT Records (N)				Percent of Genus Total			
TAT Description	Genus & species	Abate	Do Not Abate	Not a Strike Tree	Total	Abate	Do Not Abate	Not a Strike Tree	Total
Mimosa	Albizia julibrissin	10	64	18	92	11%	70%	20%	100%
Albizzia	Albizia julibrissin	3	9	7	19	16%	47%	37%	100%
Total		**13**	**73**	**25**	**111**	**12%**	**66%**	**23%**	**100%**
Loquat	Eriobotrya japonica	-	9	-	9	0%	100%	0%	100%
Locust, Honey	Eriobotrya japonica	17	109	30	156	11%	70%	19%	100%
Total		**17**	**118**	**30**	**165**	**10%**	**72%**	**18%**	**100%**

2 Species for 1 TAT Species Code		TAT Records (N)				Percent of Genus Total			
TAT Description	Genus & species	Abate	Do Not Abate	Not a Strike Tree	Total	Abate	Do Not Abate	Not a Strike Tree	Total
Bay, Calif.	Umbellularia californica or Laurus nobilis	2,868	8,904	981	12,753	22%	70%	8%	100%

Appendix D: EcoRegion Analysis

Regional Species Fire Risk Rating

The regional species fire risk rating (RSFRR) parameter was conceived and developed by the PG&E distribution vegetation management team to provide a species-specific index which is intended to characterize the wildfire risk posed by certain tree species throughout PG&E's service territory. The RSFRR, as currently implemented in the EVM TAT model, provides a quantitative parameter which relates the frequency of historical trunk and root failure outages and ignitions (with additional weight applied to ignitions) caused by a particular tree species to the proportion of the total tree population that species comprises (Figure D1).

$$\frac{\text{\% regional root and trunk outages caused by species}}{\text{species \% of total regional tree population}} + 1.5\text{ X } \frac{\text{\% regional root and trunk ignitions caused by species}}{\text{species \% of total regional tree population}}$$

FIGURE D1.
The calculation used to compute Regional Species Fire Risk Rating values.

In other words, a tree species associated with more outages and ignitions than that species' proportion of the overall tree population would be considered to represent a greater likelihood of causing outages and ignitions and thus assigned a higher RSFRR value. These species-specific values which comprise the RSFRR calculation (i.e., outages, ignitions, and percentage of total tree population) were spatially aggregated and calculated within each of PG&E's six administrative regions (i.e., Bay, Central Coast, Central Valley, North Coast, North Valley, and Sierra regions) to derive a unique RSFRR for certain species within each administrative region. Reference species composition data (i.e., the relative percentage of the total tree population represented by each species in each region) was calculated using PG&E's routine vegetation work history management database to serve as an estimate of the overall tree species composition within the vicinity of PG&E's distribution assets in each administrative region. PG&E used the 2016 – 2017 vegetation inspection cycle to form the basis of the reference species composition used in the RSFRR development and provide a "snapshot" of the relative percentage of the tree population represented by all major tree species (i.e., species responsible for ≥ 1% of the outages) in each of PG&E's six administrative regions. The regional focus was intended to help capture species-specific trends which may be related to environmental, anthropogenic, or asset-related variables which vary around PG&E's distribution service territory throughout the state of California. PG&E designed the RSFRR parameter specifically to address root and trunk failure events occurring during fire season months (i.e., May through November) and the EVM TAT model is specifically focused on reducing outages and ignitions during the most fire-prone times of the year.

The RSFRR parameter is incorporated into the "Tree Environment Score" component of the EVM TAT model and is the most heavily weighted parameter of the Tree Environment score. The RSFRR values for each species / region combination are classified into four classes with each class being assigned a numeric score (Table D1) that is subsequently added to the other Tree Environment parameter scores to arrive at a total Tree Environment score (and abatement decision after being combined with the Tree Health score) for each tree inspected with the EVM TAT which is not a Boolean abatement.

RSFRR Class	RSFRR Value	Assigned Score
Low	RSFRR $\leq$ 2	5
Medium	2 < RSFRR $\leq$ 7	15
High	7 < RSFRR $\leq$ 12	26
Very High	12 < RSFRR	36

TABLE D1: Regional Species Fire Risk Rating value ranges and assigned scores as part of the Tree Environment Score TAT component.

A review of the source input data, RSFRR methodology, methodology, overall EVM TAT model, and conversations with PG&E vegetation management conversations with PG&E vegetation management subject matter experts (SMEs) led to the identification of two primary opportunities for potential improvement of the RSFRR: 1) enhancing the spatial aggregation component of the RSFRR through the incorporation of the Environmental Protection Agency's (EPA) Level III Ecoregions (as opposed to PG&E's administrative regions); and 2) increasing the robustness of the reference species composition analysis by incorporating multiple vegetation management annual inspection cycles. The use of multiple annual inspection cycles facilitated assessing the sensitivity of selecting any single annual inspection cycle and provided a larger dataset from which to determine the regional tree species composition.

The EPA has identified and categorized ecoregions (i.e., spatially-defined zones where ecosystem characteristics are generally homogenous) at various spatial scales, which serve as a spatial framework for a variety of research, management, and monitoring objectives throughout North America. The EPA's ecoregion definitions incorporate vegetation, climate, land use, wildlife, hydrology, geology, landforms, and soils to define ecoregions at four spatial scales increasing in detail from Level I to Level IV (Omernik and Griffith, 2014). With respect to the regional species fire risk rating methodology, the Level III Ecoregions were assessed to provide the most meaningful balance between level of detail and the number of regions used for RSFRR analysis, such that the regions are not so small as to result in very low counts of outages and ignitions per species in each region. While PG&E's distribution service territory intersects nine EPA-Level III Ecoregions, this analysis was focused on characterizing historical outages and ignitions within the CPUC High Fire Threat District (HFTD) Tier 3 and Tier 2 areas, (consistent with the EVM program), which spatially constrain the analysis to five primary Level III Ecoregions: 1) Cascades; 2) Central California Foothills and Coastal Mountains; 3) Coast Range; 4) Klamath Mountains / California High North Coast Range; and 5) Sierra Nevada (Figure D2). As compared to the PG&E administrative regions which are strictly managerial in nature, the EPA's Level III ecoregions provide a spatial framework which is more meaningful from an environmental and geospatial perspective by facilitating the aggregation of historical outages and ignitions into more homogenous zones that are defined by characteristics with increased relevance to wildland fire.

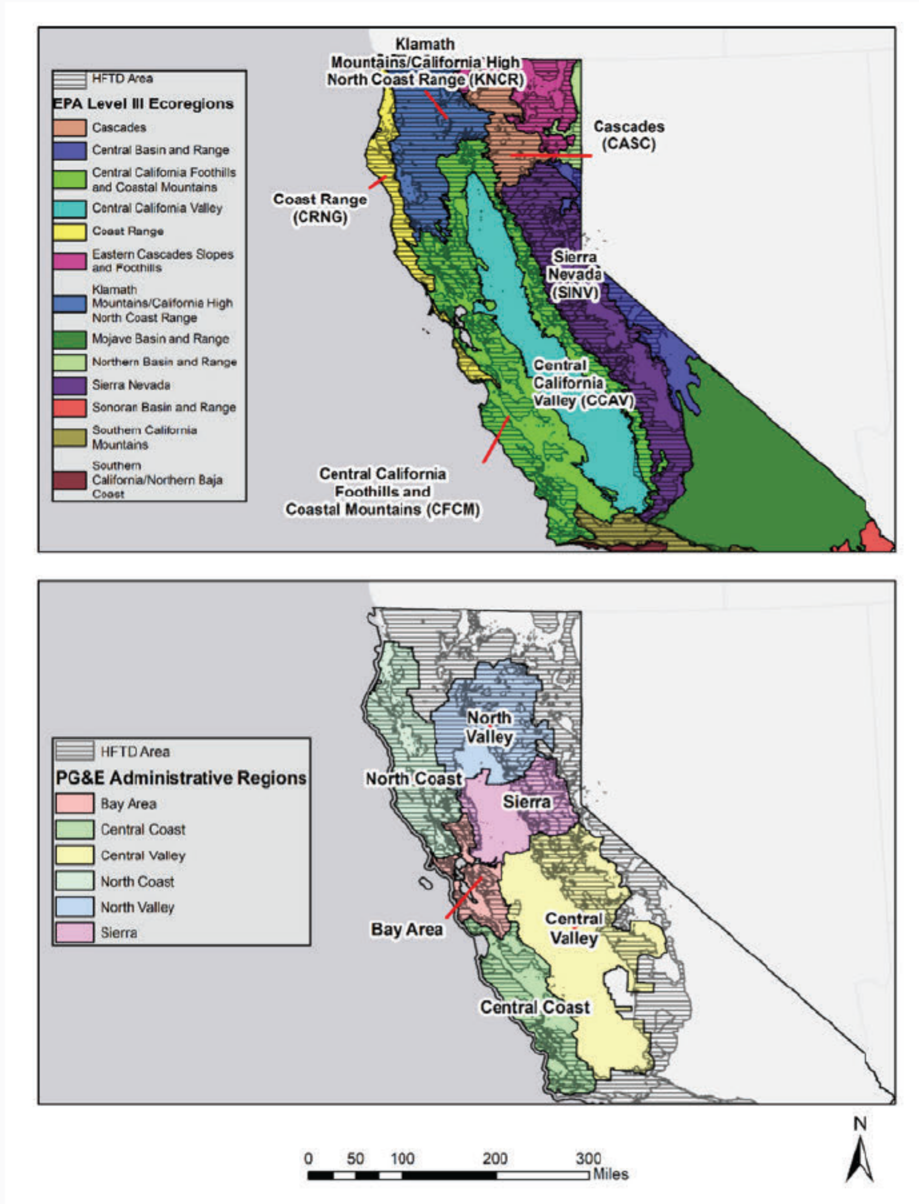


Figure D2. Overview map depicting EPA Level III Ecoregions (top panel) and PG&E administrative regions (bottom panel), with CPUC HFTD areas indicated by horizontal black hatching.

The potential temporal sensitivity associated with using a single, annual vegetation management inspection cycle was assessed by increasing the time frame of analysis to include seven annual inspection cycles ranging from 2013 – 2020 (the maximum number of available inspection cycles deemed useable from the distribution routine work history database). This subset of the distribution routine work history database consisted of approximately 38 million records and formed the basis of the multi-year, ecoregion-based species composition calculations.

The primary PG&E datasets used to enhance the RSFRR parameter were: 1) historical PG&E distribution outage and ignition database; 2) PG&E distribution routine vegetation management work history database; 3) EVM TAT inspection records database. The historical outages and ignitions were spatially filtered to the HFTD areas to focus the analysis on the most inherently fire prone areas and to be consistent with the EVM program focus in the HFTD areas. Historical outages and ignitions were temporally filtered to only the fire season months (May through November) to focus the analysis on species-specific trends which occur during the months of the year where a tree failure is more likely to cause an ignition (as compared to the wetter winter months where a tree failure is less likely to cause an ignition). The overall temporal range of the historical outage and ignition data, after the described filtering, was from October 2007 through June 2021 and consisted of approximately 4,717 tree failures used for analysis. These tree failures represent only those outages and ignitions caused by root or trunk failure mechanisms to be consistent with the focus of the EVM TAT model on targeting root and trunk failure fall-in failures. The routine work history database was similarly filtered to the HFTD areas such that the reference tree species composition data was based on the same geographic extent as the failure trees. No fire season temporal filtering was performed on the routine work history dataset because this dataset was used to estimate the regional tree species composition and is not sensitive to the time at which any particular tree was inspected or worked in the past.

Using the routine work history database, the estimated species composition of each ecoregion was determined by calculating the total number of trees in an ecoregion and dividing the count of each tree species by that regional total to estimate the regional percent composition. This was done separately for each of seven annual inspection cycles which occurred from 2013 – 2020 to reduce the sensitivity of the RSFRR parameter to any one particular year of routine work history data. A mean species composition of the seven annual inspection cycles was also calculated by taking the averages of the total regional tree counts and species-specific regional tree counts across the seven inspection cycles. With the reference species compositions estimated, the historical outages and ignitions caused by root and trunk failures were analyzed to determine the number of outages and ignitions caused by each species in each ecoregion.

The total number of outages and ignitions per ecoregion were summed and the species- specific outage and ignition counts per ecoregion were divided by these regional totals to determine the percentages of outages and ignitions caused by each species in each ecoregion. To focus the analysis on the most significant species with respect to historical outages and ignitions and reduce data artifacts caused by uncommon species which may have only been responsible for a single outage or ignition over the 13-year study period (as well as to be consistent with the existing

RSFRR methodology), any species responsible for less than 1% of the outages or ignitions in a particular ecoregion was not included in further RSFRR calculations. The regional reference species compositions and species-specific regional outage and ignition percentages were then input into the existing RSFRR equation (Figure D1) and resultant RSFRR values were obtained for the significant species in each ecoregion across the seven annual inspection cycles and the averaged mean inspection cycle. The boxplots in Figures D3-D7 show the enhanced RSFRR values for all significant species in each of the five ecoregions, with the distribution of the RSFRR values shown on the Y-axis representing the range of RSFRR values across the seven annual vegetation inspection cycles. Figure D8 (page 103) shows the same RSFRR calculation applied to the HFTD as a whole (i.e., treating the entire HFTD as one single region).

In the context of assessing the sensitivity and significance of using any single annual inspection cycle to define the reference species composition of the RSFRR calculation, the boxplots shown in Figures D3-D7 may be considered by examining the extent of overlapping RSFRR values amongst the significant species in each ecoregion.

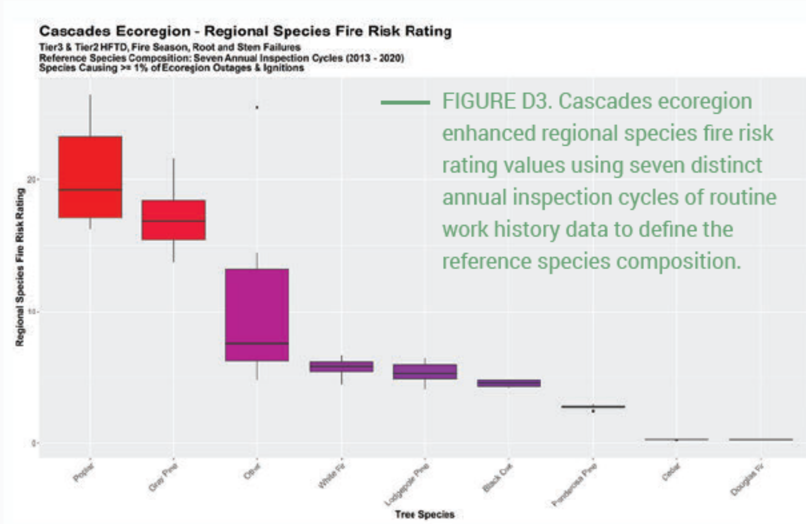


FIGURE D3. Cascades ecoregion enhanced regional species fire risk rating values using seven distinct annual inspection cycles of routine work history data to define the reference species composition.

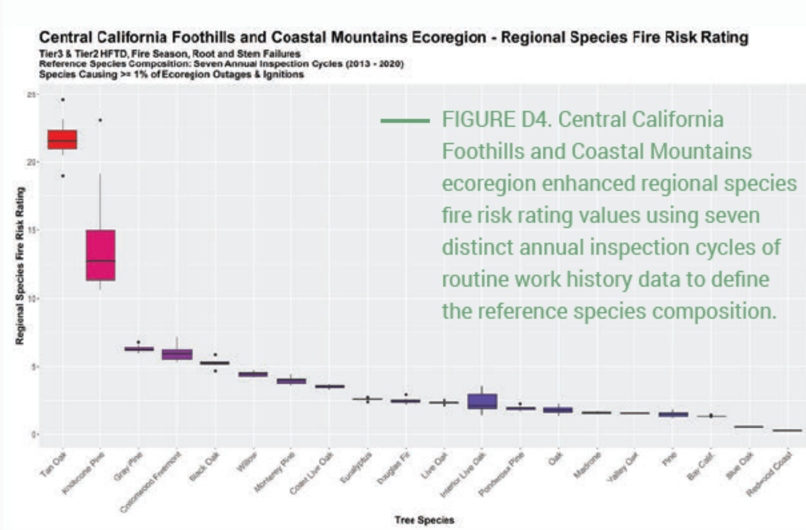


FIGURE D4. Central California Foothills and Coastal Mountains ecoregion enhanced regional species fire risk rating values using seven distinct annual inspection cycles of routine work history data to define the reference species composition.

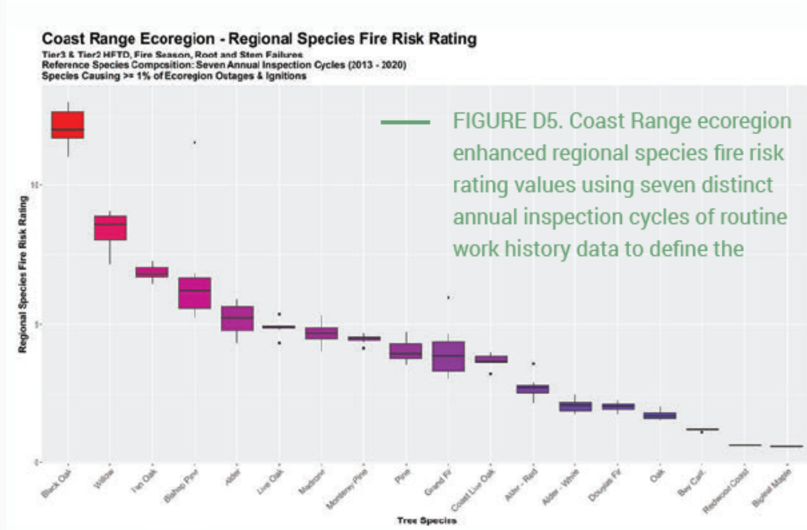


FIGURE D5. Coast Range ecoregion enhanced regional species fire risk rating values using seven distinct annual inspection cycles of routine work history data to define the

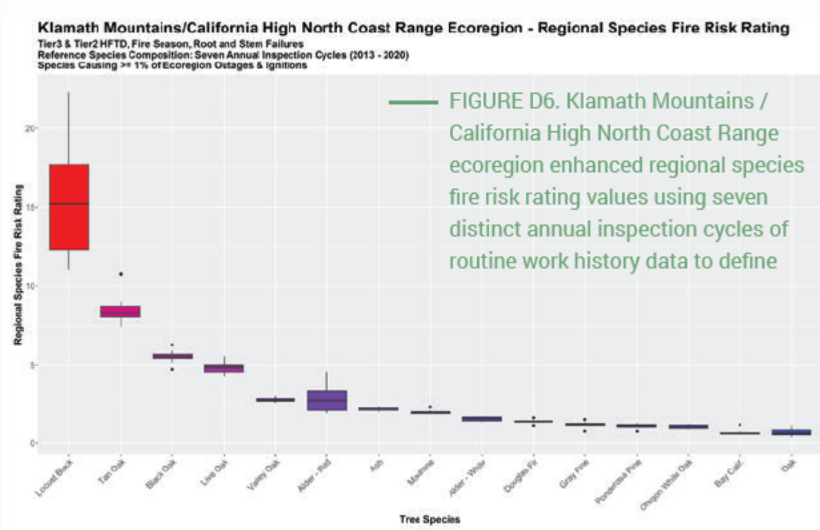


FIGURE D6. Klamath Mountains / California High North Coast Range ecoregion enhanced regional species fire risk rating values using seven distinct annual inspection cycles of routine work history data to define

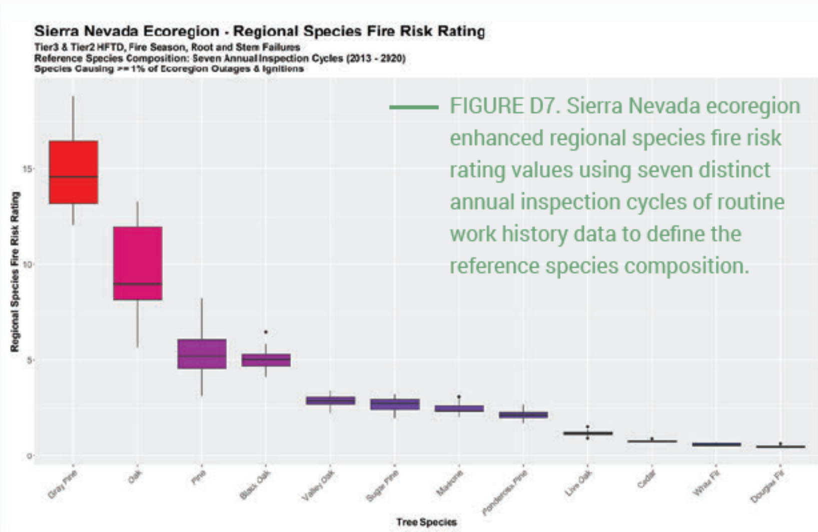


FIGURE D7. Sierra Nevada ecoregion enhanced regional species fire risk rating values using seven distinct annual inspection cycles of routine work history data to define the reference species composition.

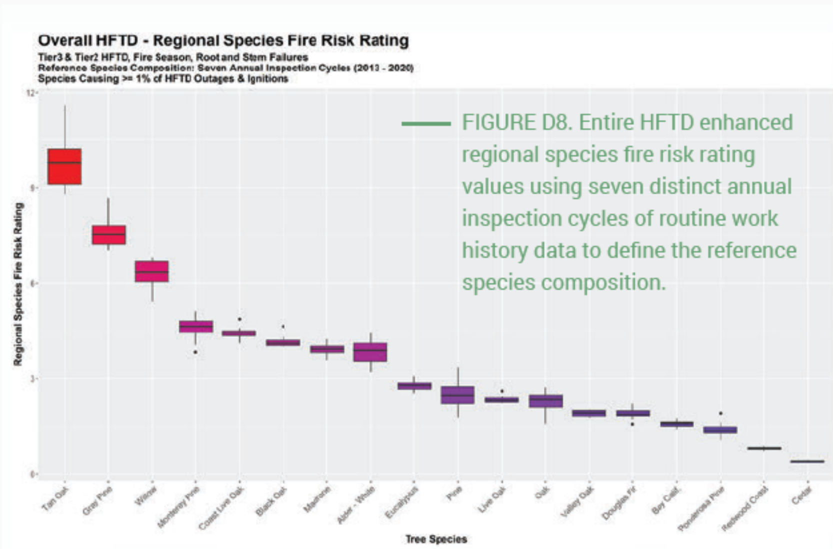


FIGURE D8. Entire HFTD enhanced regional species fire risk rating values using seven distinct annual inspection cycles of routine work history data to define the reference species composition.

If many species within a particular ecoregion had a substantial amount of overlap in their RSFRR values across the seven annual inspection cycles, this would indicate that the RSFRR calculation is more sensitive to the choice of which single annual inspection cycle was used to define the reference species composition. For example, if three different species in a particular ecoregion all exhibited a boxplot with 25th and 75th percentile RSFRR values of 5 and 10, respectively, this would indicate that these species have a large overlapping range of potential RSFRR values and thus would be sensitive to which inspection cycle was used. However, a review of the ecoregion-based RSFRR boxplots shows that, generally speaking, the distribution of RSFRR values have minimal overlap between different species. In cases where several species share some overlapping values, these value ranges tend to be quite small compared to the overall range of RSFRR values in that ecoregion. This indicates that the RSFRR values are not very sensitive to an arbitrary choice of which annual inspection cycle is used as a reference species composition, based on the PG&E distribution routine work history database. It follows that the decision by PG&E to use the 2016 – 2017 annual inspection cycle as the reference species composition of the current RSFRR methodology is a reasonable and appropriate decision based on these observations. Nevertheless, there is still some variation associated with the selection of an annual inspection cycle and the use of a reference species composition averaged over several years of routine work history data is proposed and recommended as an improvement over the use of a single inspection cycle.

It is difficult to perform a meaningful comparison of the resultant RSFRR values between the two spatial aggregation methodologies due to the differing regional extents, each of which generally overlap multiple portions of the other aggregation units as seen on the map in Figure D2. The boxplots shown in Figure D9 depict the range of regional RSFRR values for each species, showing the range of values across all spatial aggregation units where that species was responsible for at least 1% of the outages or ignitions in that region. Despite the difficulty in assessing which

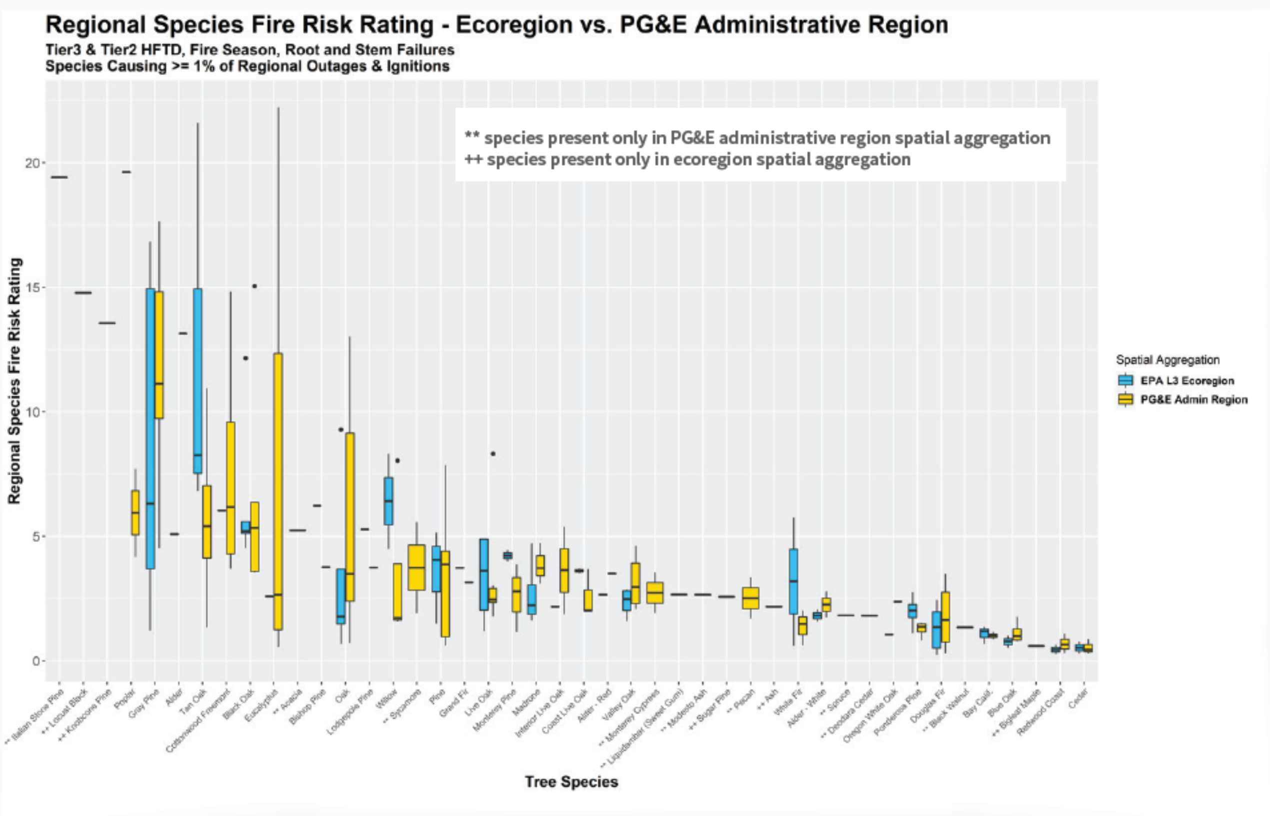


FIGURE D9. Comparison of RSFRR values computed using EPA Level III Ecoregion vs. PG&E administrative region spatial aggregation by species. The range of RSFRR values shown on the Y-axis represents the range of RSFRR values across the respective spatial aggregation units (i.e., ecoregions or administrative regions) for each significant species.

spatial aggregation method is more "accurate" in the context of characterizing species-specific wildfire risk, the use of the EPA Level III Ecoregions as a unit of spatial aggregation is intuitively more meaningful and appropriate based on the relevance of those biotic and abiotic criteria used to delineate these ecoregions as compared to an arbitrary administrative boundary which does not consider any such criteria. For example, the North Valley PG&E administrative region includes portions of five different Level III Ecoregions, ranging from the high elevation Sierra Nevada mountain range to the low elevation central valley and out to the coastal mountains, comprising a large variety of vegetation communities, land management areas, weather patterns, etc. When attempting to characterize distinct regional trends in natural features such as individual species of trees, it is desirable to group together similar species in similar environmental conditions because those are the variables of interest which relate to the historical occurrences of wildland fires, while the administrative boundaries of PG&E's management units do not.

The line plot shown in Figure D10 represents the number of regions in which each species was found to be responsible for at least 1% of outages or ignitions between the ecoregion and administrative region spatial

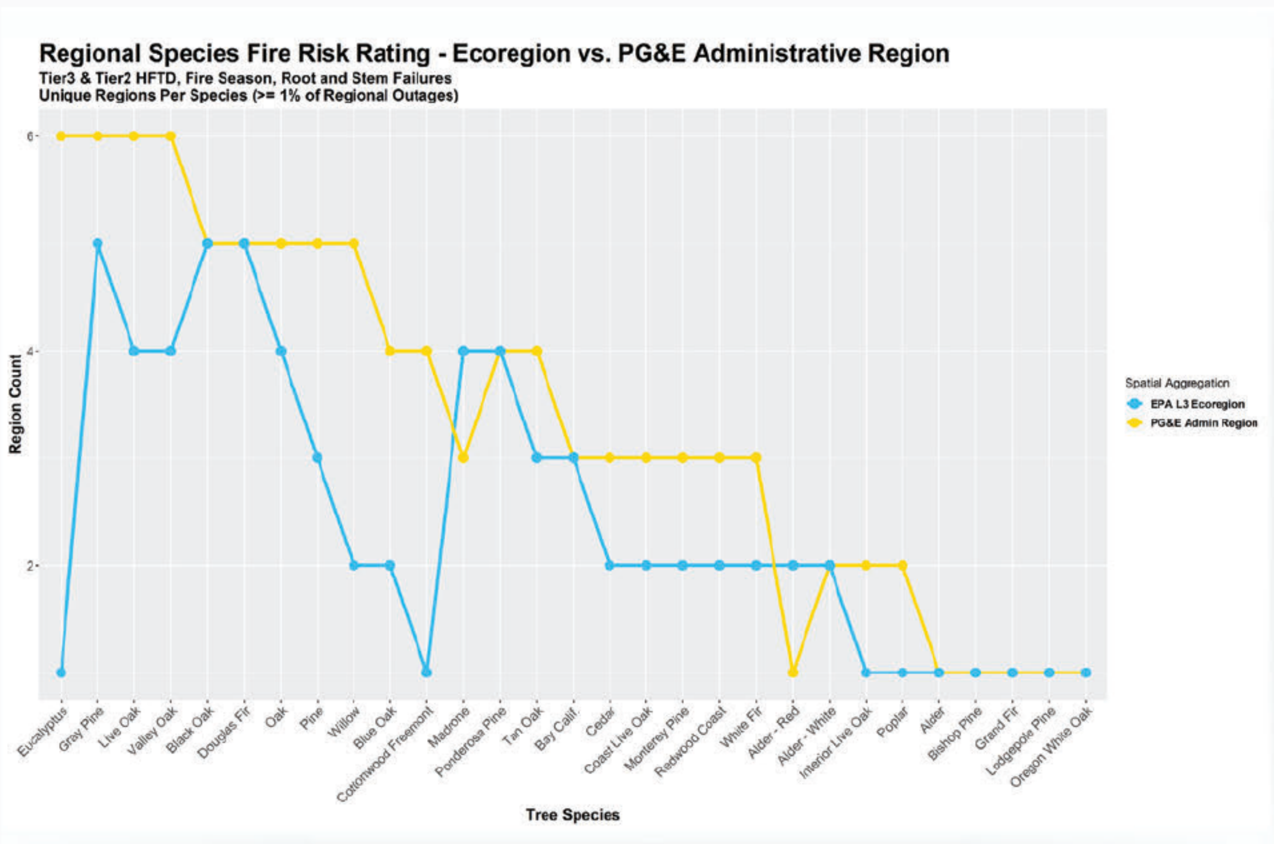


FIGURE D10. Comparison of the number of unique regions for which each tree species was responsible for at least 1% of historical outages and ignitions.

aggregation techniques. While there are only five ecoregions in use compared to the six administrative regions, this figure illustrates that the use of ecoregions as the unit of spatial aggregation generally results in fewer unique regions per tree species as compared to the administrative units. This is considered indicative of more meaningful and intuitive spatial clustering of similar trees under similar conditions. Given the aforementioned advantages of utilizing ecoregions as compared to administrative regions as the spatial aggregation unit of the RSFRR, it is proposed and recommended that the EPA-Level III Ecoregions be used in place of the PG&E administrative regions as an improvement to the RSFRR methodology.

The hypothetical changes in tree abatements, amongst the 640,501 trees already inspected with the current EVM TAT model, were calculated by replacing the existing RSFRR scores of the Tree Environment Score component with the proposed enhanced RSFRR scores (using the mean species composition of the seven annual inspection cycles). The proposed RSFRR values were classified into the same four-class structure as used in the current EVM TAT model (Figure D1) for the sake of a consistent comparison, but these threshold values could be revised based on SME input and consideration of these results. Using the new RSFRR scores based on the proposed enhancements, the Tree Environment Score component of the EVM TAT model was recalculated for every relevant tree and the final hypothetical outcomes were updated based on the existing EVM TAT decision matrix. It must be noted that due to the nature of the EVM TAT model implementation and database conventions, these hypothetical abatement count comparisons were only calculated for the trees which were not already designated as Boolean abatements (i.e., automatically abated due to the Boolean criteria of severe lean towards facilities, tree mortality, fruiting bodies, major wounds, or significant insect attack damage) due to the fact that these trees would be abated regardless of their RSFRR value. Omitting the Boolean abatements and trees considered to pose no risk to PG&E assets (i.e., blocked or non-strike trees) leaves a total population of 450,833 trees which were either designated as non-Boolean abatements or “do not abate” trees in the existing EVM TAT database. Implementing the proposed RSFRR methodology improvements and assessing these trees using the same scoring thresholds as currently used in the EVM TAT model results in a net increase of 796 tree abatements across the entire HFTD area which has been inspected using the EVM TAT so far (Figure D11 - page 107).

While a hypothetical net increase of 796 tree abatements is relatively minor with respect to the total number of existing non-Boolean tree abatements (20,763), there were in fact 3,904 trees with revised hypothetical abatement outcomes (2,350 new abatements and 1,554 retracted abatements). The species-specific hypothetical abatement counts show some significant changes on a per-species basis and suggest that the same amount of EVM tree work being currently conducted could be directed more efficiently towards species with greater relative regional fire risk potential (Figure D12 - page 108).

FIGURE D11. A comparison of the total number of non-Boolean tree abatements if the proposed RSFRR enhancements were hypothetically used in place of the current RSFRR methodology for the trees already evaluated with the EVM TAT.

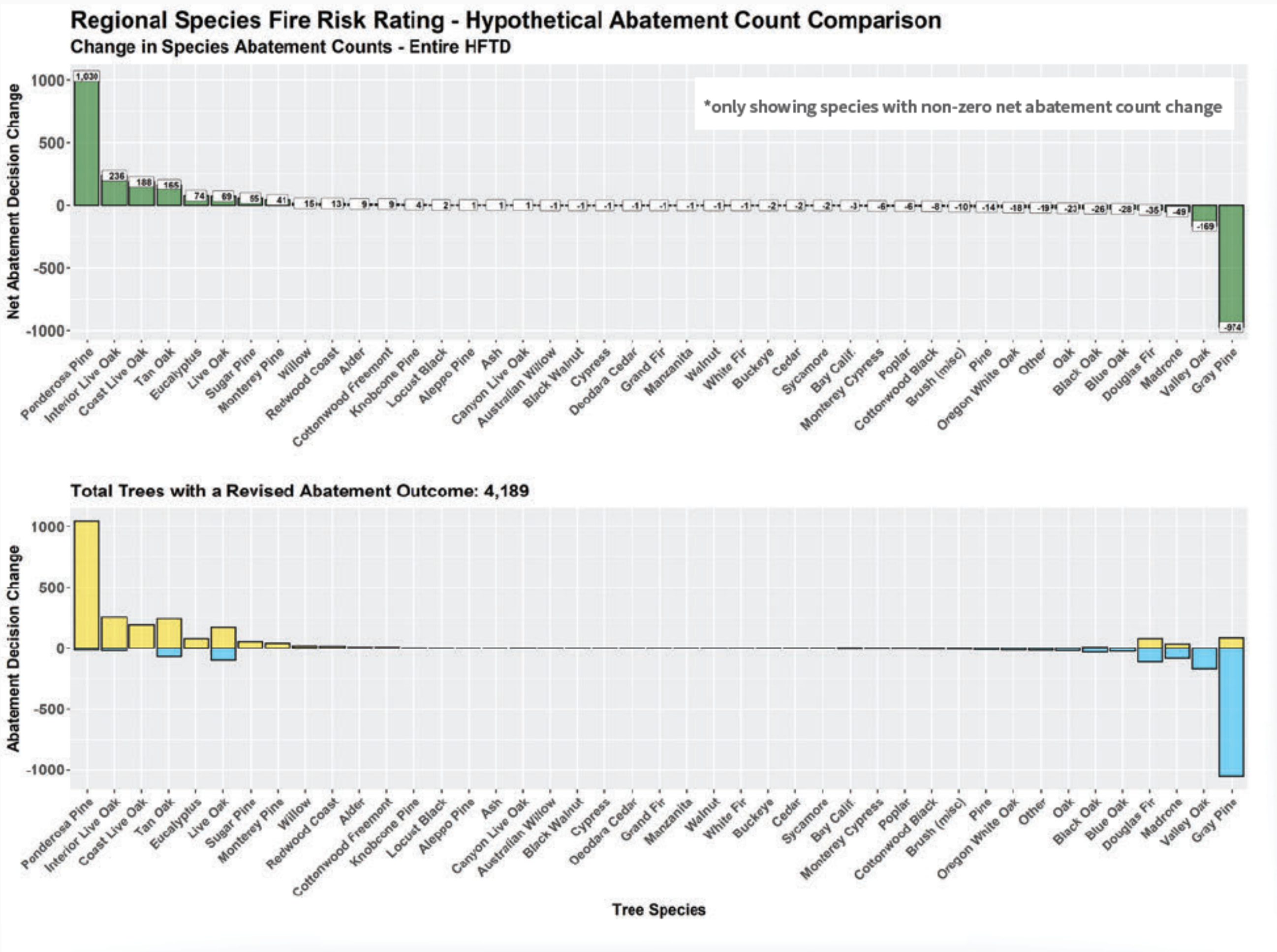


FIGURE D12. Changes in hypothetical non-Boolean abatements using the proposed RSFRR methodology enhancements.

New Abatement

Retracted Abatement

The hypothetical changes in non-Boolean abatements in each ecoregion can be seen in Figure D13 (page 109) and are indicative of the impacts of aggregating historical outages and ignitions based on ecoregions as compared to administrative regions.

In the current implementation of the EVM TAT, only 0.7% of the trees assessed as being in the "very high" risk class of the existing RSFRR result in non-Boolean abatements, while 9.7% of those trees in the very high risk class were marked for abatement due to one of the Boolean health or significant lean parameters; leaving 75.1% of the these trees designated

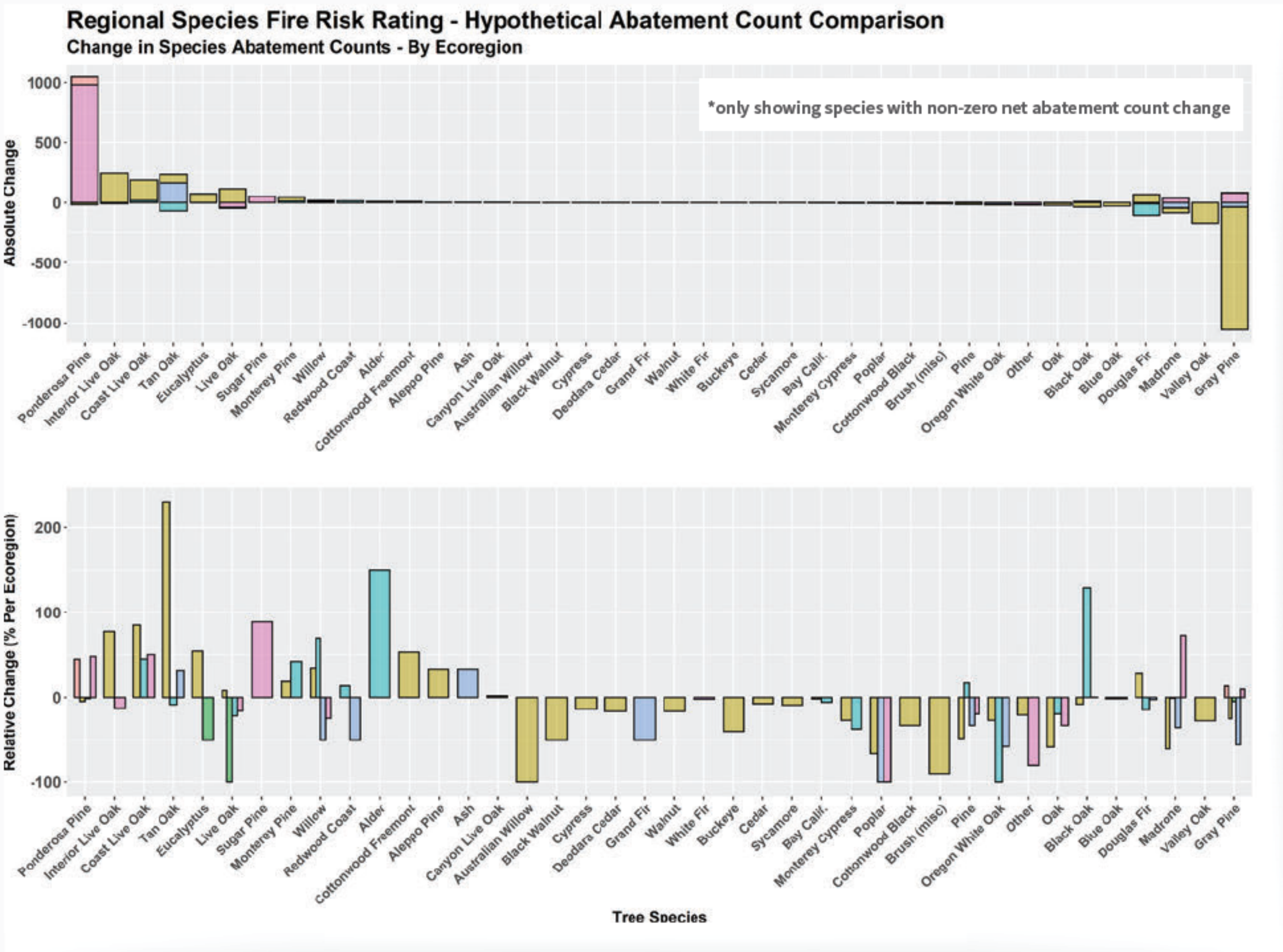


FIGURE D13. Changes in hypothetical non-Boolean abatements using the proposed RSFRR methodology enhancements in each EPA Level III Ecoregion.

as “do not abate” and the remaining 14.6% being left standing due to their assessment as a non-strike tree, blocked tree, or tree that is leaning significantly away from the distribution asset (Figure D14- page 110). If this behavior is not intended by the PG&E vegetation management SMEs, the scoring and weighting mechanisms of the EVM TAT model could be adjusted to increase the non-Boolean abatement frequency of trees which are in the very high RSFRR class but currently score low enough on the Tree Health Score component to result in a “do not abate” decision despite the

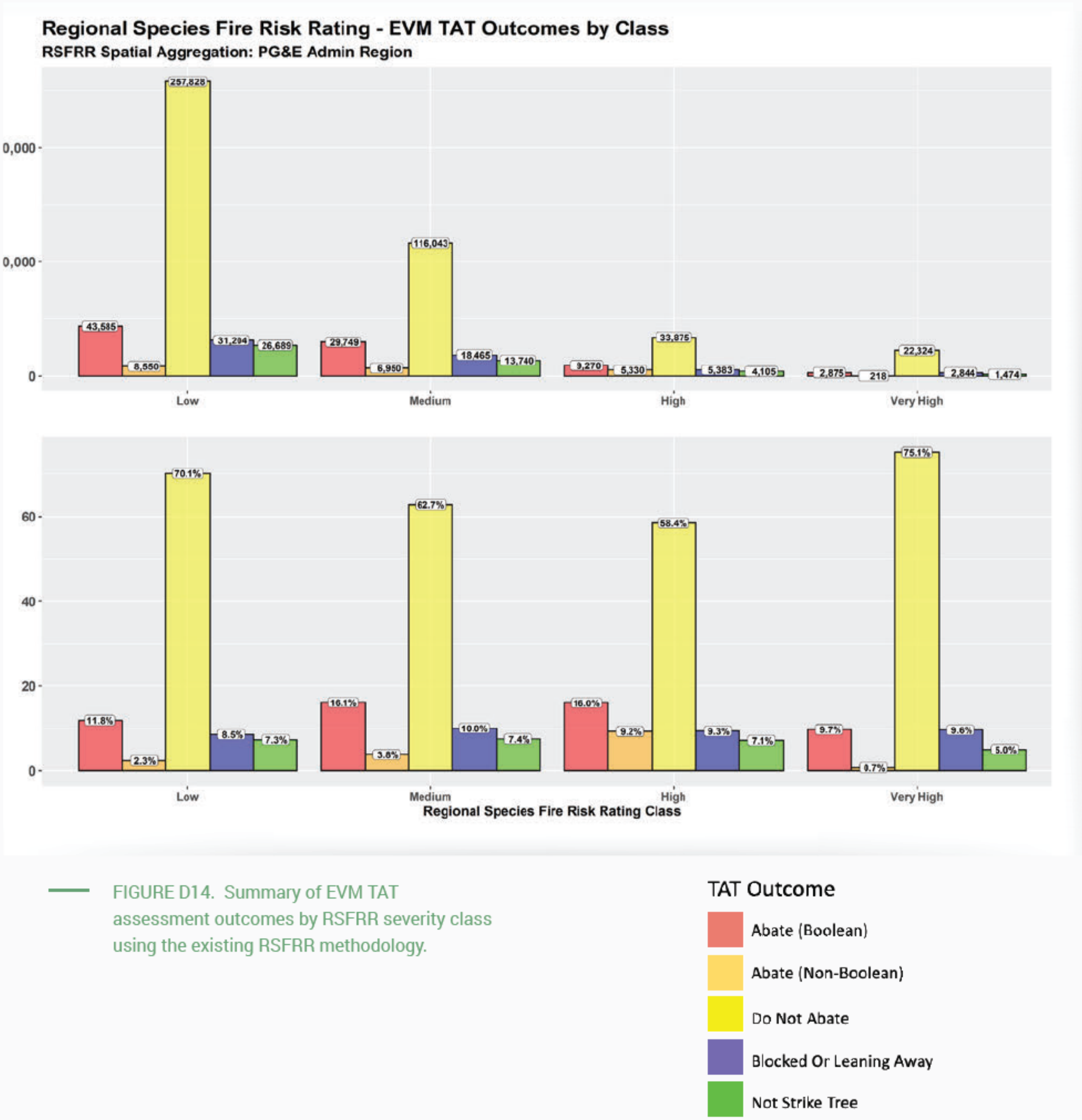


FIGURE D14. Summary of EVM TAT assessment outcomes by RSFRR severity class using the existing RSFRR methodology.

high overall Tree Environment Score value. This revised RSFRR methodology is proposed and recommended as an enhancement to the existing RSFRR methodology originally developed by PG&E and offers a data-driven and spatially-informed approach to targeting certain tree species with a historically higher occurrence rate of outages and ignitions based on PG&E's long-term databases.

TREE HEALTH & DEFECT ANALYSIS (BY ECOREGION)

The EVM TAT inspection database provides an opportunity to analyze species-specific tree health and defect trends based on the 640,501 trees inspected from March 2020 to June 2021. With each tree receiving a 360° inspection, these inspection records represent a large, valuable dataset which may facilitate the detection and evaluation of trends at the species- and regional-level. This analysis was focused on the four Boolean health parameters recorded in the EVM TAT database which were considered most likely to have a meaningful underlying relationship to individual tree species and regional conditions: 1) tree mortality; 2) fruiting bodies; 3) major wounds; and 4) significant insect damage. The EPA-Level III Ecoregions were used as spatial aggregation units to provide an ecologically-based framework for characterizing regional trends, consistent with the proposed use of these ecoregions for the revised regional species fire risk rating methodology. It should be noted that the EVM TAT database currently comprises only the portion of PG&E's distribution system which had been inspected up to June 2021, and therefore does not provide a comprehensive inventory of trees from which to analyze species-specific trends. As additional portions of the PG&E service territory are inspected with the EVM TAT, trend analyses should be updated to continue increasing sample sizes and better characterize trends associated with tree species and ecoregions as more trees are inspected over additional areas.

The prevalence of each Boolean health parameter was calculated for each tree species as the percentage of that species exhibiting that Boolean parameter in the EVM TAT database for each ecoregion (Figure D15). For example, if 500 trees of "Species A" were recorded as having significant insect damage in an ecoregion and "Species A" consisted of a total of 2,000 trees in that ecoregion, "Species A" would have a significant insect damage occurrence rating of 25% in that ecoregion based on the current EVM TAT database.

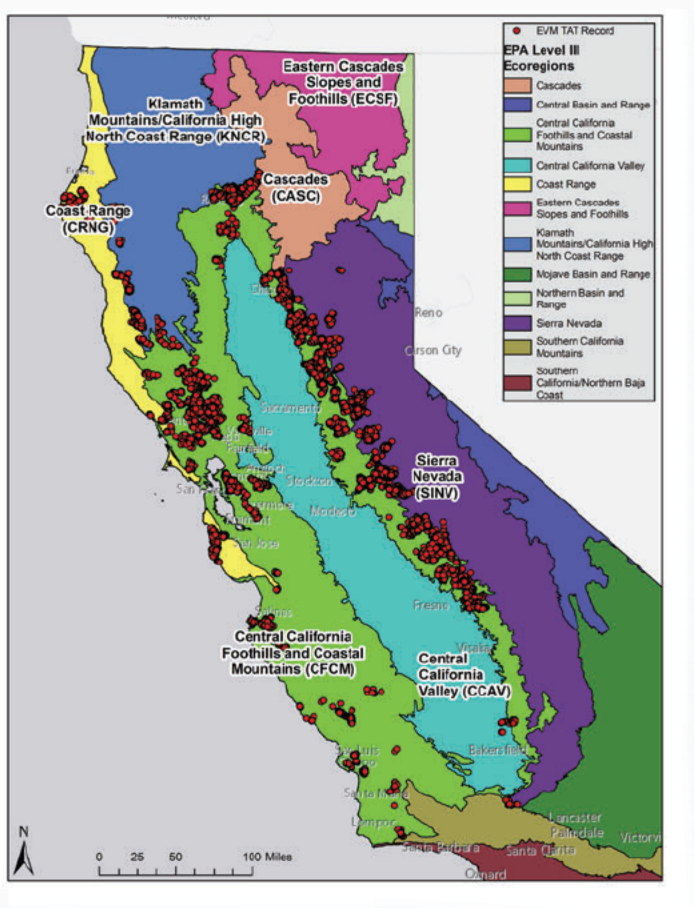


FIGURE D15. Map of trees inspected with the EVM TAT as of June 2021, overlaid on EPA Level III Ecoregions.

These occurrence percentages were calculated for each of the four Boolean health and defect parameters on a per-species basis for all tree species present in the EVM TAT database. Tree species with fewer than 250 records in the entire EVM TAT database or fewer than 25 records in an ecoregion were excluded from analysis to reduce analytical artifacts caused by species with a very small sample size. Figures D16 through D20 visualize the percent occurrence of each Boolean parameter for each ecoregion in the form of bar plots ordered by the percent occurrence for each parameter.

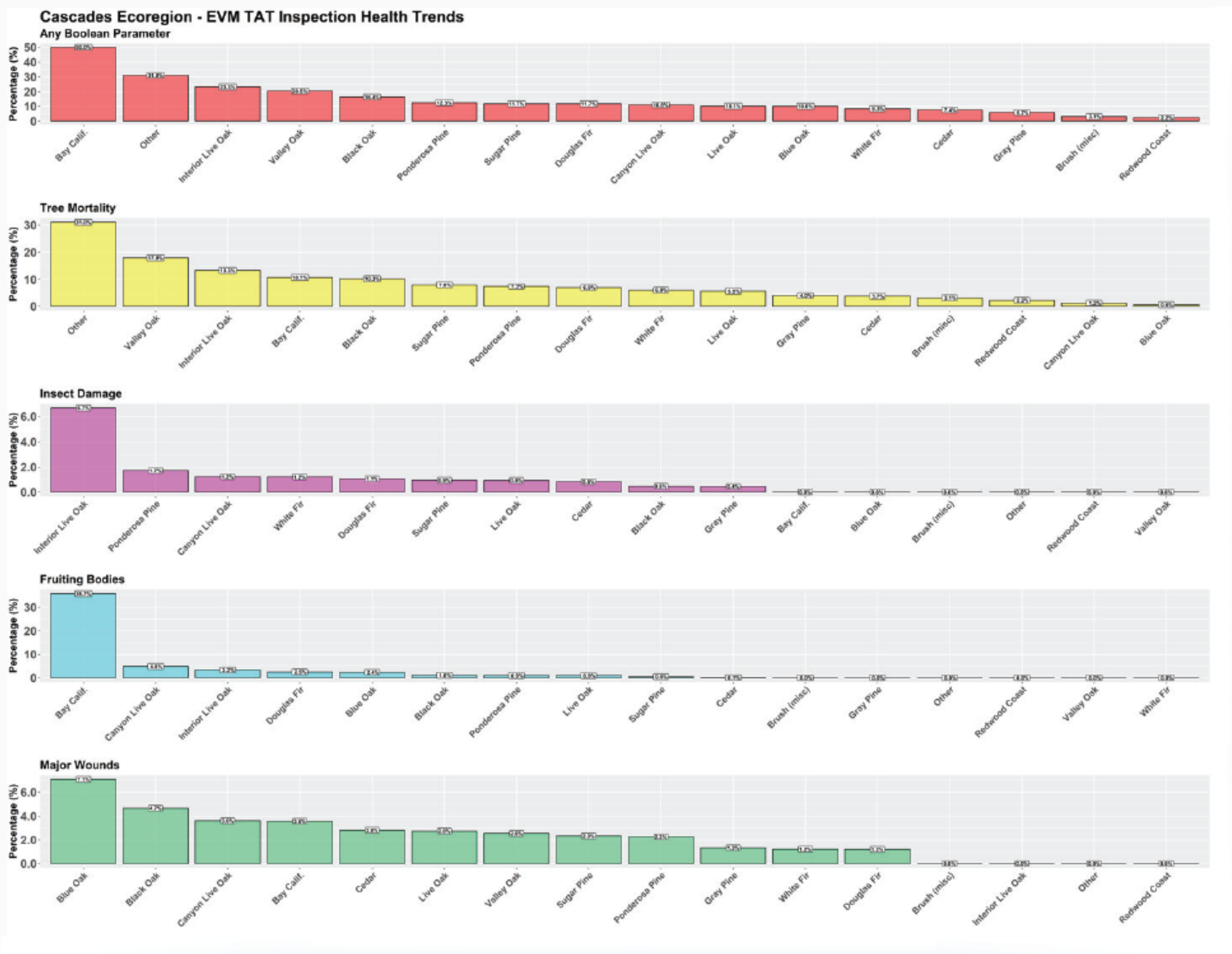


FIGURE D16. Cascades ecoregion EVM TAT inspection species health trends.

The “Any Boolean Parameter” designation refers to the percent occurrence of that species with the presence of any Boolean health parameter issue noted and serves as a more general indicator of potential trends associated with each regional species analysis. For example, if in a particular ecoregion “Species B” had 50 trees with major wounds and 50 trees with insect damage, out of a total of 500 trees of that species in the ecoregion, the “Any Boolean Parameter” percentage of Species B would be 20%. In the EVM TAT database, inspected trees are only assigned a single dominant Boolean health or defect parameter and therefore the “Any Boolean Parameter” does not risk double counting trees which could conceivably be flagged with multiple Boolean conditions.

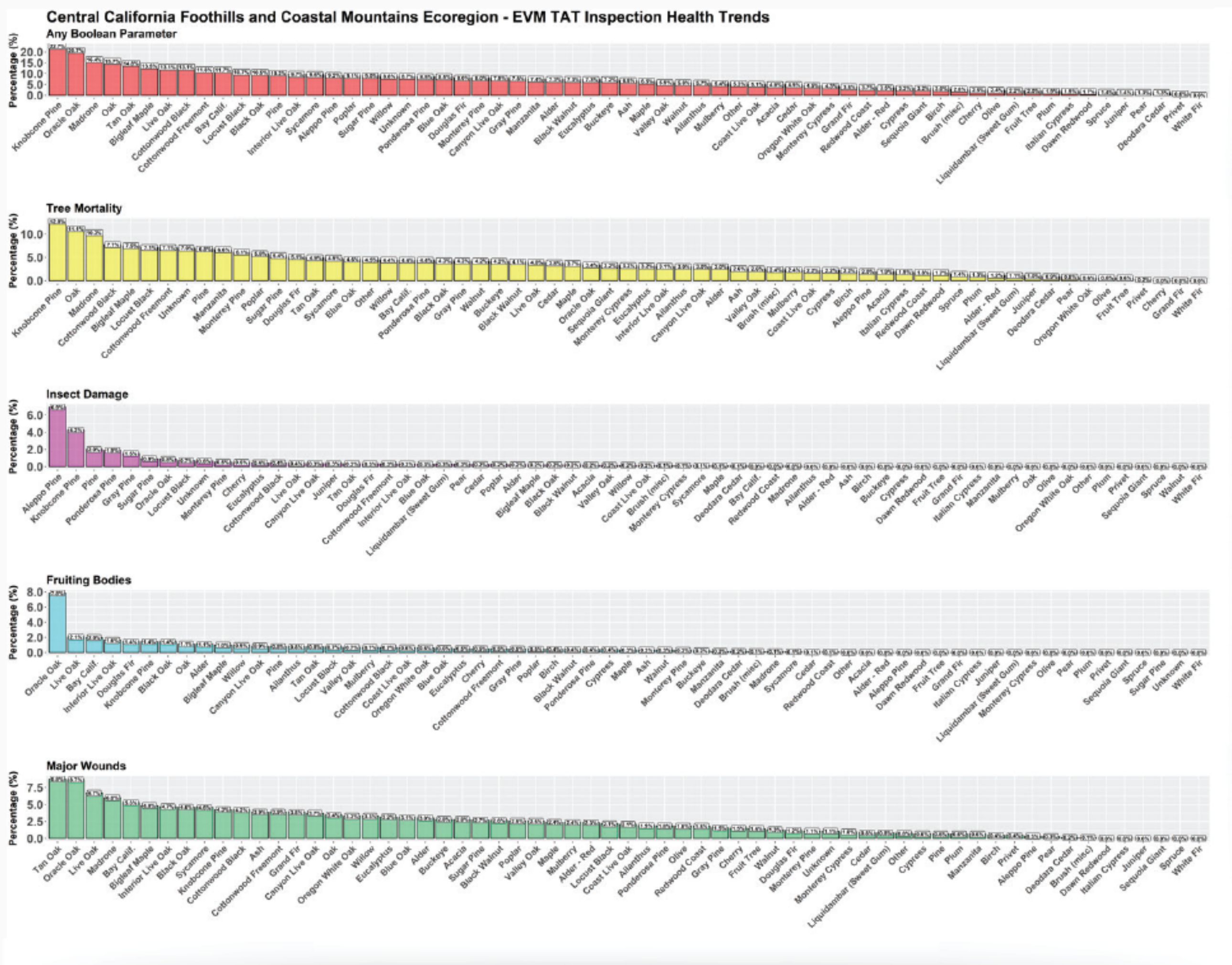


FIGURE D17. Central California Foothills and Coastal Mountains ecoregion EVM TAT inspection species health trends.

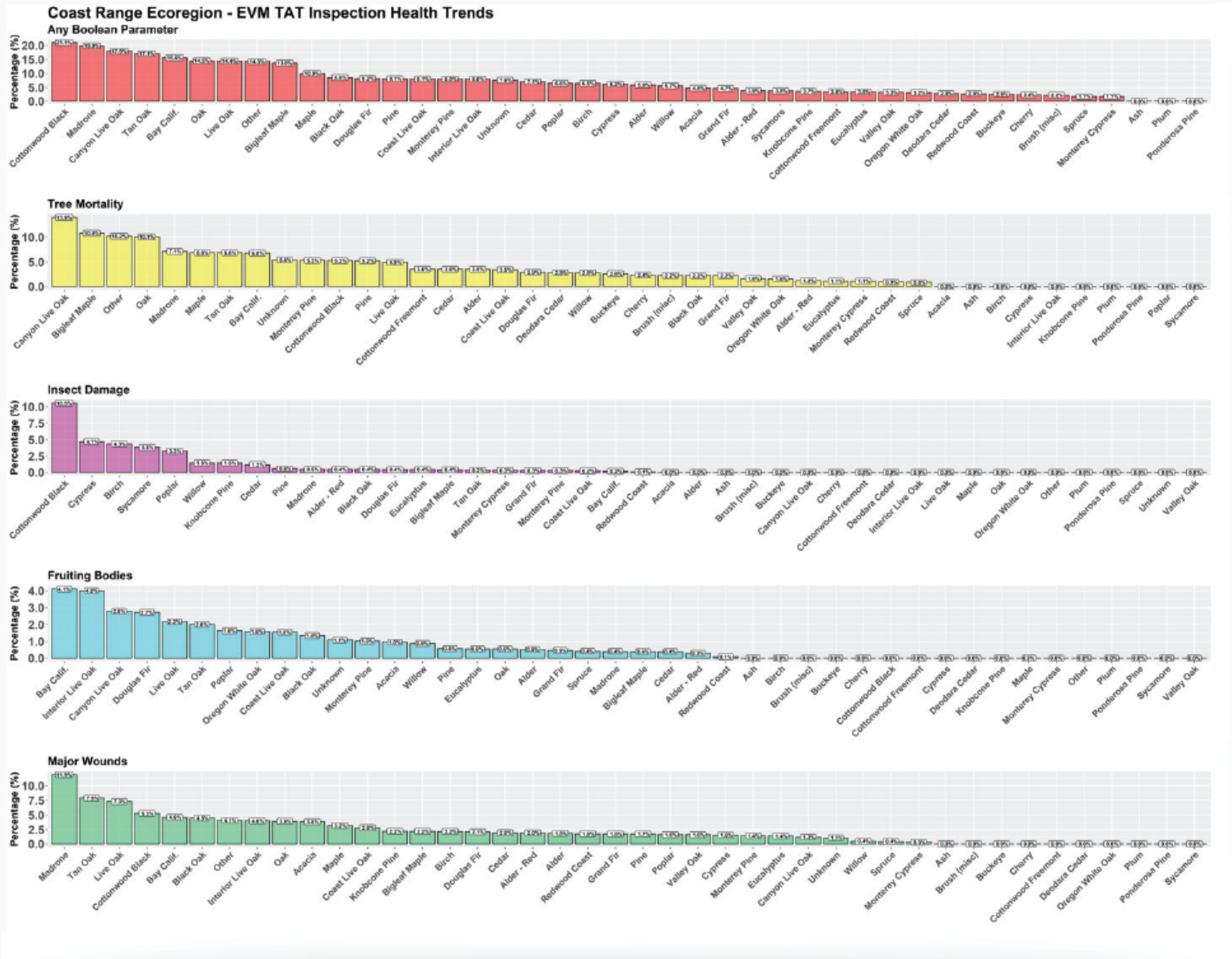


FIGURE D18. Coast Range ecoregion EVM TAT inspection species health

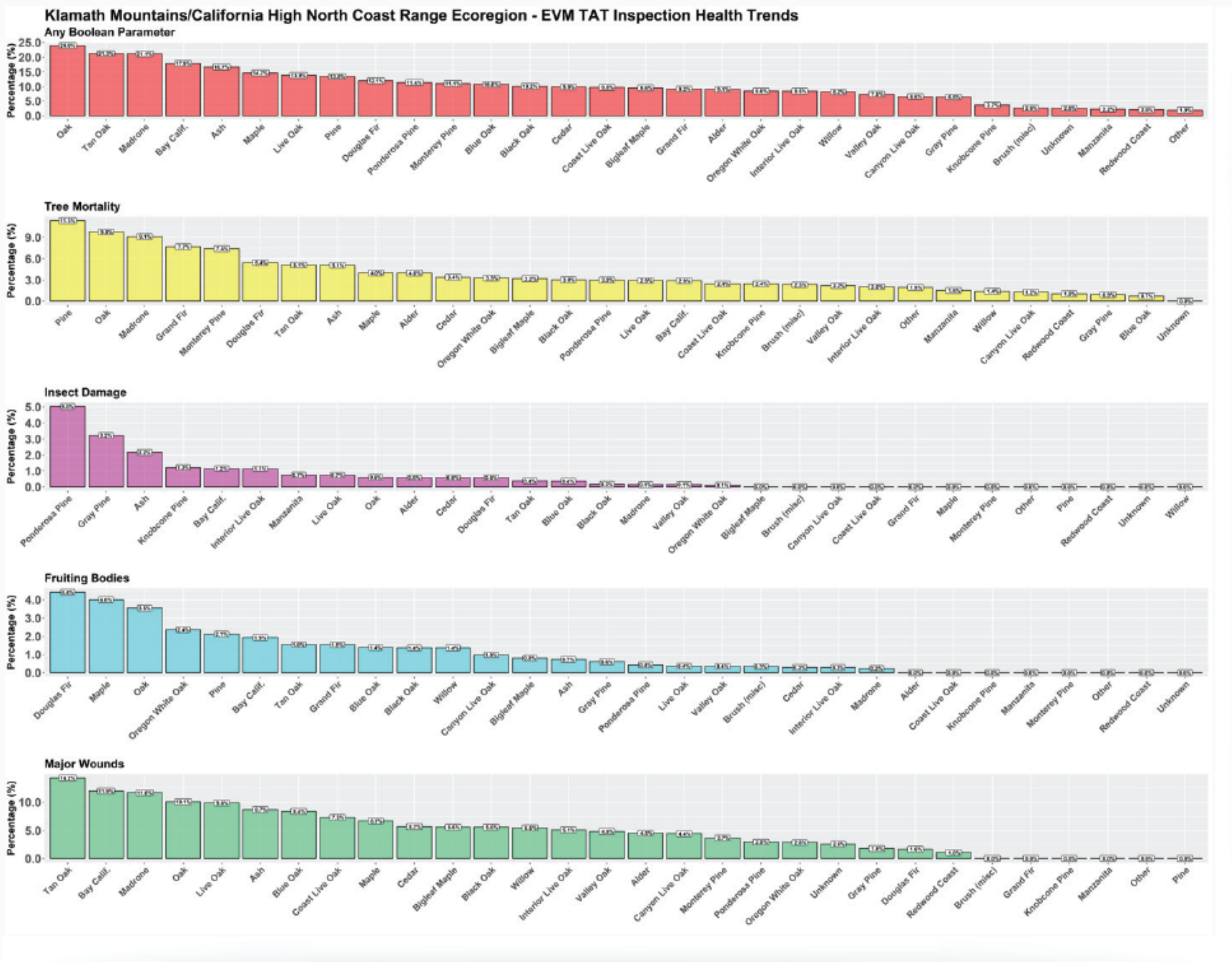


FIGURE D19. Klamath Mountains / California High North Coast Range ecoregion EVM TAT inspection species health trends.

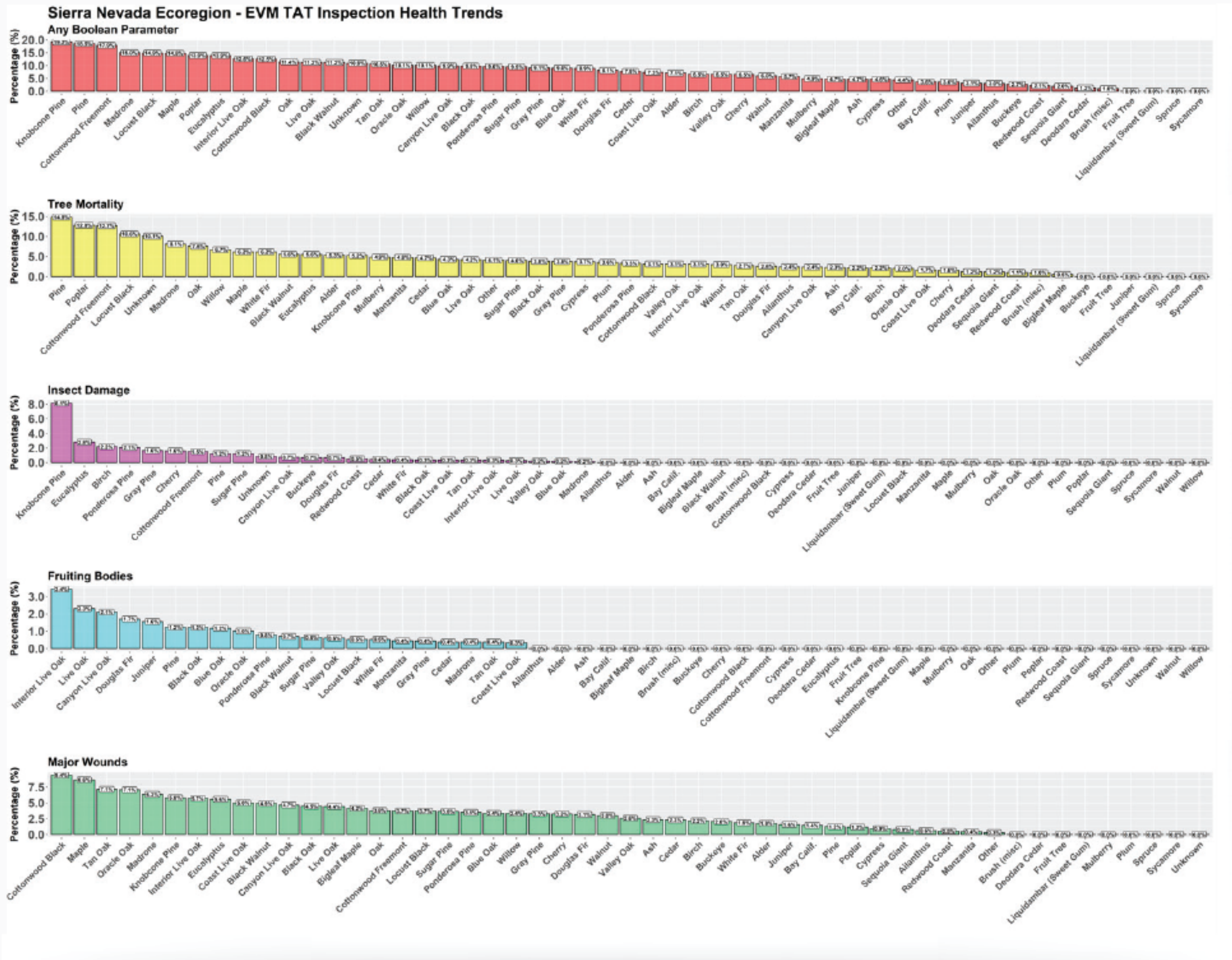


FIGURE D20. Sierra Nevada ecoregion EVM TAT inspection species health trends.

Additionally, the boxplots shown in Figures D21 through D25 show the range of species percent occurrence values for each Boolean parameter across all ecoregions where that species was significant (with the value range on the Y-axis representing the range of values for that species across all significant ecoregions). This serves to visualize the range of these occurrence percentages on a per species basis, illustrating the variability across ecoregions and providing a more "region-agnostic" view of these species' trends. While it is important to remember that the underlying EVM TAT database used for these calculations is "incomplete" in the sense that these inspections only represent the portion of PG&E's distribution service territory which has been inspected so far, these records represent ~640,000 trees inspected in detail and may offer insight into trends which could be used to prioritize vegetation management activities. As the EVM program continues to cover more ground and additional trees are inspected, these findings could easily be updated on a rolling basis. In addition to serving as a means of prioritizing regional tree work, this (or similar) analysis could eventually be used as a quantitative complement to the enhanced regional species fire risk rating to serve as another indicator of potential wildland fire risk on a regional, species-specific basis. In this way, the regional species fire risk rating would represent the historical risk based on actual outages and ignitions, while the ecoregion species health and defect trend data would characterize the propensity of these tree species to exhibit the Boolean health defects associated with an increased likelihood of stem and root failure based on recent tree inspections.

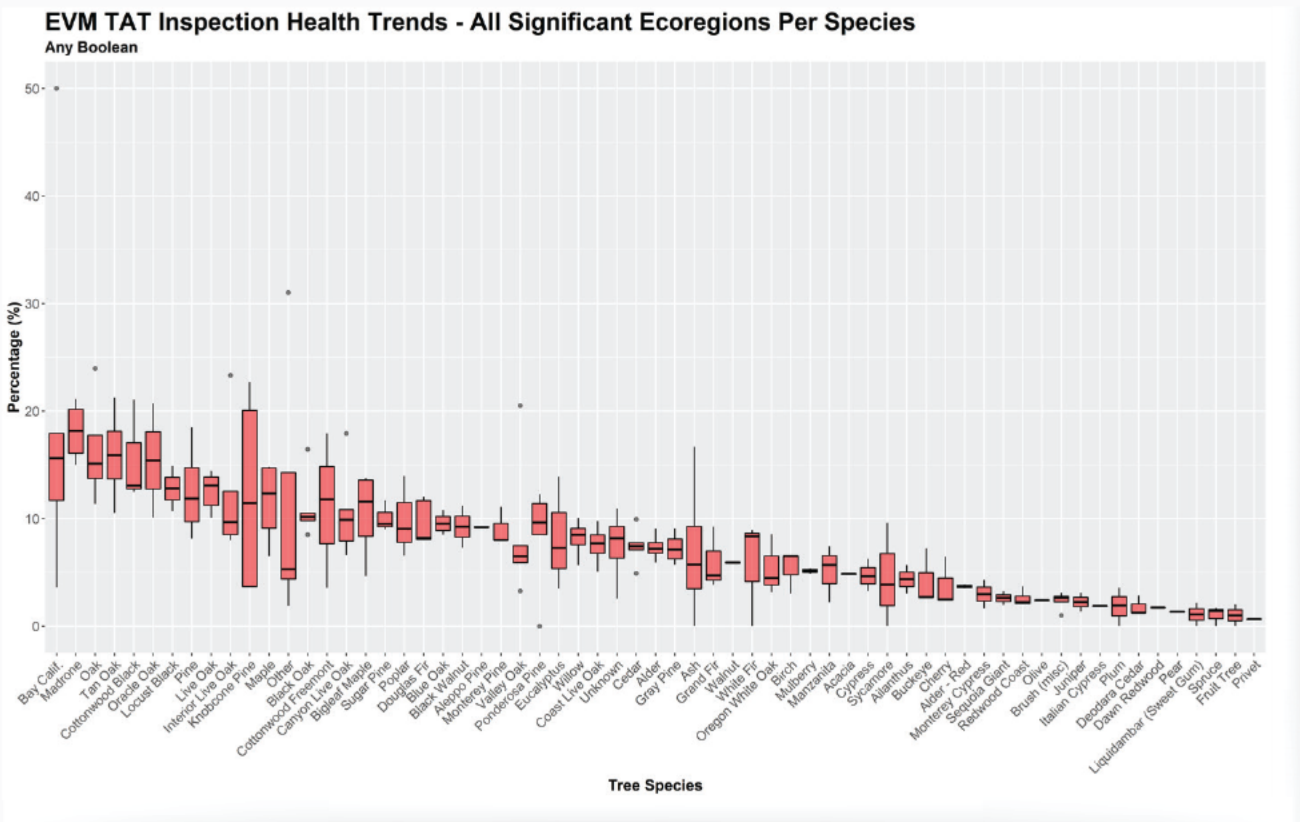


FIGURE D21. EVM TAT inspection health trends for any Boolean health parameter.

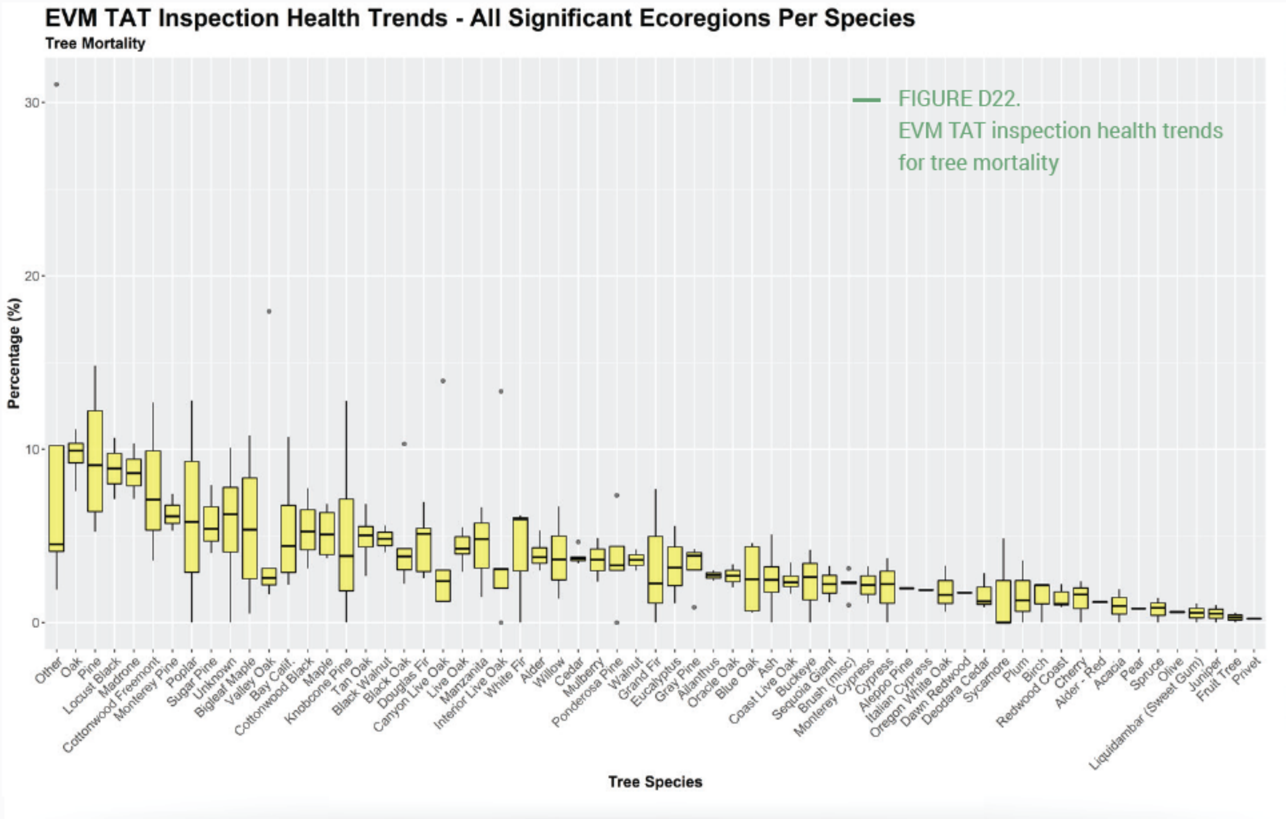


FIGURE D22.
EVM TAT inspection health trends for tree mortality

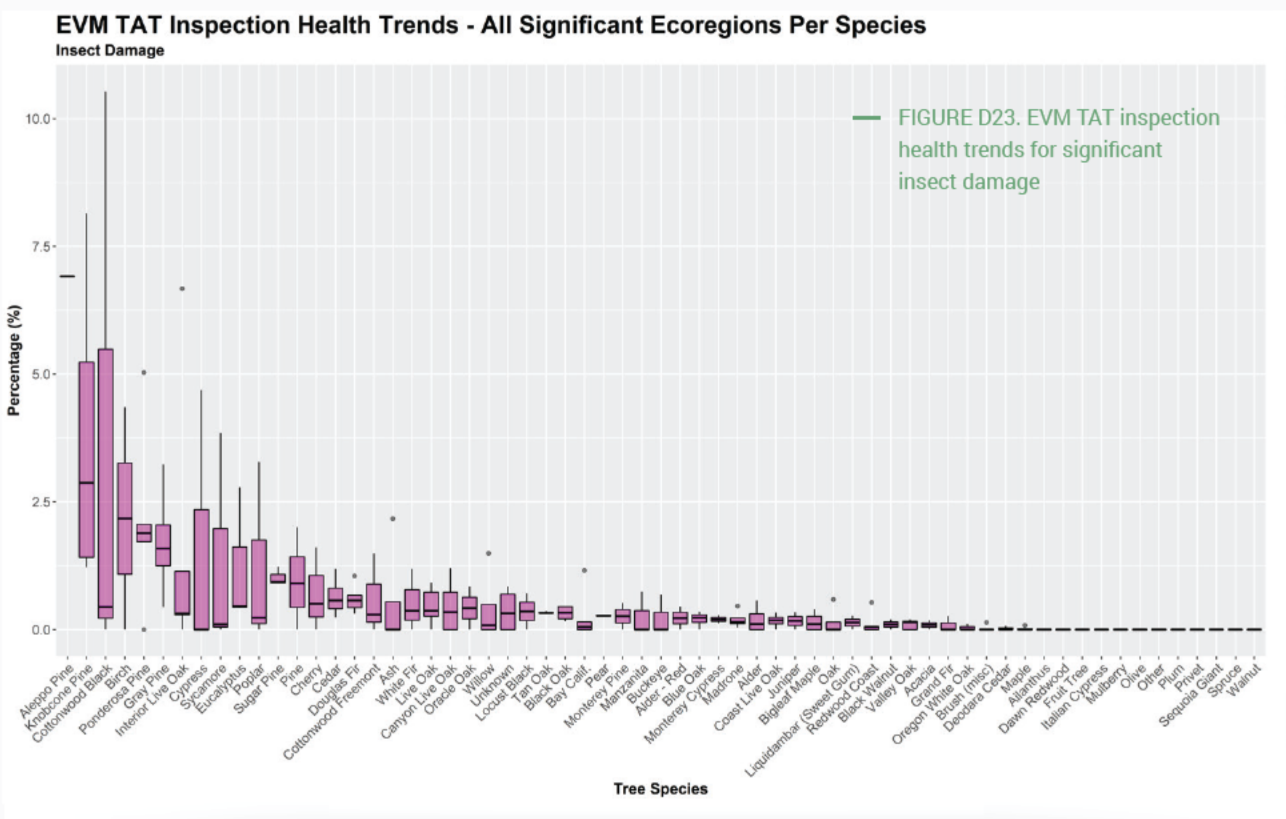


FIGURE D23. EVM TAT inspection health trends for significant insect damage

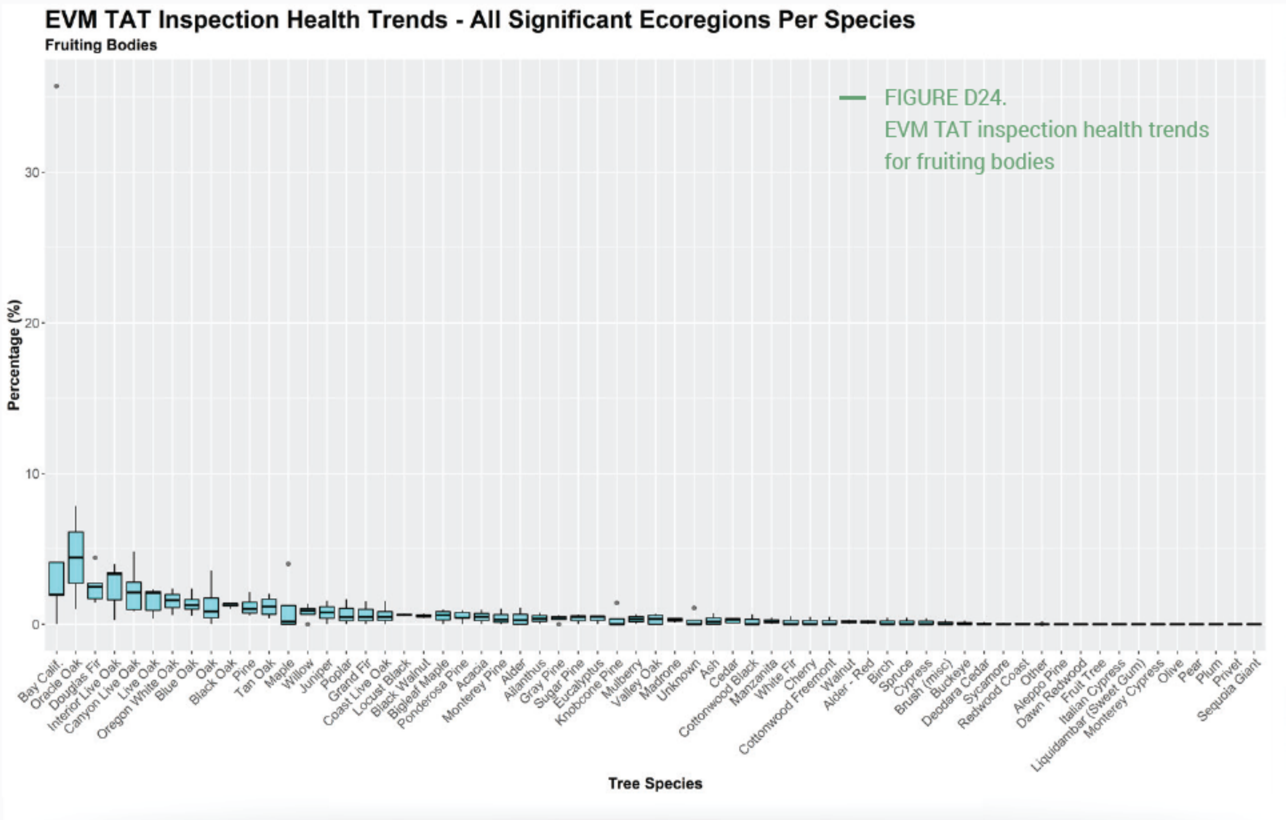


FIGURE D24. EVM TAT inspection health trends for fruiting bodies

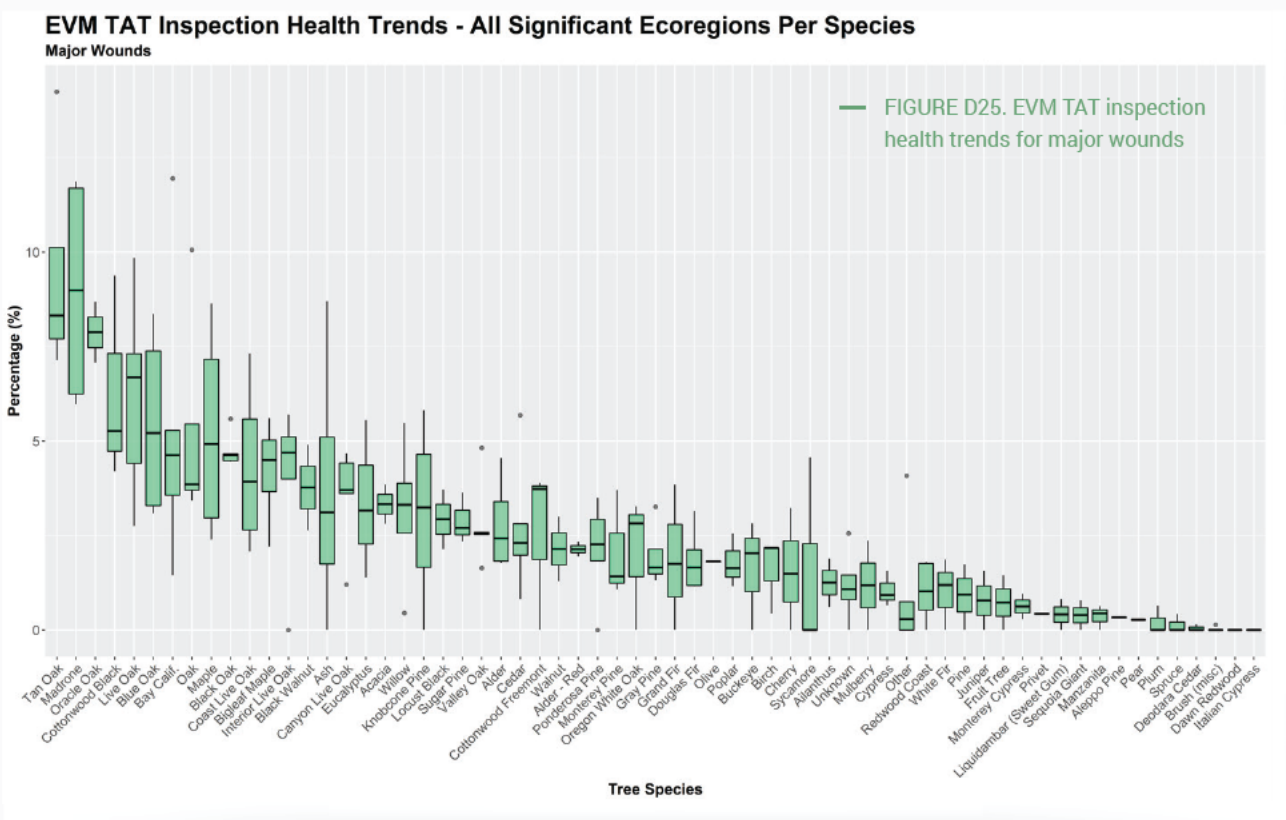
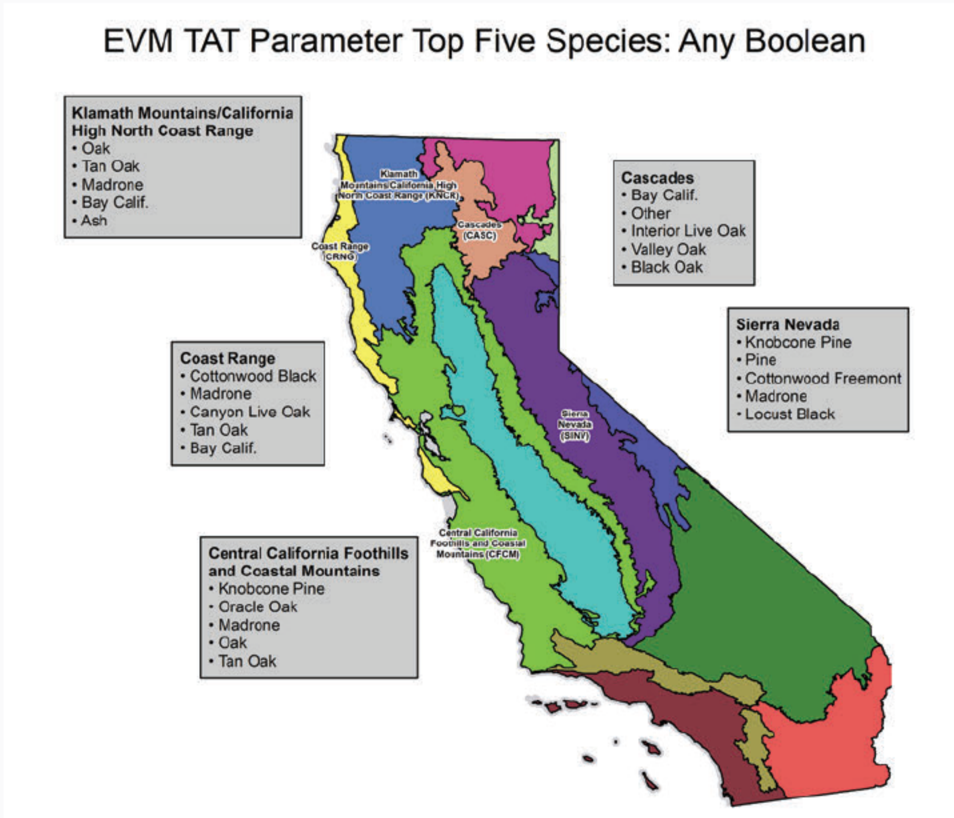
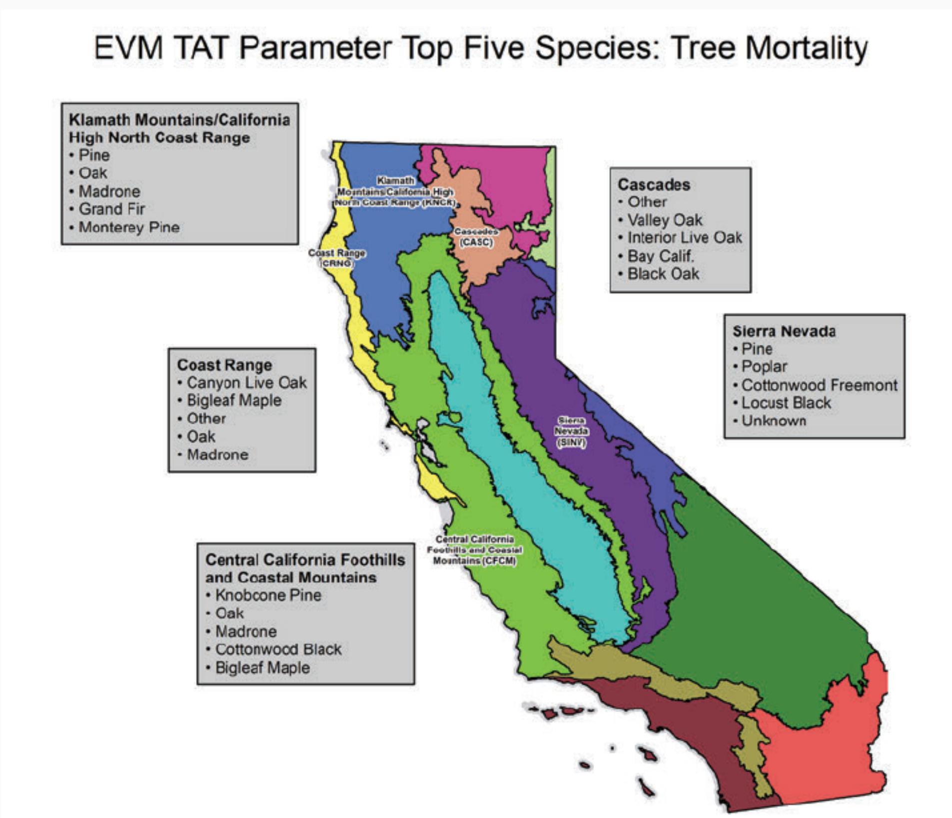


FIGURE D25. EVM TAT inspection health trends for major wounds

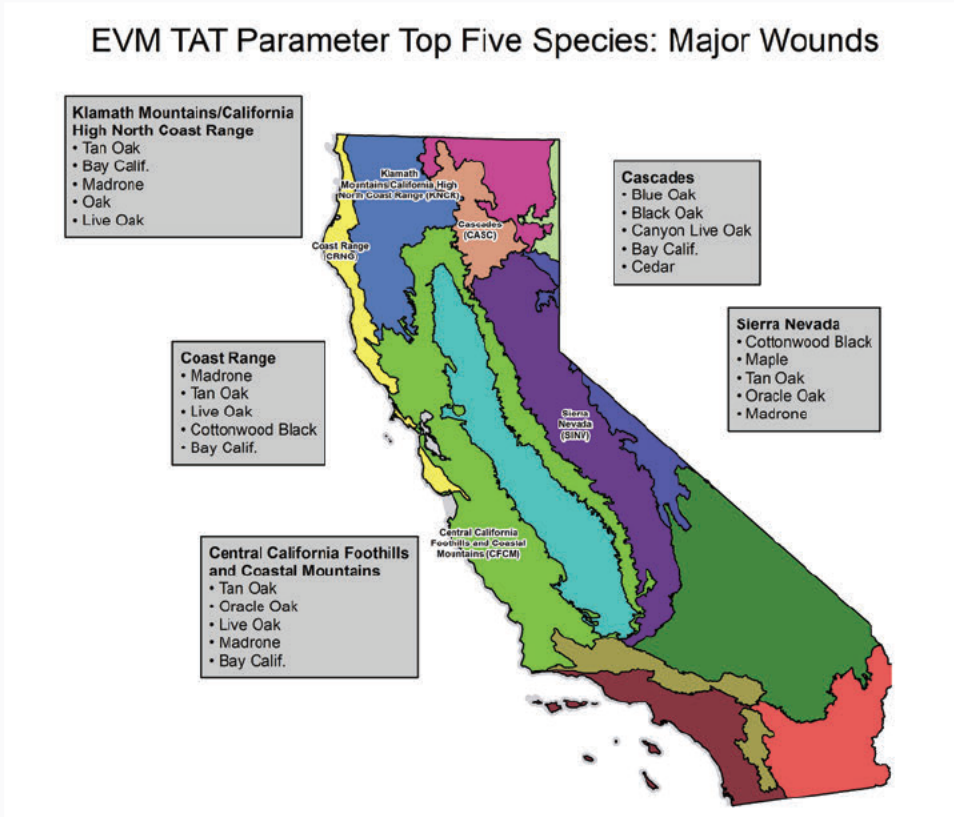
— FIGURE D26. EVM TAT Parameter Top 5 Species: Any Boolean





— FIGURE D27. EVM TAT Parameter Top 5 Species: Tree Mortality

FIGURE D28. EVM TAT Parameter Top 5 Species: Major Wounds



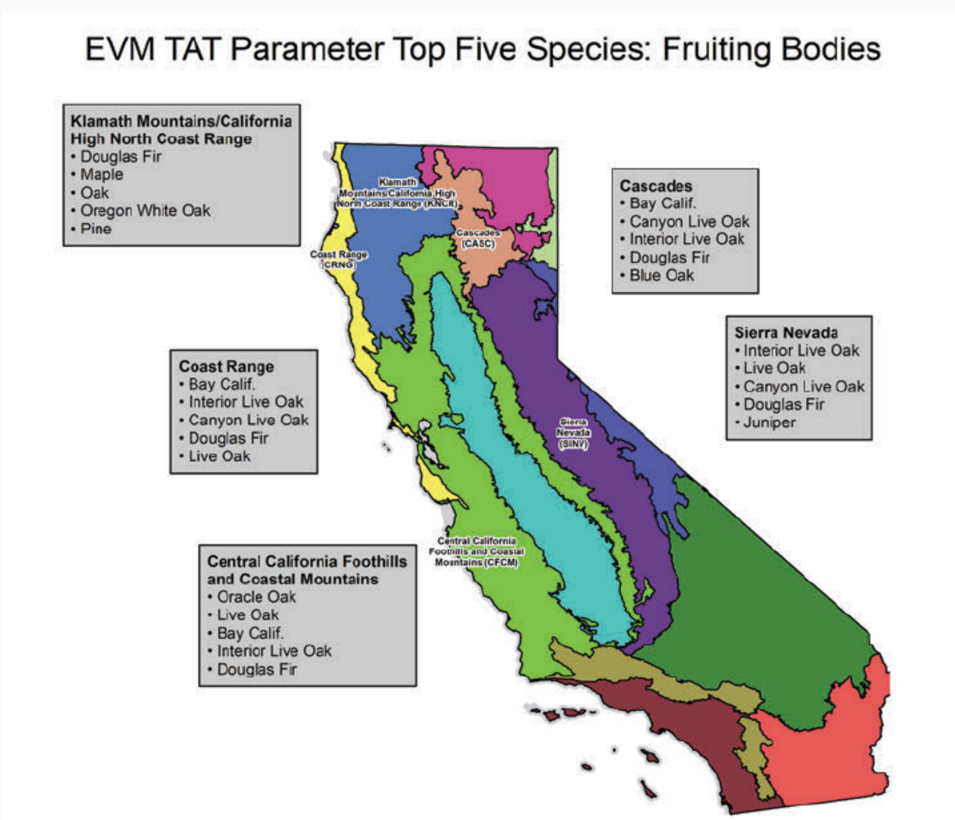
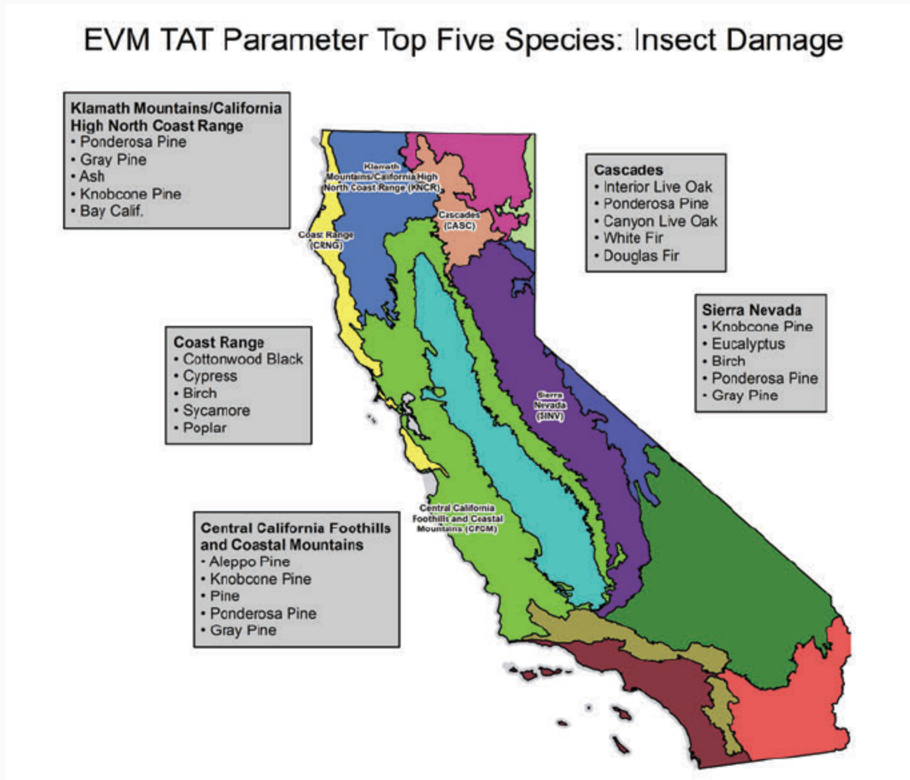


FIGURE D29. EVM TAT Parameter Top 5 Species: Fruiting Bodies

FORMATION ENVIRONMENTAL

— FIGURE D30. EVM TAT Parameter Top 5 Species: Insect Damage



TREE HEALTH & DEFECT ANALYSIS (BY ECOREGION) Summary

- EPA-Level III Ecoregions were used as spatial aggregation units for species specific EVM TAT tree health parameters considered most likely to have a meaningful underlying relationship to individual tree species and general site conditions: 1) tree mortality; 2) fruiting bodies; 3) major wounds; and 4) significant insect damage.

- It should be noted that the EVM TAT database currently comprises only the portion of PG&E's distribution system which had been inspected up to June 2021, and therefore does not provide a comprehensive inventory of trees from which to analyze species-specific trends within ecoregions.

Appendix E: Wind Model Development

Wind Parameter Analysis & Comparison to North American Land Data Assimilation System

Two analyses were conducted to assess the significance of the TAT wind parameter in abatement decisions and the correlation between wind condition and Outage & Ignition historical events. The first analysis evaluated TAT wind parameter scores and their effects on tree abatement decisions and the second analysis utilized NLDAS wind speed data compared to the O&I datasets to determine wind effect on historical vegetation-caused outages and ignitions.

Analysis 1: TAT Wind Parameter Scores vs. TAT Abatement Effect

The goal of this analysis was to understand how the wind condition score is calculated and its effect on tree abatement outcomes. The TAT wind condition classification utilizes the average of daily maximum wind speeds generated from PG&E's internal meteorology data. The TAT classification has three classes: (1) Slight Wind, (2) Moderate Wind (3) Severe Wind and they are assigned wind scores of 0, 3 and 9, respectively. Figure E1 illustrates the PG&E average daily maximum wind speeds map and the corresponding TAT wind classification.

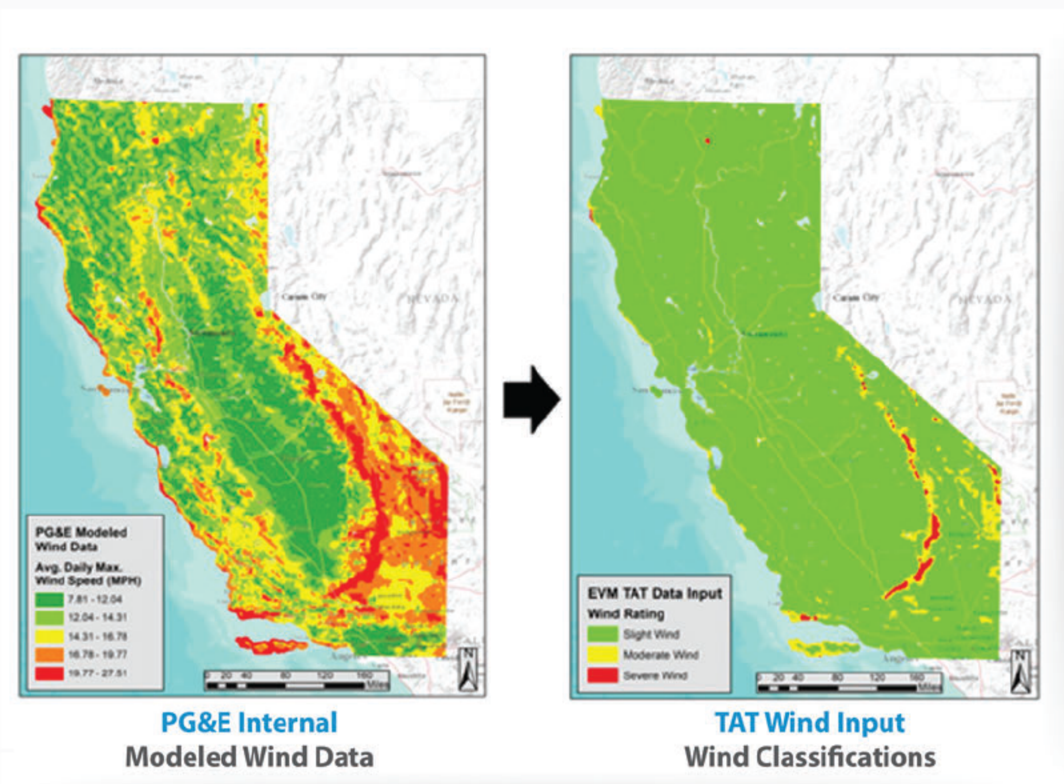


FIGURE E1. Wind classification data used in TAT

The existing EVM TAT model computes wind scores as the average of the maximum daily wind speeds, extracted from the PG&E modeled wind data map and the mean (μ) and standard deviation (σ) are calculated and a modeled gaussian distribution for wind values is created. The wind condition score classes: slight, moderate, and severe wind are then calculated by assigning regions on the modeled gaussian distribution based on how many standard deviations from the mean a wind value is. These wind classifications and regions are given in Table E1.

TAT Wind Classification	Modeled Wind Value Region
Slight	**0 to $\mu + \sigma$**
Moderate	**$\mu + \sigma$ to $\mu + 2\sigma$**
Severe	**$\mu + 2\sigma$ to ∞**

TABLE E1. Wind classification assignments in TAT

Upon overlaying the PG&E wind map (average maximum wind speed) distribution and the modeled distribution, it was found that the actual distribution is not gaussian and skewed to the left. This implies that classifications based on the modeled distribution result in a greater portion of the actual wind values being classified as the slight wind state-wide. Additionally, observing the locations of high wind speeds, most high wind speeds occur in the south, mostly outside PG&E's service territory. This biases the classification even further toward the slight wind class.

Furthermore, analyzing the effect of the full PG&E modeled wind values relative to the modeled wind classes by way of the empirical cumulative probabilities (the fraction of total number of dataset entries which are at or below a wind speed), it is observed in Figure E2 that 95%+ of all TAT and O&I entries are being classified as slight wind with the shaded red region showing the region of slight wind classification. This supports the earlier conclusion of the X^2 test showing that the wind condition score is not a statistically significant predictor of risk due to most of the TAT entries being classified under the slight wind category.

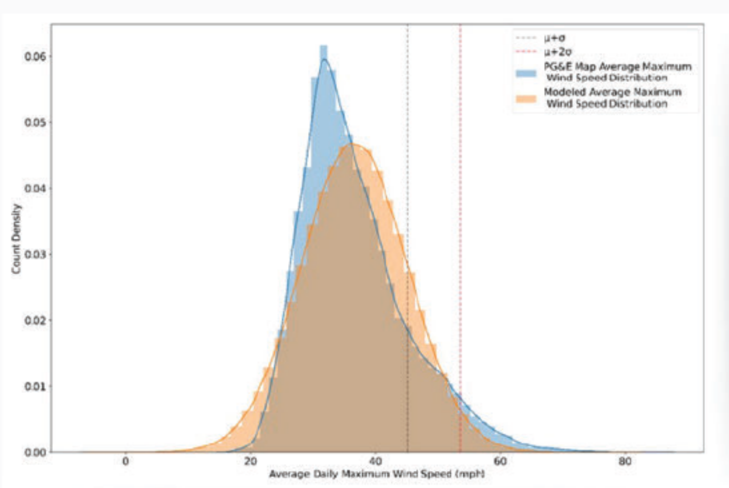


FIGURE E2. Overlay of the PG&E wind map (average maximum wind speed) distribution and the modeled distribution

Finally, a count of TAT records by Abatement Decisions (Abate, Do Not Abate, or Not a Strike Tree) and Wind Classification details the negligible effect of wind classification on the final tree abatement outcome. Table E2.

	ABATE	DO NOT ABATE	NOT A STRIKE TREE
SLIGHT	20,704	428,523	16
MODERATE	68	1,577	0
SEVERE	0	0	0

TABLE E2. Existing TAT Wind Classification Vs. Final Abatement Outcome Counts

Analysis 2: NLDAS Wind vs. O&I Data: While the previous analysis shows the impact of wind in the current TAT model, additional analysis is necessary to determine the actual effect of wind on vegetation-caused outages utilizing the O&I databases and to explore a potential revised wind classification. The NLDAS (external wind data) was used in the second wind analysis. Outage and Ignition data was categorized into two separate groups: Wildfire Season and Non-Wildfire Season. The total number of events per day were plotted as shown in Figure E3. Non-wildfire Season days are shown in gray color whereas Wildfire Season days are shown in orange and red colors. From the figure, spikes are noticed, and they are days that have a higher number of outages and ignitions. Those high number of occurrence days were hypothesized to occur on high wind days and therefore be potentially indicative of windspeeds which cause increasing tree failures.

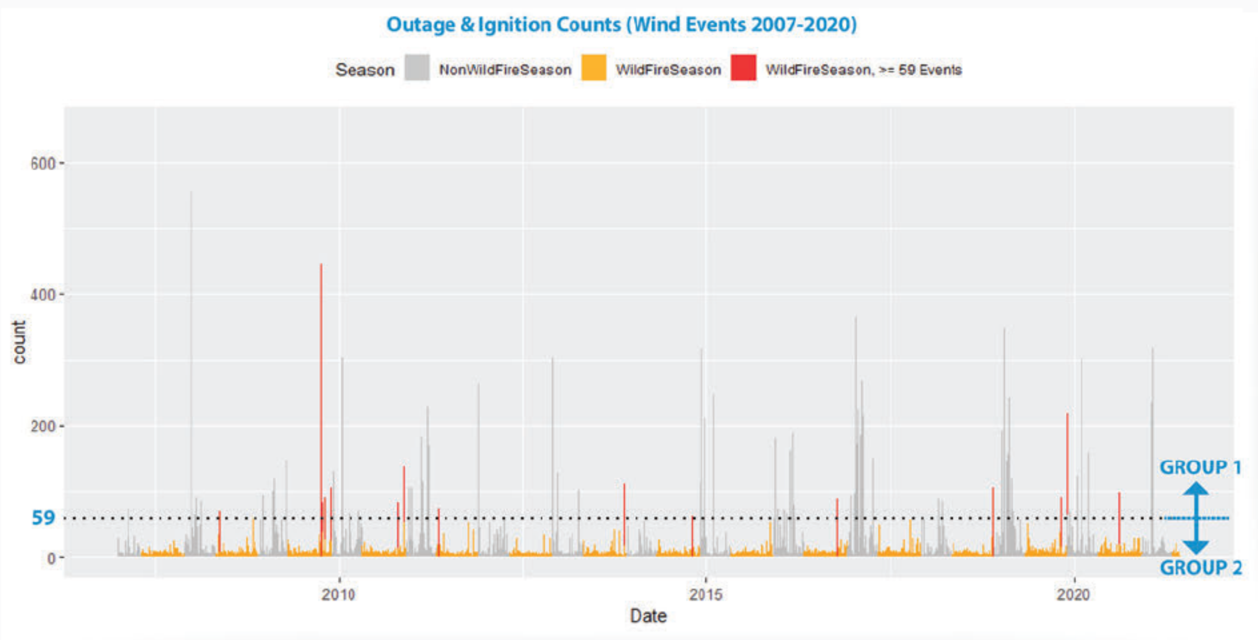


FIGURE E3. Total number of Outage and Ignition per day from 2007 to 2020

A sensitivity analysis was conducted to identify a wind event threshold to distinguish between high and low wind event dates. The threshold range considered for the sensitivity analysis is from 5 to 80. For each threshold used, the outage and ignition data are categorized into two groups:

- Group 1: Less Than Threshold
- Group 2: Equal or More than threshold

The median of daily maximum windspeed was calculated for these two groups. The difference between two medians is plotted in Figure E4 The higher the difference value, the bigger separation between two groups. From Figure E4, we noticed that the maximum value happened when 59 tree failure events is picked for the threshold. The variation of the difference is minimal after a threshold of 20. Figure E5 shows the distribution of daily maximum windspeed for all the days (Wildfire Season only) that has less and more than 59 events. The hypothesis is correct as it is observed that the high event group has a higher windspeed compared to the low event group.

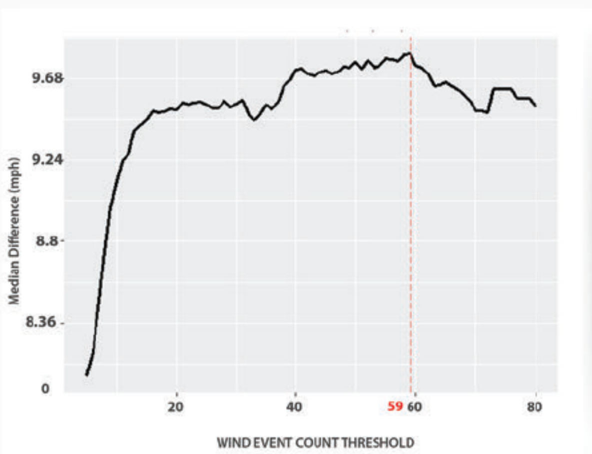


FIGURE E4. Median Difference between G1 & G2

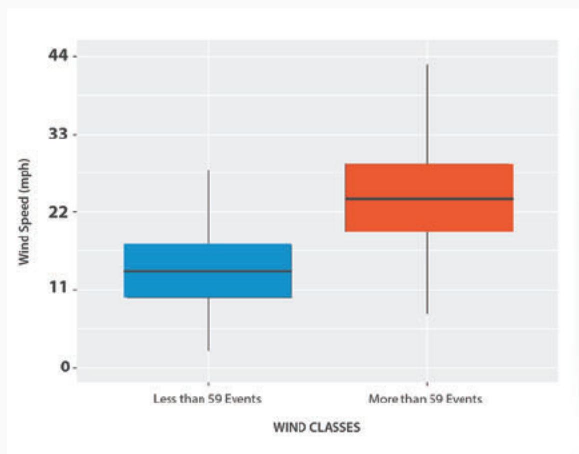


FIGURE E5. Wind Speed Distribution

As previously shown in the plot with high event date groupings, October 13, 2009 occurs during a wildfire month and has a significant number of high wind events. Thus, this date was chosen to illustrate the spatial correlation between the wind data and the Outage & Ignition data. The events that occurred on October 12 and 13 were extracted from the Outage and Ignition database and plotted as points on a map overlaid with daily maximum wind speed.

Figure E6 shows higher wind speed is shown in red color and lower wind speed is shown in green color. The Oct 12 map illustrates majority of calm wind as it has more "green" color on the map, corresponding to the 5 high wind events that occurred. However, on Oct 13, high wind speeds were detected broadly across northern California (depicted in orange and red colors), corresponding to a total of 446 events that occurred that date. The locations of the O&I events depict a high spatial correlation between the outage and ignition events and high wind speeds.

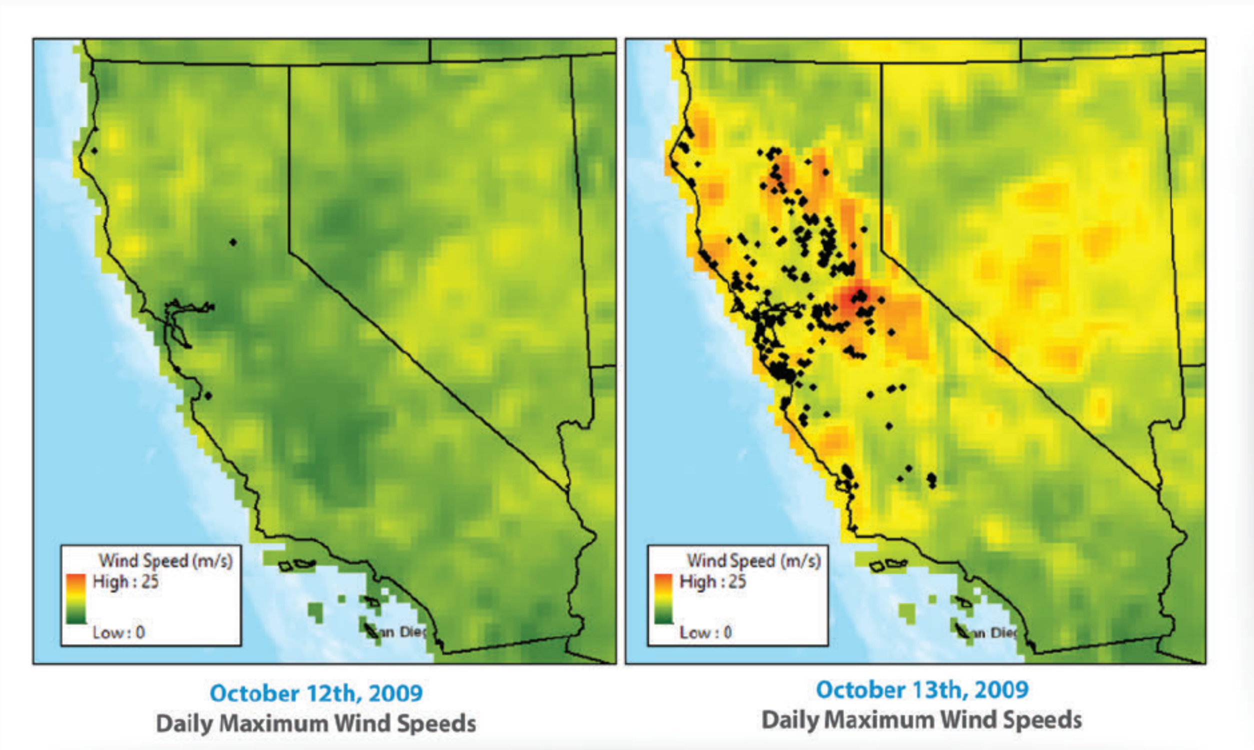
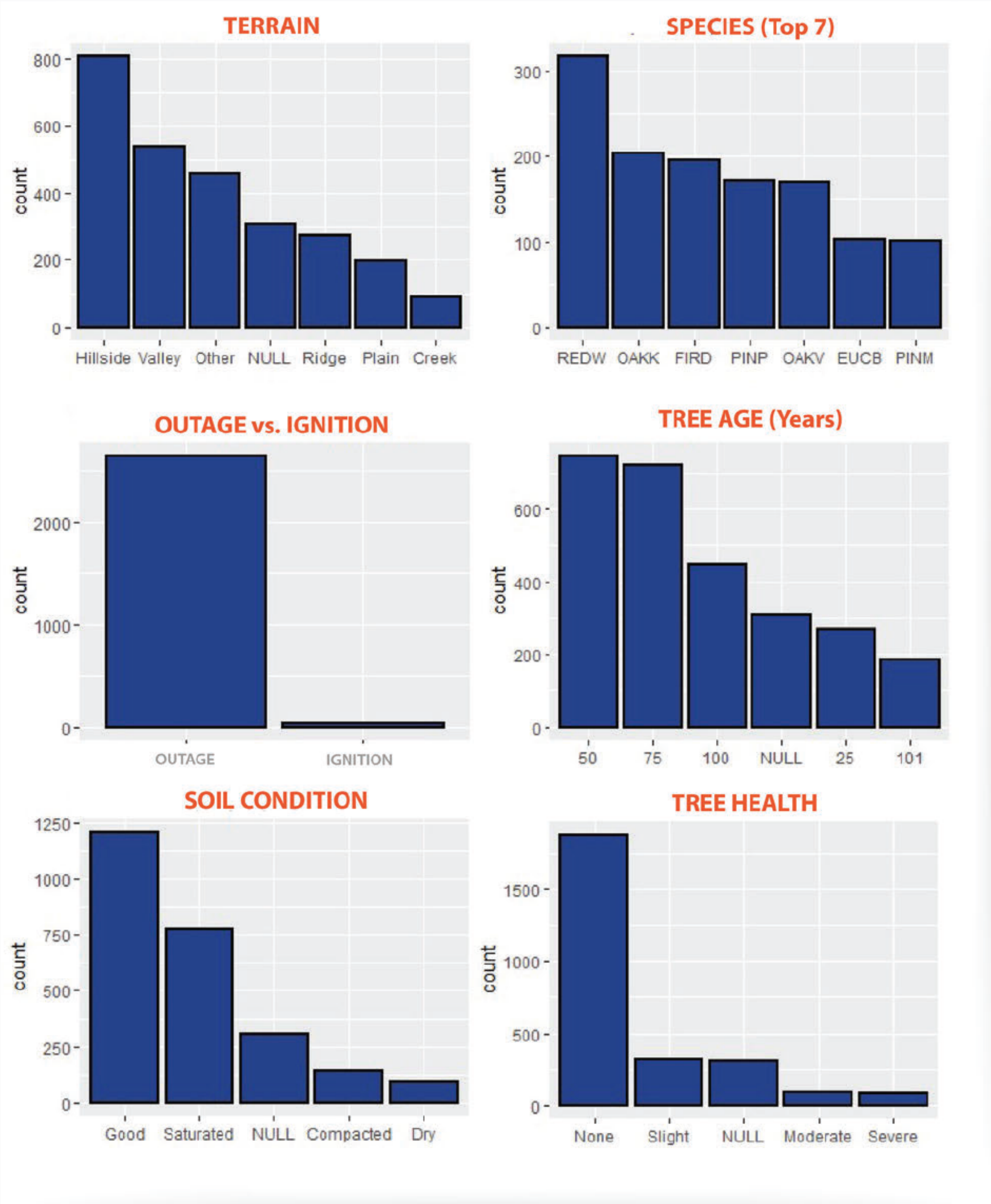


FIGURE E6. (Left) Oct. 12, 2009 O&I Events, (Right) Oct. 13, 2009 O&I Events

Additional investigation was conducted on the reported vegetation parameters associated with the Outage and Ignition data for all dates in Group 1 (with greater than 59 events). The vegetation associated parameters include Terrain (cTerrain), Tree Species (cSpecies), Ignition/Outage, Tree Age (nTreeAge), Soil Condition (cSoil), Tree Health (cTreeHealth), Tree Condition (bTreeDead), Outside Tree Root Condition (cTreeRotOutside), Main Cause (cCause), Interior Tree Rot Condition (cTreeRotInside) and nHeight/nDBH Ratio. Each parameter was represented in a histogram distribution displaying the categorical data with total counts for the vegetation-caused outages and ignitions on dates with >59 events . Figures E7-17 (next two pages).



FIGURES E7-12. Parameters For Vegetation-Caused O&I On High Wind Event Days

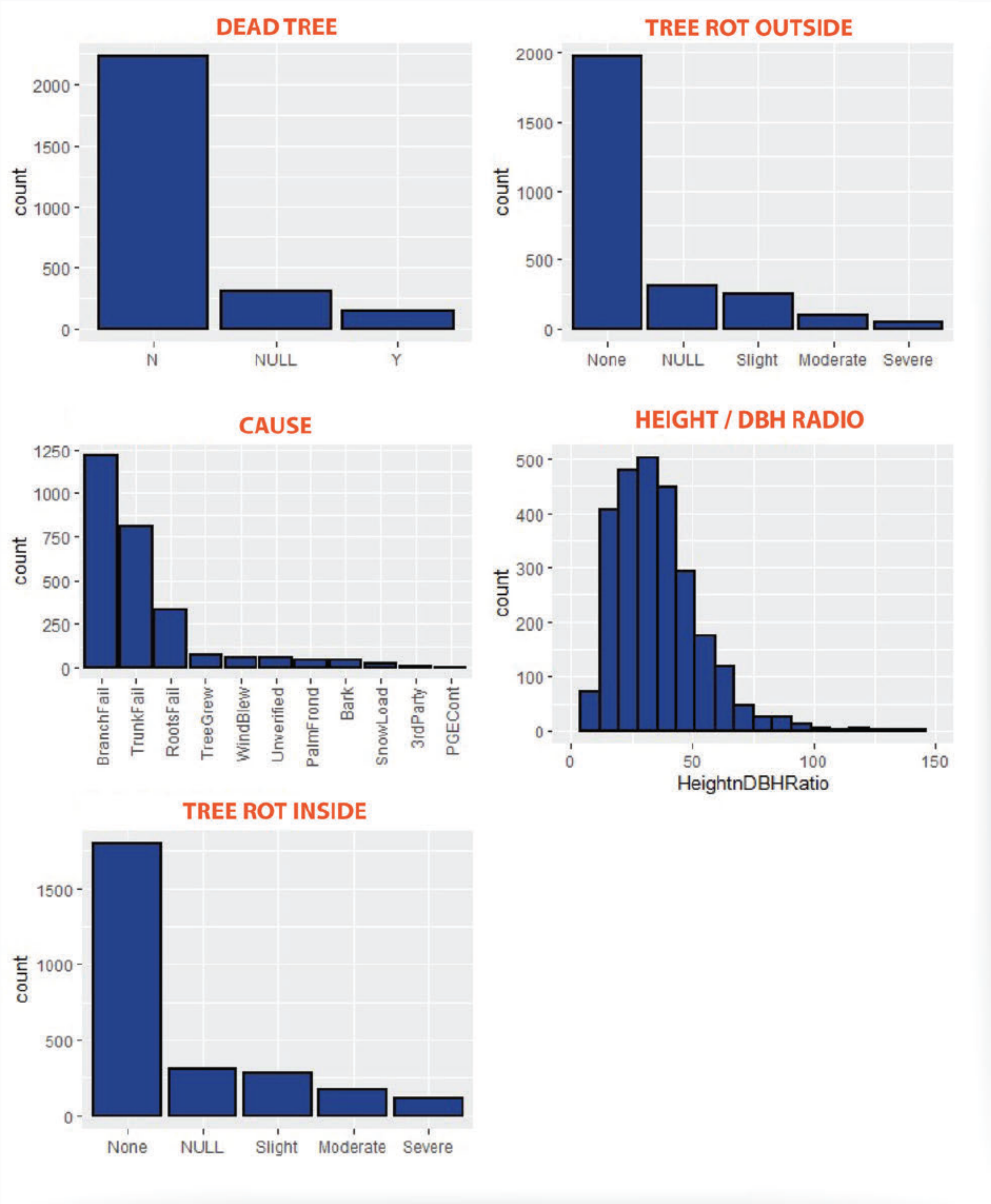


FIGURE E13-17. Parameters For Vegetation-Caused O&I On High Wind Event Days

A summarization of these histograms conveys that reported failed vegetation for these O&I events were mostly healthy, live trees without a visible presence of root rot or other significant defects. Failure causes were predominantly related to branch or trunk failures with a high percentage of failed trees located on hillsides. These conditions suggest that the current TAT Booleans and weighted parameters would likely not have resulted in abatement of these failure trees since the wind condition effect is currently insignificant.

Approach A: 59 Event Threshold: Since this analysis has shown that wind is likely an influencer on the Outage and Ignition events but only during high wind days, two approaches (A&B) with model variations were employed to create optional new maps for wind scores (1) to communicate the regions of higher wind risk and (2) to estimate how the new wind condition scores would have affected the TAT's abatement records. Since the high wind days can be construed as outliers, simply using the average of the maximum daily wind speed will bias the resulting raster toward low maximum wind speeds and will not accurately reflect higher wind risk. To remedy this, all fire season days with outage/ignition numbers greater than 59 are found within the NLDAS wind dataset to eventually average. To give more weight to the days with higher likelihood of wind-caused outage/ignitions, the weighted average of those high event days is taken with the weights being the number of outage/ignitions for that day. The resultant raster is shown in Figure E18.

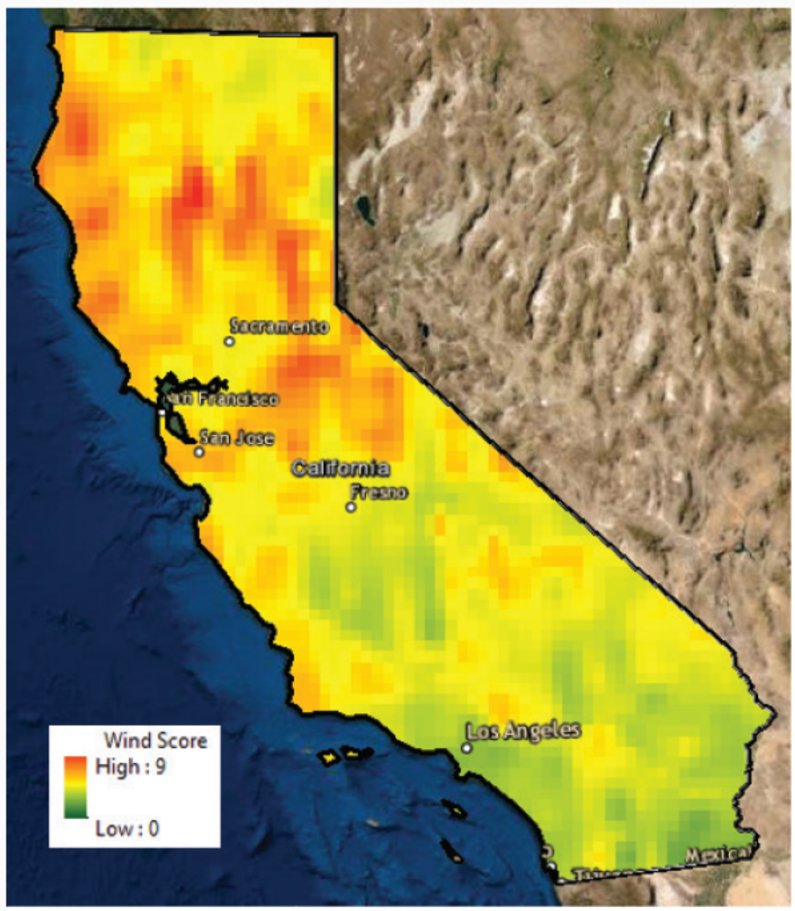


FIGURE E18. Raster Map Of Weighted Average For High Wind Event Days

Approach B: Combination of 3 Sub-models: Each of the models is weighted differently before being combined into the final score. The three models are:

- **Model 1:** Percent tree failures caused by strong wind
- **Model 2:** Maximum of daily maximum wind speed for the days above threshold
- **Model 3:** Probability of occurrence for the days above threshold

Model 1: Calculate percent Tree Failure Caused by Strong Wind: The outage and ignition database was used in model 1 to identify tree failures likely caused by strong winds. Tree failures associated with strong wind conditions were identified by searching for key words such as "Strong Wind", "Windy", "High Wind", etc. in the free-text comment field named "cReason", in which inspectors often enter a brief written description of the tree failure event and note relevant environmental conditions such as high winds, saturated soils from recent precipitation events, etc. All failure trees, both wind-related and otherwise, were aggregated to a 13 km x 13 km grid, consistent with the NLDAS wind dataset (Figure E19). The formula used to calculate the score of the model 1 was:

$$\text{Percent of Failure Trees} = \frac{\textit{Total Number of Failure Trees Caused by Strong Winds (Trunk \& Root Failure Only)}}{\textit{Total Number of Failure Trees}}$$

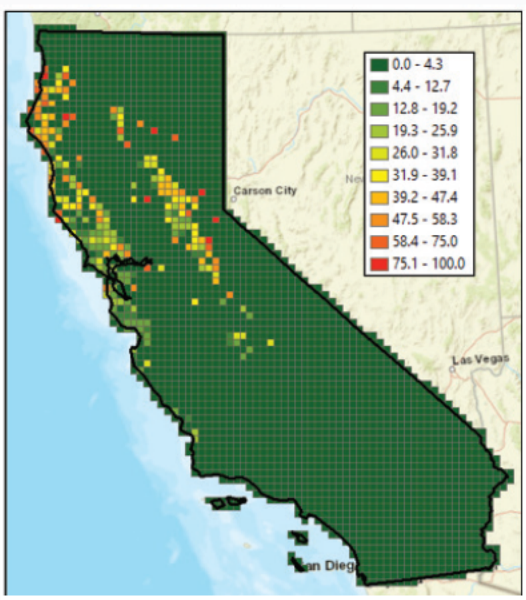


FIGURE E19. Percent of Tree Failure (Trunk and Root Failure) caused by strong wind

The score ranges from zero to 100%, where 100% means all the failure trees within the grid are caused by "strong wind" and zero percent means none of the failure tree within the grid were caused by "strong wind". No value is assigned to the grid if the grid had less than five failure trees due to uncertainty in Outage and Ignition's spatial inaccuracy. The objective of model 1 is to calculate the percentage of wind-related tree failures out of the total number of tree failures in each grid cell, to identify areas which are particularly prone to wind-related tree root and stem failures, under the assumption that these areas may pose a greater risk of wind-related tree failures in the future as well.

Model 2: Calculate the Max of Daily Max for the days above threshold: Model 2 and 3 utilize a data-driven threshold to categorize the wind speed into two classes: low wind zone and high wind zone. This threshold was calculated from the failure tree population that was caused by strong winds in outage and ignition database, as described in the model 1 section. The failure trees were further filtered to include only root and trunk failures to be consistent with the focus of the EVM TAT on mitigating potential fall-in trees and constrained to the fire season only (i.e., May – November) to focus on the dry season weather patterns most relevant to the EVM TAT. Wind speeds for the final selected wind-related tree failure population were then extracted from NDLAS Wind Speed dataset using the date of the reported tree failure to compile the maximum daily wind speeds associated with tree wind-related tree failures. The threshold was defined as the average of the daily maximum wind speed of the wind-related root and trunk tree failure population and is shown in Figure E20 as red line. The threshold value is 9.5 m/s and this value was used to separate high and low wind zones. High wind zone is the class which will potentially cause the tree to fail. The analysis essentially evaluates the daily maximum wind speed raster on a daily basis throughout the fire season. Every pixel/grid is compared to the threshold calculated earlier from the outage and ignition database and separated into two groups:

- **Group 1: Below the threshold**
- **Group 2: Equal or Above the threshold**

The score of Model 2 is calculated by taking the maximum of Group 2's wind speed at the pixel/grid level. The score ranges from 0 to 100% and is shown in Figure E21.

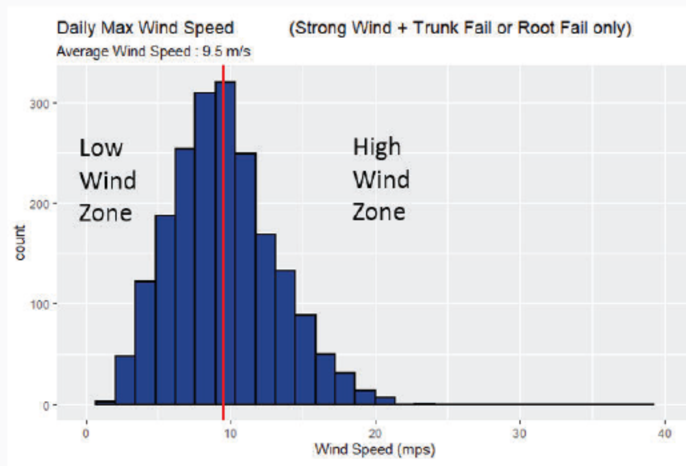


FIGURE E20. Wind speed distribution of tree failure caused by strong wind.

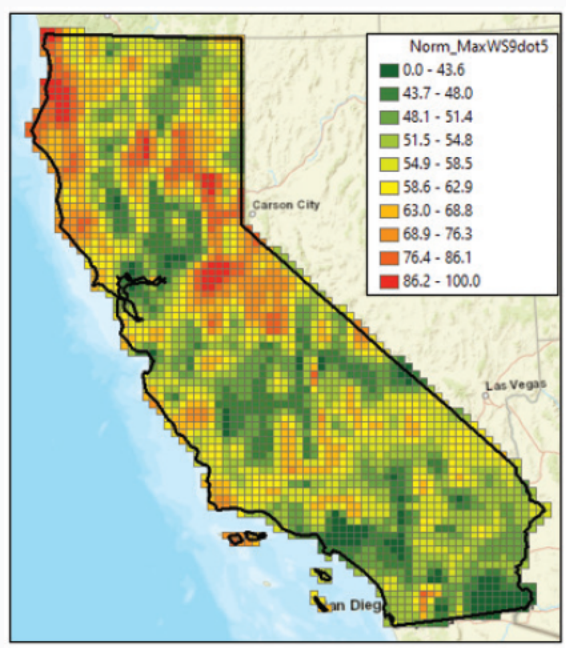


FIGURE E21. Maximum of Daily Maximum for the days above threshold

Model 3: Calculate the probability of occurrence for the days above threshold: Model 3 is very similar to Model 2. Only fire season NLDAS data is included in the analysis. The analysis essentially evaluates daily maximum wind speed raster and every pixel/grid is compared to the threshold calculated earlier from the outage and ignition database and separated into two groups:

- **Group 1: Below the threshold**
- **Group 2: Equal or Above the threshold**

The score of Model 3 is the ratio between the total count of days greater than or equal to the threshold and total days in the fire season. The formula of the model 3 is shown below. The score ranges from 0 to 100% and is shown in Figure E22.

$$\text{Score} = \frac{\textit{Total Days Equal or Above the Threshold}}{\textit{Total Days}} \times 100\%$$

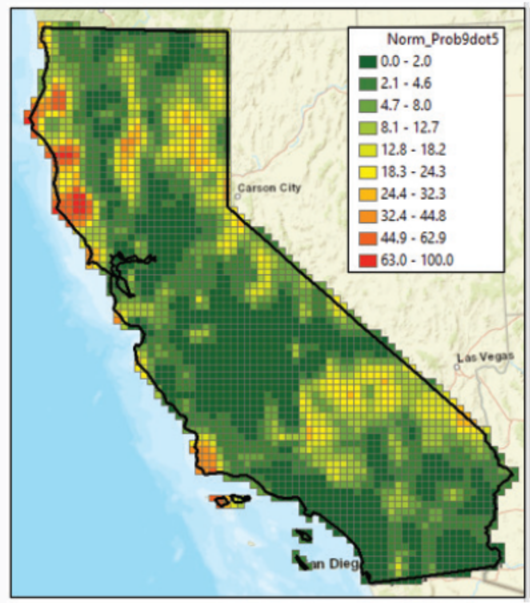


FIGURE E22. Probability of Occurrence for the days above threshold

The final score is calculated by adding the scores from all the models since all the scores are normalized and scaled to 100%. A weighting factor is assigned to each model to reflect the importance to the final score. Since Model 1 utilized field observations by inspectors following a tree failure in the O&I database, a 50% weighting factor is assigned. Model 2 and 3 are assigned with 25% weighting factors each. The formula to calculate the score is expressed below. The final score was then scaled to 0-9 to match the current wind score range of the TAT model. The result is shown in Figure E23.

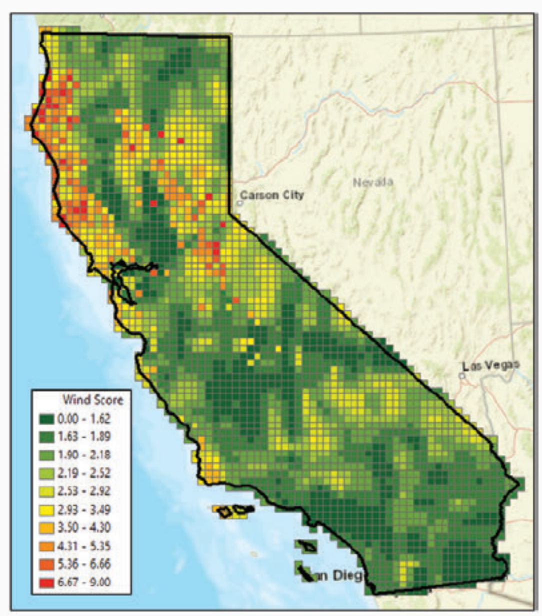


FIGURE E23. Final Wind Score calculated from all models

The potential outcomes associated with the implementation of Approach A or Approach B revised wind scoring methodologies were assessed by calculating the change in hypothetical tree abatements which would have occurred if these wind scores were in use at the time of evaluation for the current EVM TAT database. These hypothetical abatement calculations can only be performed for EVM TAT records which were not Boolean abates, since the Boolean abate trees are designated for removal regardless of any other factors and these trees do not have a complete TAT record entry past the point of Boolean abatement, meaning they do not contain the information required to compute the Tree Health Score and Tree Environment Score as would be required to reach a non-Boolean scored abatement decision. Hypothetical abatements based on these revised wind scores were determined by using these wind scores associated with each EVM TAT record in place of the original wind score in the current EVM TAT. With these new wind scores, an updated Tree Environment Score is calculated for each EVM TAT record that was either designated as a non-Boolean abatement or a “do not abate” in the original EVM TAT database to determine if its status would change in light of these revised wind scoring methodologies. The Approach A wind methodology resulted in a net increase of 7,084 tree abatements (Figure E24) and Approach B resulted in a net increase of 4,026 tree abatements (Figure E25 - next page). These significant increases in the net number of tree abatements are not surprising considering the limitations of the wind scoring methodology currently being used in the EVM TAT model.

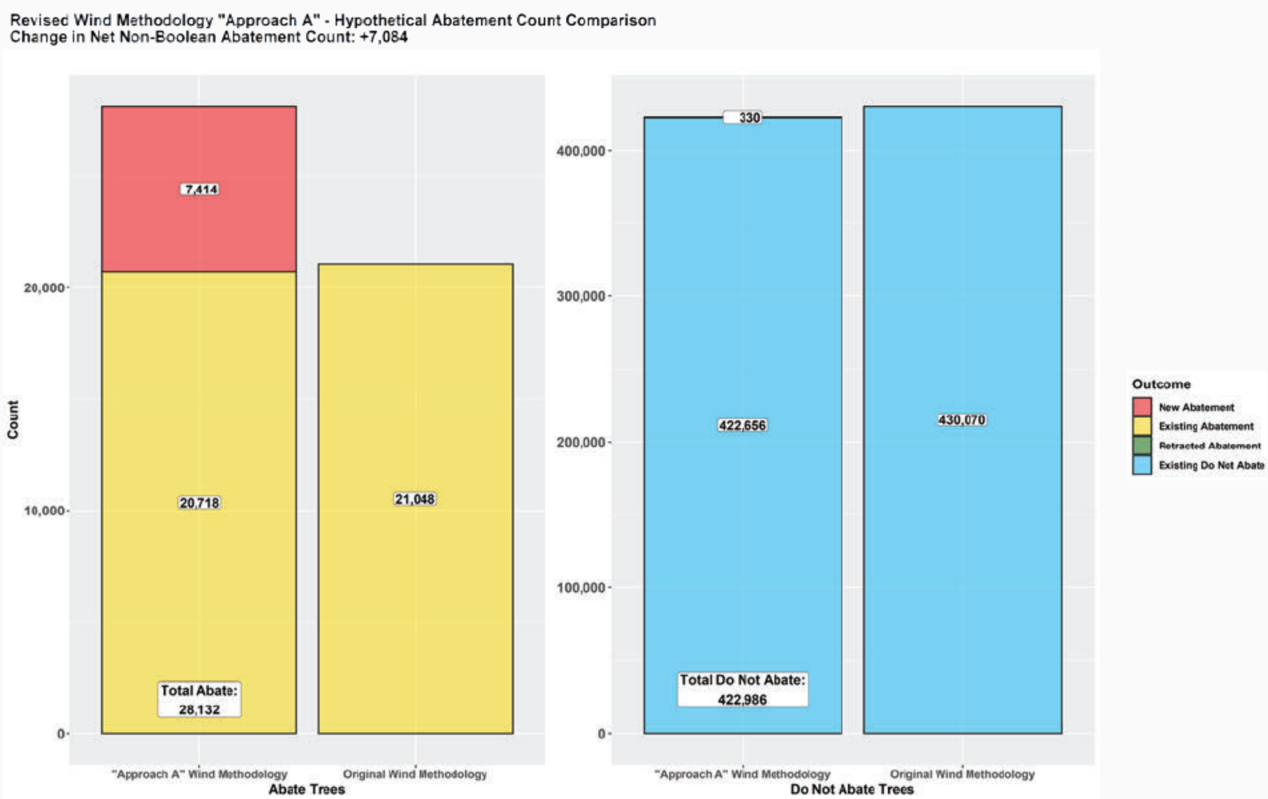


FIGURE E24. Change in hypothetical non-Boolean EVM TAT abatements using the Approach A revised wind methodology to calculate updated Tree Environment Scores and corresponding abate decisions.

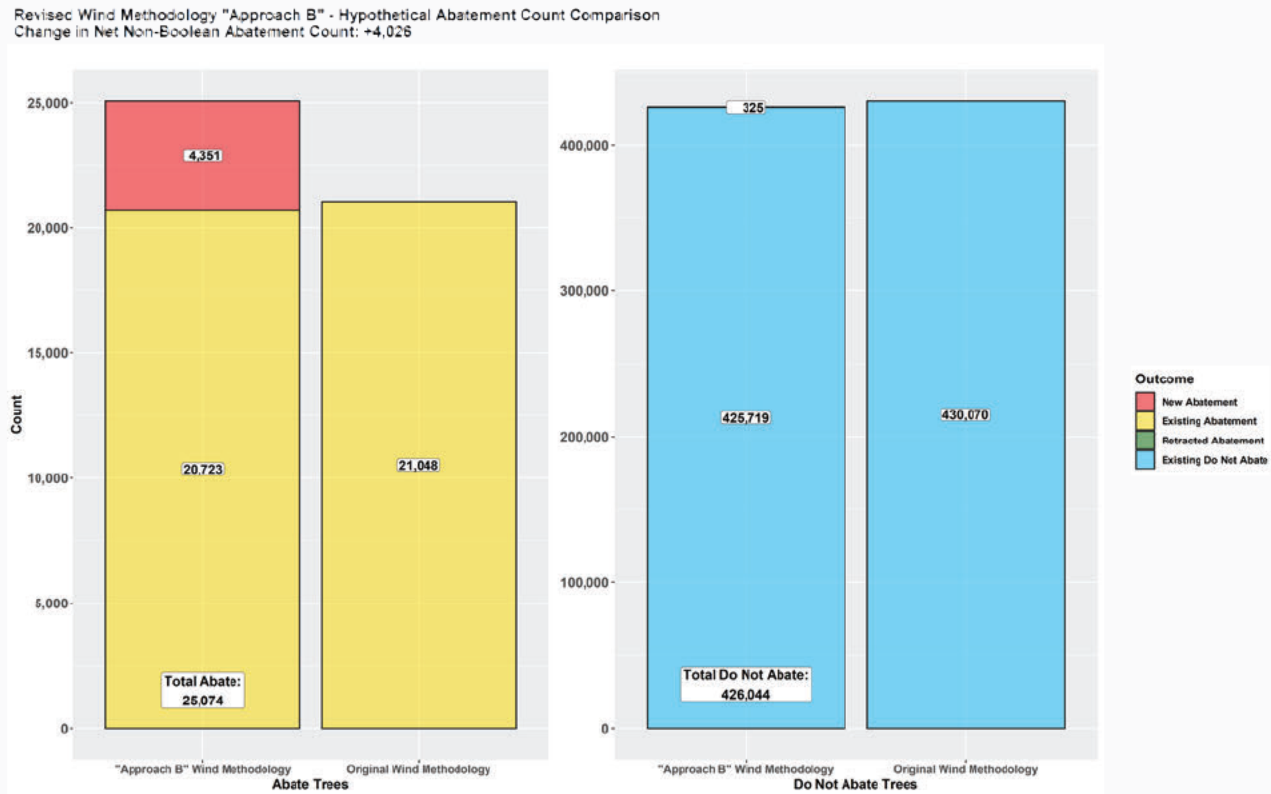


FIGURE E25. Change in hypothetical non-Boolean EVM TAT abatements using the Approach B revised wind methodology to calculate updated Tree Environment Scores and corresponding abate decisions.

Figures E26 and E27 (next page) show the geographic distribution of changes in hypothetical TAT abatements for Approach A & B if the wind methodologies described were implemented. With approximately 99.6% of all current EVM TAT records being placed in the "slight" wind category with a corresponding wind score of zero, almost any meaningful alternative approach would be expected to result in a significant increase in abatements. These methodologies used to compute revised wind scores are considered preliminary, particularly due to the use of the NLDAS dataset to determine daily maximum wind speeds at the location and time of wind-related tree failures. The recommendation regarding the final implementation would be to utilize this conceptual framework but using a meteorological dataset with increased spatial resolution and modeling accuracy, such as the Weather Research and Forecasting Model (WRF), for the purposes of determining the mean of daily maximum wind speeds associated with wind-related tree failures as well as providing the frequency of which this wind speed is exceeded from a spatial perspective.

FIGURE E26. The change in hypothetical EVM TAT abatements if the "Approach A" wind methodology were implemented.

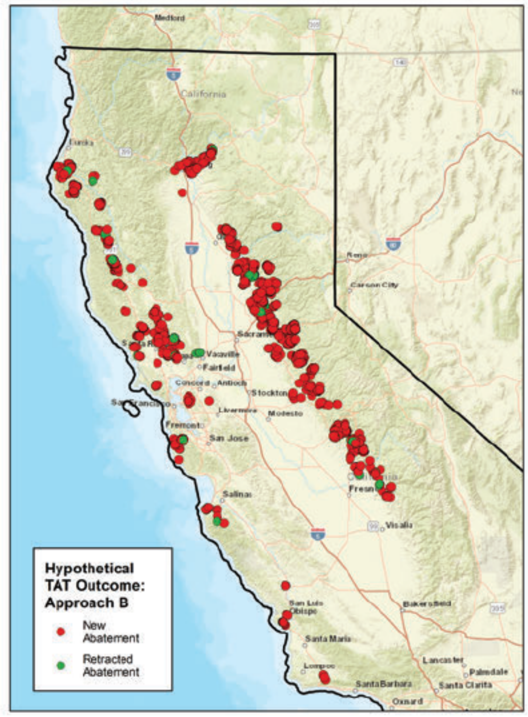


FIGURE E27. The change in hypothetical EVM TAT abatements if the "Approach B" wind methodology were implemented.

Appendix F: Species Height:DBH Model Development

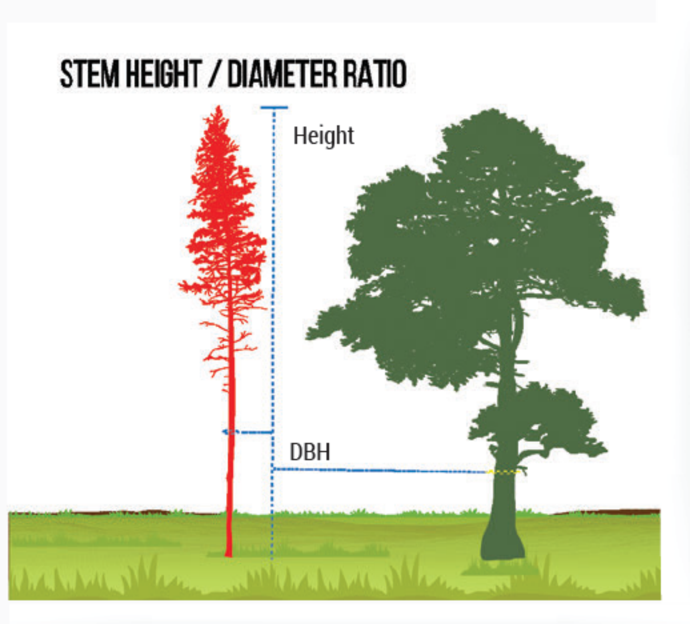


FIGURE F1. Depiction of stem height to DBH ratio, showing a more slender tree (red) and a less slender tree (green).

Tree height to diameter ratios have been used to understand and predict susceptibility to windthrow and storm damage and are proposed as a new parameter for addition to the EVM TAT. The tree height to diameter ratio refers to the ratio derived by a tree's height divided by the diameter-at-breast-height of its trunk (Figure F1), with both measurements being in the same units. Generally, trees with higher height to DBH ratios (i.e., thinner trunks relative to their height) are considered more prone to failure in response to wind and gravitational forces (e.g., snow loading) acting on the tree. Height to DBH ratio is most associated with stem breakage failures, as opposed to uprooting which is more a result of root and soil conditions (Wonn and O'Hara, 2001). Height to DBH ratio is an important individual tree characteristic which affects susceptibility to stem breakage while a tree's overall likelihood of root or trunk failure in response to external forces is a complex interaction between individual tree characteristics and species, stand level characteristics, soil conditions, topographic exposure characteristics, and meteorological conditions (Stathers, Rollerson, and Mitchell, 1994). While the complexity of accurately characterizing individual tree susceptibility to root or trunk failure throughout the entire PG&E service territory is likely impractical given the specialized knowledge, experience, time required, and complexity to do so for any individual tree, the height:DBH ratio of an individual tree can be quickly and accurately assessed during an EVM TAT inspection and represents an opportunity to enhance the EVM TAT by considering this important factor as a predictor to storm damage caused by high wind speeds or snow loading.

PG&E distribution databases were used to calculate and compare the height:DBH ratio of failure trees from the O&I database which caused an outage or ignition as a result of a trunk failure to the height:DBH ratio of standing trees as recorded in the routine work history and EVM TAT inspection record databases.

A single year of the routine work history database (2019 inspection cycle) was used to prevent the duplication of trees which are present in the database year over year. This analysis was performed both on an overall tree population level (i.e., without consideration of tree species) to assess and validate the general relationship between tree failure mechanism and height:DBH ratio along PG&E's distribution service territory as well as at the species-specific level to increase the specificity of analysis and identify statistically significant trends and parameter thresholds unique to certain species where possible. The three input datasets were prepared for analysis by omitting any records with missing or erroneous height or DBH values as well as removing any very small trees with a DBH under 2 inches or height less than 15 feet. The height:DBH ratio of all failure trees and standing trees was calculated by simply dividing the tree's height by its diameter, with both measurements being in the same units. The height to diameter ratios of standing trees were compared to those of failure trees and aggregated by failure mechanism (i.e., branch, root, and trunk failures) to determine if any potential differences of height:DBH were most prominent amongst trees which failed due to snapped trunks, as would be expected based on the findings of Wonn and O'Hara (2001), Stathers, Rollerson, and Mitchell (1994), and discussion with PG&E vegetation management SMEs. The summary statistics comparing the height to diameter ratio of standing trees to failure trees, by failure mechanism, is shown in Table F1 and the tree failure type with the highest height:DBH ratio is the set of trunk failure trees, indicating these results are generally in agreement with the behavior expected based on relevant scientific literature.

Dataset	Count	First Quartile	Median	Mean	Third Quartile
O&I Trunk Failures	13,813	34.38	36.92	40.45	51.43
O&I Root/Trunk Failures	25,316	25.38	36.92	40.01	50
O&I Branch/Root/Trunk Failures	43,581	23.33	33.1	36.38	45.45
Standing Trees	4,718,769	20.45	30	35.88	45

TABLE F1. Height to diameter ratio summary statistics of standing trees compared to failure trees.

The height to diameter ratio of stem failure trees was tested against the total population of standing trees using the Wilcoxon rank-sum test, which is similar to a t-test but does not require or assume an underlying Gaussian distribution and compares the sample medians to determine if a statistically significant difference exists. The height to diameter ratio distributions of stem failure trees compared to all standing trees is shown in Figure F2 and the Wilcoxon rank-sum test found a statistically significant difference ($p < 0.001$), with the stem failure trees having a higher height:DBH ratio than the standing trees.

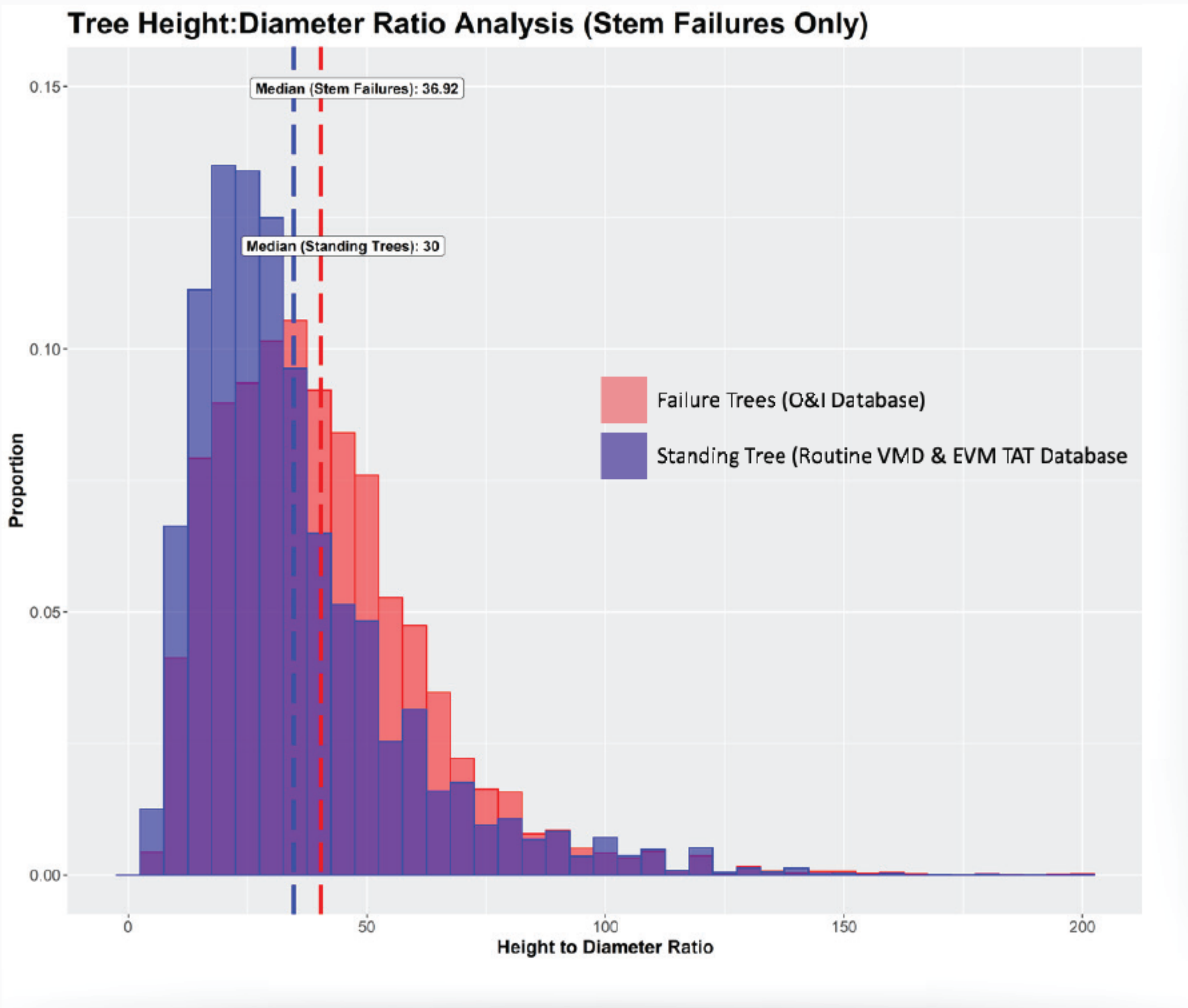


FIGURE F2. Height to diameter ratio distribution comparison of stem failure trees against all standing trees.

Species-specific comparisons between stem failure trees and standing trees were conducted to assess trends at the species-level and develop height:DBH thresholds which could be incorporated into the EVM TAT model. For each tree species with at least 20 stem failures in the historical O&I database, the distribution of height to diameter ratios was evaluated against the height to diameter ratios of standing trees of the same species and tested with the Wilcoxon signed-rank test at a 95% confidence level to identify those species for which the stem failure trees had a statistically significant difference in height:DBH as compared to the standing trees of that species.

Species which were found to be statistically significant ($p < 0.05$) are shown in Figure F3, where positive values indicate the stem failure trees have a greater height to diameter ratio compared to the standing trees of that species. Several oak species (Black Oak, Interior Live Oak, Blue Oak, and Valley Oak) were found to exhibit the opposite relationship based on the underlying PG&E datasets. Based on input from vegetation management SMEs, this finding is likely driven by the fact that many oak tree stem failures result from various diseases or rot conditions which are more common in older oak trees (which generally have a higher height:DBH ratio than younger oak trees), rather than these trees being more susceptible to stem breakage due to the mechanical characteristics of their trunks having a lower height:DBH value.

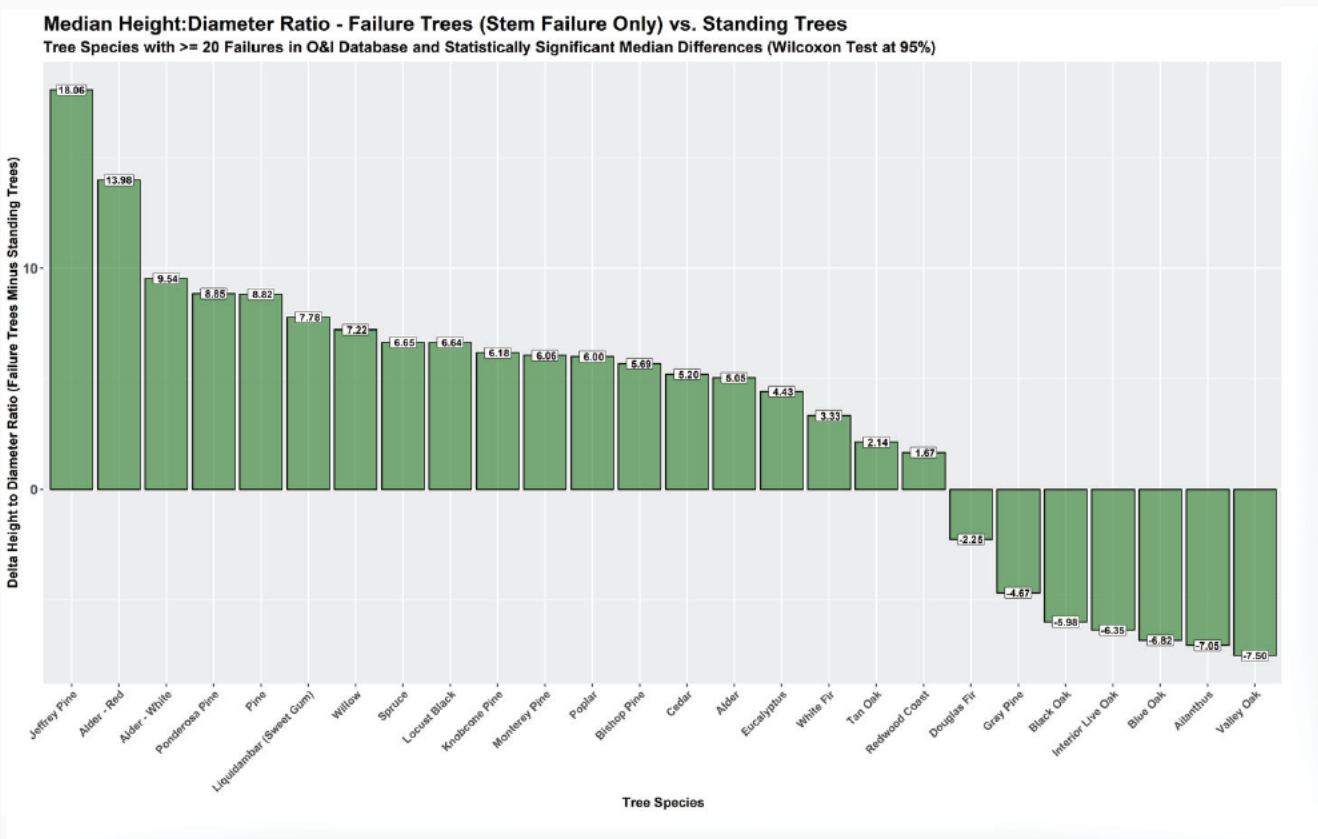


FIGURE F3. Comparison of statistically significant ($p < 0.05$) failure tree to standing tree median height to diameter ratios.

For the species where stem failure trees had statistically significant higher height:DBH ratios as compared to standing trees, EVM TAT parameter scoring thresholds of “low,” “medium,” and “high” (consistent with the current TAT’s general scoring methodology) were developed based on the calculated percentiles of height:DBH ratios of the stem failure tree population alone. The 85th, 70th, and 60th percentiles of height:DBH ratio of the stem failure trees were selected to represent the high, medium, and low classes of height to diameter ratio scoring, respectively, based on a qualitative review of these data (Table F2). For tree species where the stem failure trees had a lower median height:DBH ratio than the standing trees, or species which could not be included in this analysis (i.e., species with fewer than 20 outages in the O&I database or species for which the stem failure trees were not statistically significant in their difference from standing trees), thresholds could potentially be estimated with additional datasets or SME input as appropriate.

TREE SPECIES	COUNT (Stem Failure Trees)	COUNT (Standing Trees)	85th PERCENTILE Height:DBH ("High" Class)	70th PERCENTILE Height:DBH ("Med" Class)	60th PERCENTILE Height:DBH ("Low" Class)	DELTA: Height:DBH (Median Stem Failure Minus Median Standing Trees)
Jeffrey Pine	20	3,608	78	67	60	18.06
Alder-Red	96	12,423	75	65	60	13.98
Alder-White	53	10,915	53	48	46	9.54
Ponderosa Pine	1,591	272,851	80	65	60	8.85
Pine	286	51,440	61	48	43	8.82
Liquidambar	56	35,170	49	44	40	7.78
Willow	170	78,324	60	44	38	7.22
Spruce	69	10,313	69	53	58	6.65
Locust Black	39	18,151	60	50	41	6.64
Knobcone Pine	62	3,597	68	60	51	6.18
Monterey Pine	544	71,133	46	39	36	6.06
Poplar	65	11,870	60	49	43	6.00
Bishop Pine	131	131	60	48	45	5.69
Cedar	615	615	60	51	47	5.20
Alder	91	11,903	67	52	49	5.05
Eucalyptus	411	58,374	51	40	36	4.43
White Fir	159	32,597	74	60	60	3.33
Tan Oak	1,452	90,530	68	57	51	2.14
Coast Redwood	861	247,908	55	44	40	1.67

TABLE F2. Proposed height to diameter ratio thresholds derived from species-specific percentiles of historical stem failure trees.

Species-specific plots showing the relationship of height:DBH between stem failures and standing trees are shown in Figures F4-F28.

- **Failure Tree (O&I Database)**
- **Standing Tree (EVM TAT Database)**
- **Standing Tree (Routine VM Database)**
- **Median Height: DBH Ratio (All Standing Trees)**
- **Median Height: DBH Ratio (Stem Failure Trees)**
- **Height: Diameter Ratio Percentile Thresholds**

FIGURES F4-F28. Comparison of statistically significant ($p < 0.05$) stem failure tree to standing tree median height to diameter ratios by species.

FIGURE F4

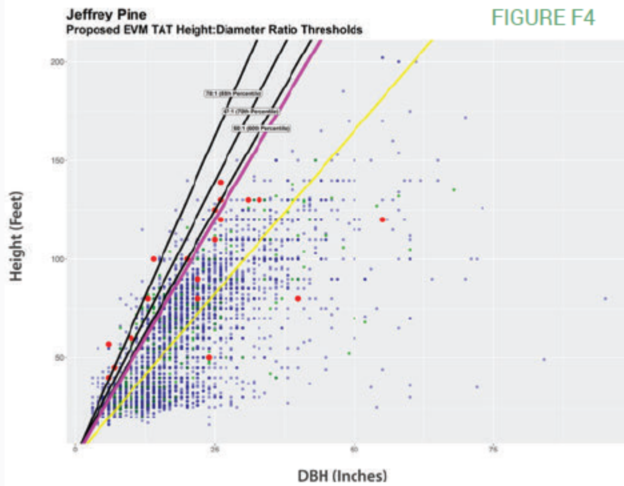


FIGURE F5

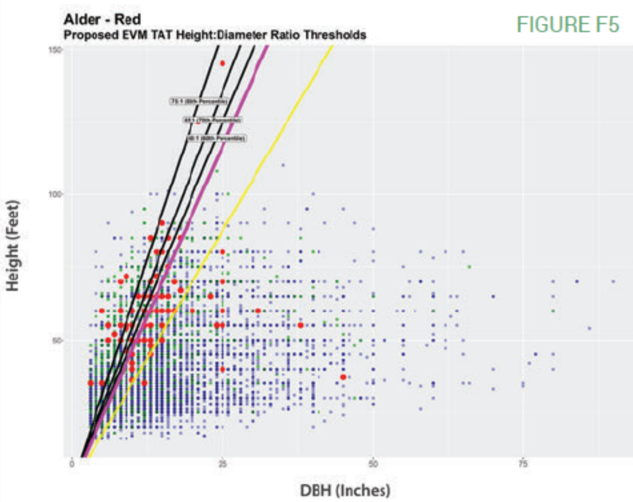


FIGURE F6

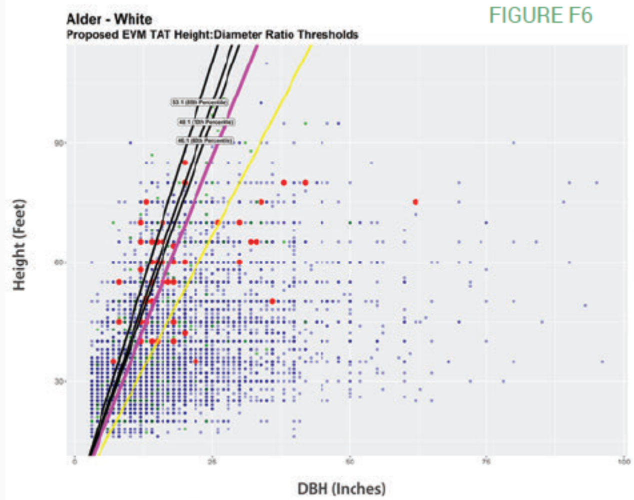


FIGURE F7

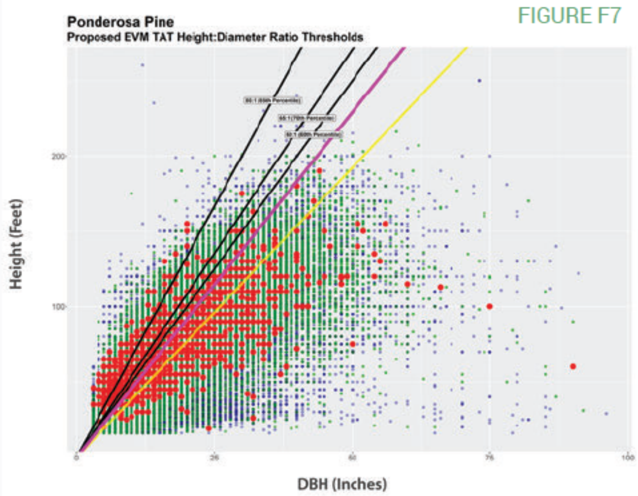


FIGURE F8

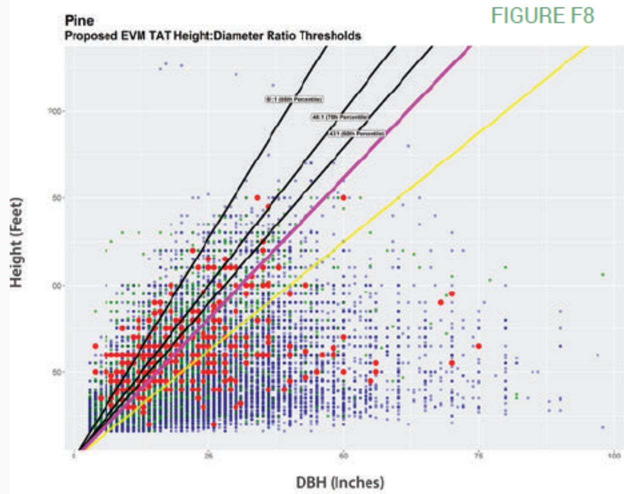


FIGURE F9

Liquidambar (Sweet Gum)
Proposed EVM TAT Height:Diameter Ratio Thresholds

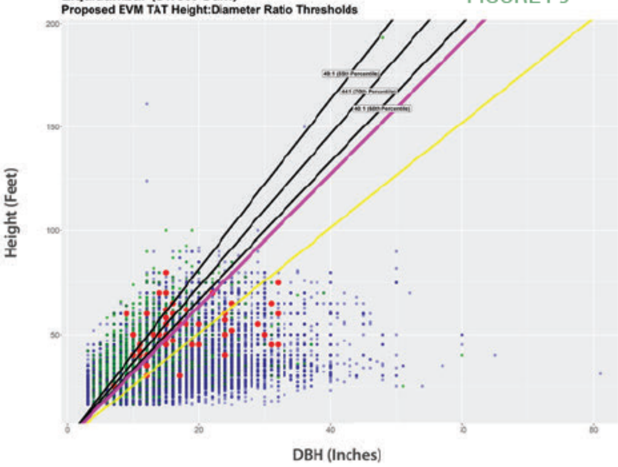


FIGURE F10

Willow
Proposed EVM TAT Height:Diameter Ratio Thresholds

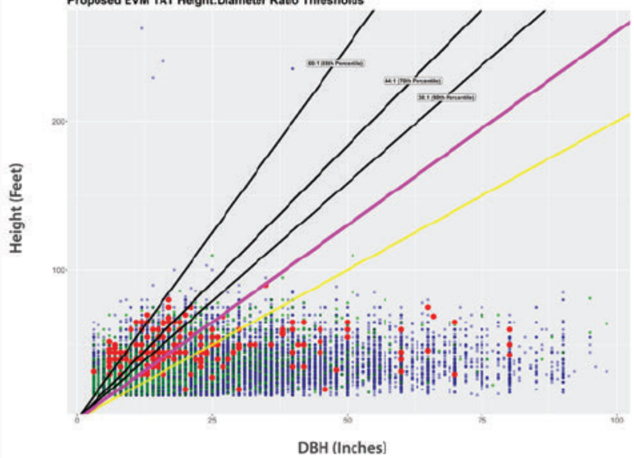


FIGURE F11

Spruce
Proposed EVM TAT Height:Diameter Ratio Thresholds

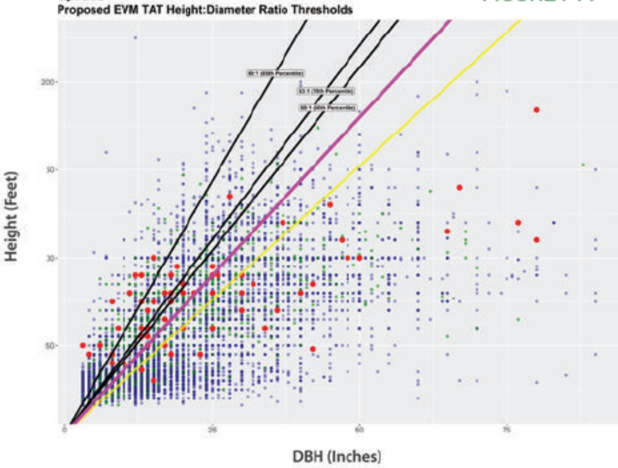


FIGURE F12

Locust Black
Proposed EVM TAT Height:Diameter Ratio Thresholds

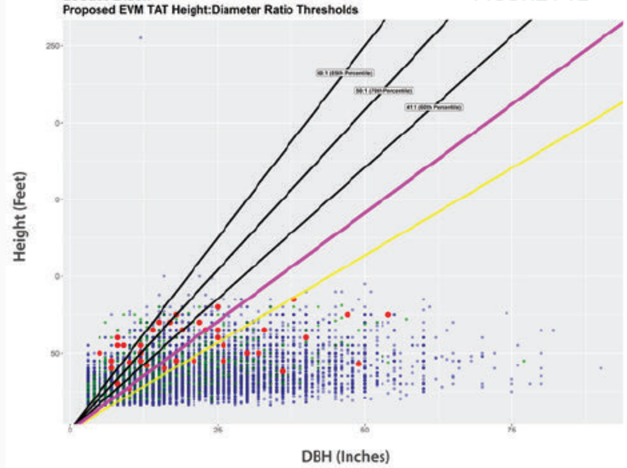


FIGURE F13

Knobcone Pine
Proposed EVM TAT Height:Diameter Ratio Thresholds

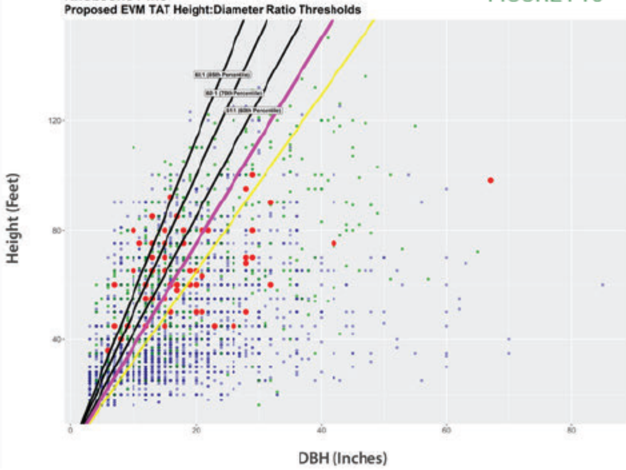


FIGURE F14

Monterey Pine
Proposed EVM TAT Height:Diameter Ratio Thresholds

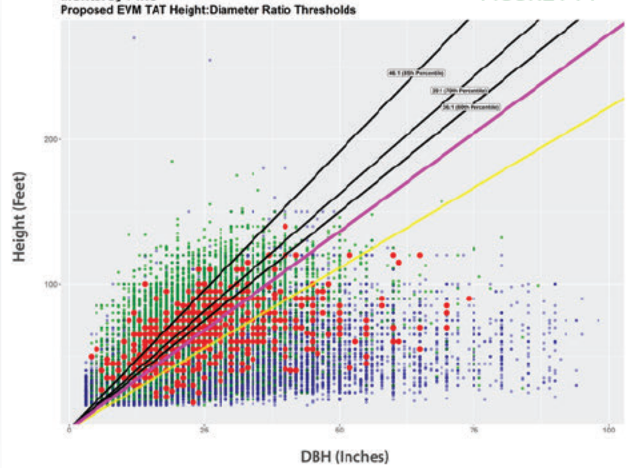


FIGURE F15

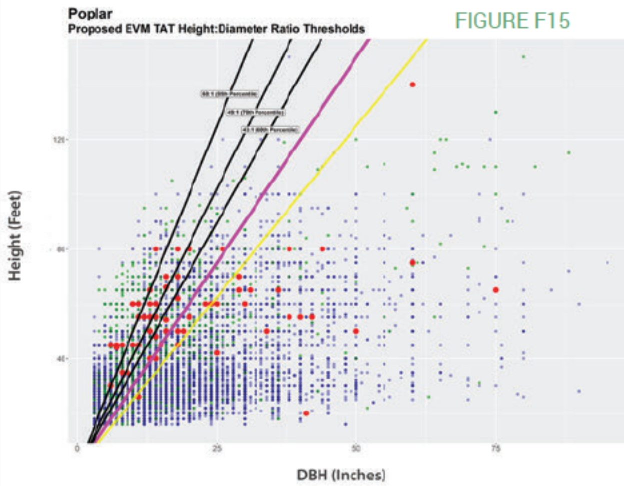


FIGURE F16

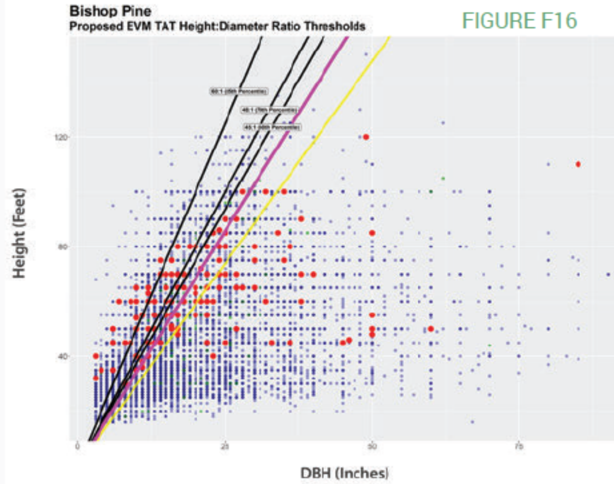


FIGURE F17

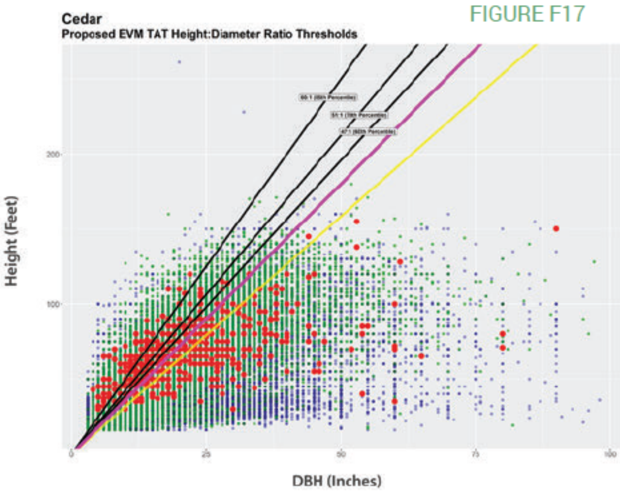


FIGURE F18

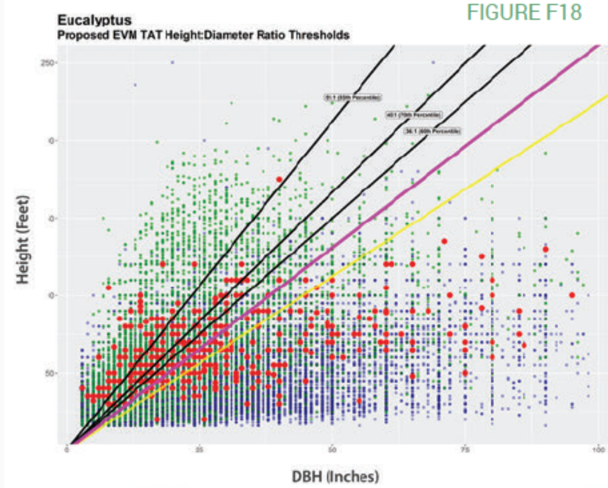


FIGURE F19

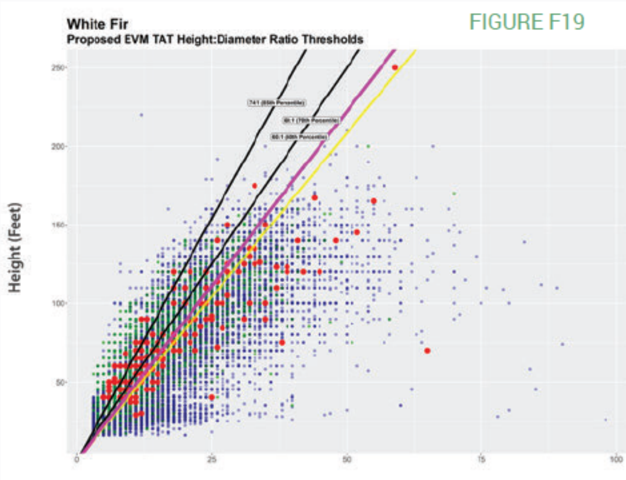


FIGURE F20

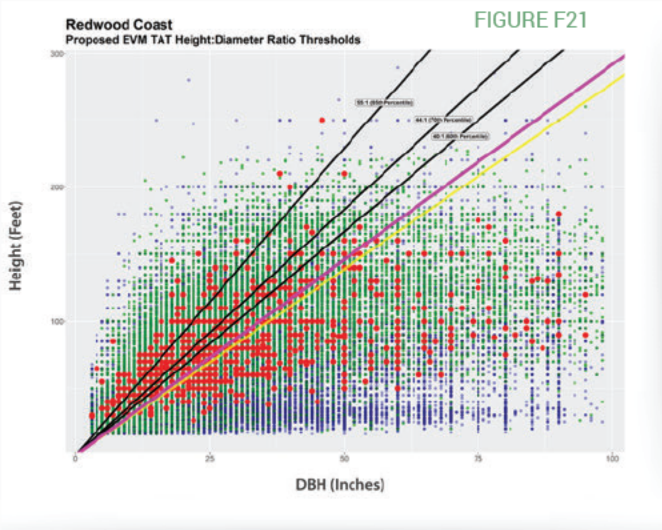


FIGURE F21

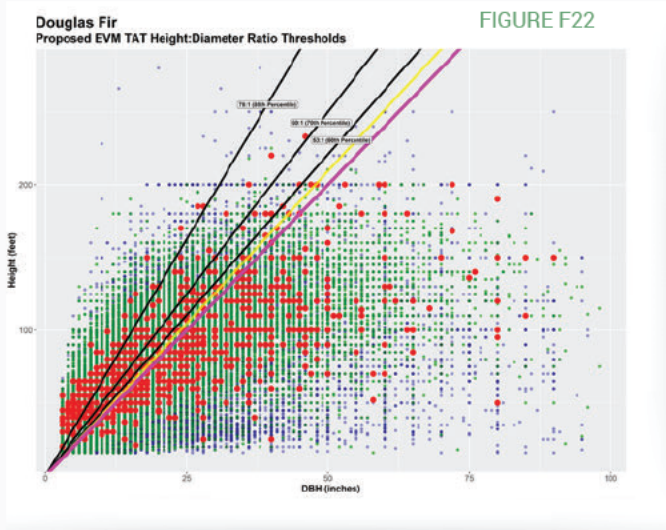


FIGURE F22

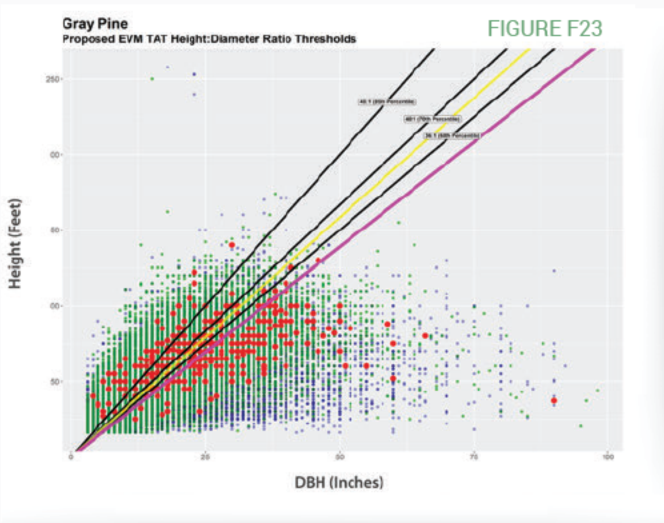


FIGURE F23

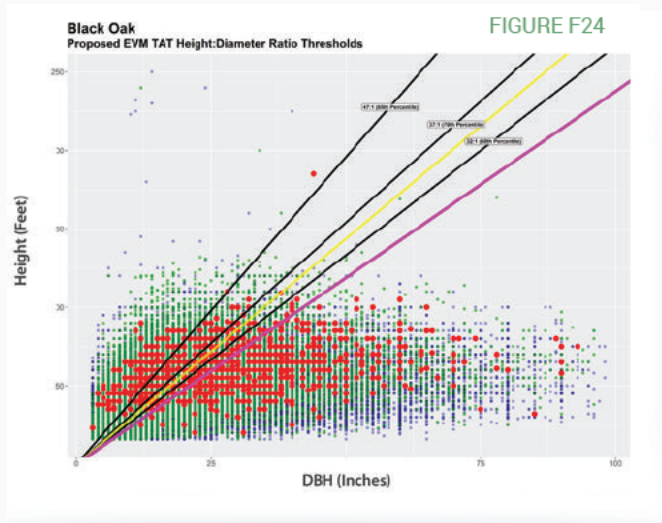


FIGURE F24

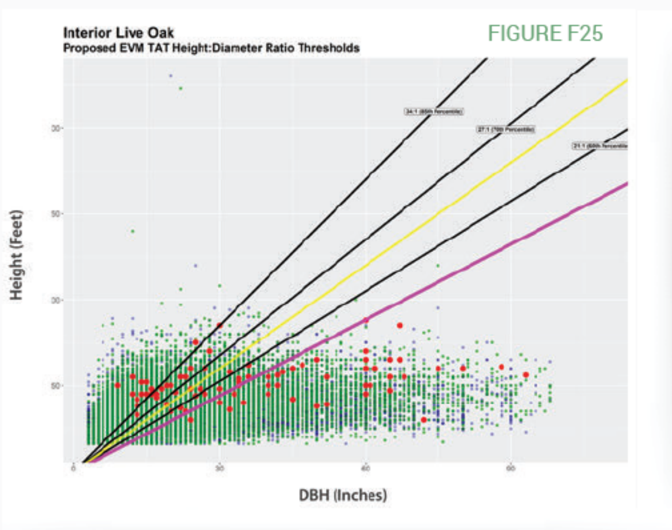


FIGURE F25

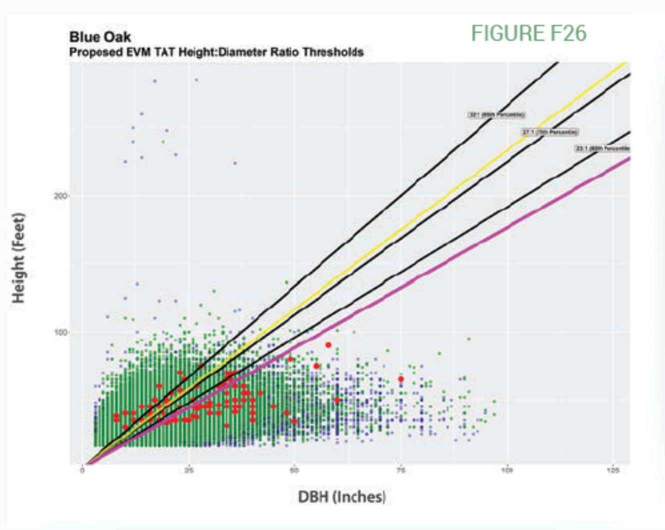


FIGURE F26

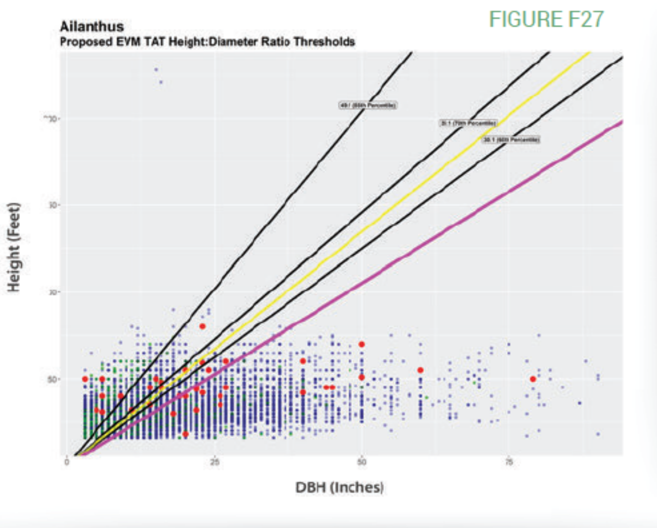


FIGURE F27

FIGURE F28

The potential implications of adding a height to diameter threshold to the EVM TAT were evaluated by calculating the hypothetical change in tree abatements which would have occurred if the height:DBH parameter were included in the EVM TAT model for trees already inspected. The species-specific height:DBH thresholds in Table F2, representing all statistically significant species where stem failure trees had a higher height:DBH than standing trees, were used as shown. The height to diameter ratio parameter was incorporated into the existing Tree Health Score component of the EVM TAT with high, medium, and low class values having scores of 5, 7, and 10, respectively. Any tree with a height:DBH ratio less than the threshold for the “low” class was assigned a score of zero. The height:DBH scores were treated as an addition to the Tree Health Score such that they were simply added to the Tree Health Score component of the TAT without making any modifications to the TAT decision matrix thresholds. For any tree species not shown in Table F2, no changes were made to the Tree Health Score and thus the height:DBH parameter did not affect the hypothetical abatement of these species. These parameter weightings could be further refined with additional data or SME input as appropriate.

The hypothetical abatement decisions based on the inclusion of the height to diameter parameter were determined by calculating an updated Tree Health Score, as described above, and subsequent TAT outcome using the current EVM TAT decision matrix. These hypothetical abatement decisions could only be calculated for those trees which were not Boolean abatements in the EVM TAT database, since the Boolean abate trees would be abated regardless of the other non-Boolean parameters and these trees do not have recorded scores for all of the Tree Health Score variables which would be needed to recalculate a hypothetical abatement decision. Trees without valid height or DBH values could not be assessed and any tree designated as being not a strike tree, leaning significantly away from the conductor, or being blocked from falling towards the conductor were unable to be assessed due to the lack of data necessary to generate a revised Tree Health Score. The addition of the height to diameter parameter to the Tree Health Score results in a net effect of increasing overall non-Boolean tree abatements by 3,845 trees (Figure F29).

FIGURE F29. The change in net number of hypothetical non-Boolean tree abatements which would occur if the height to diameter ratio thresholds were implemented and applied to those trees already inspected with the EVM TAT.

Hypothetical species-specific absolute and net changes in non-Boolean abatement counts are shown in Figure F30 (page 148), with Ponderosa Pine, Tan Oak, and Coast Redwood trees showing the largest increases in hypothetical abatements.

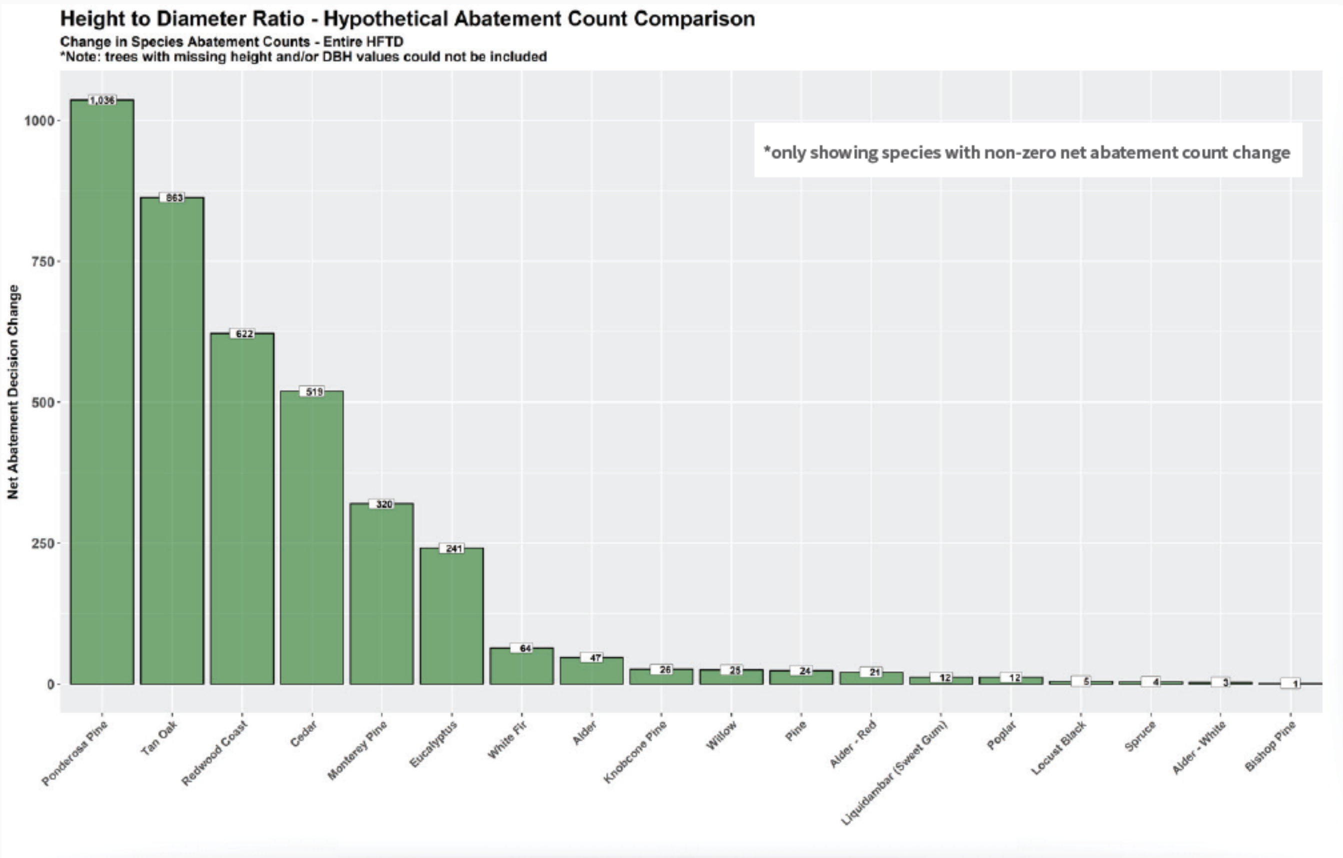


FIGURE F30. Species-specific changes in hypothetical non-Boolean abatements with the proposed addition of the height to diameter ratio parameter to the EVM TAT.

Figure F31 (page 149) visualizes the height to diameter ratios of these new hypothetical abatements as the addition of this parameter increased targeted abatements of trees with high height:DBH ratios (with many of these trees exceeding a 100:1 ratio) and therefore hypothetically removing these trees from the PG&E distribution system service territory which may pose an elevated risk of stem failure based on PG&E's databases. While the height to diameter ratio thresholds proposed could be refined with additional datasets or SME input, these hypothetical abatement comparisons demonstrate the potential to target trees exhibiting characteristics associated with increased risk of stem failure and may be of use to PG&E vegetation managers when considering the potential integration of this parameter into a revised EVM TAT model.

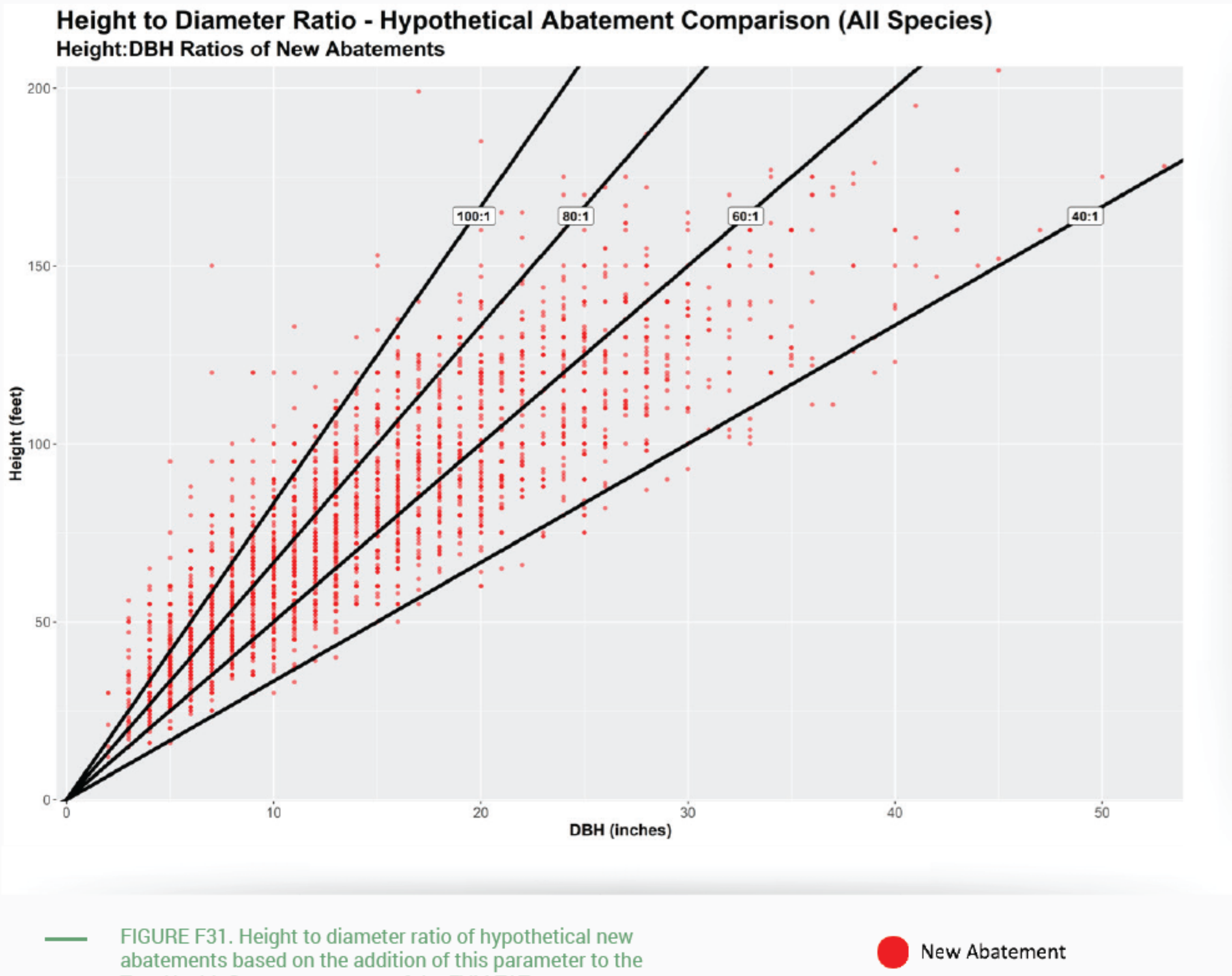


FIGURE F31. Height to diameter ratio of hypothetical new abatements based on the addition of this parameter to the Tree Health Score component of the EVM TAT.

Appendix G: Peer Review Panel Bios

Mr [redacted] - Eric Brown & Associates Consulting, LLC

Mr. [redacted] is a subject matter expert in utility vegetation management with extensive experience with the Hazard Tree Rating System (HTRS). He is a certified arborist with decades of experience working with SMUD and PG&E vegetation management programs. He has served as director for the El Dorado County Fire Safety Council since 2017 and served as peer review lead for North American Transmission Forum (NATF) for the Tree Risk Score Back-Test Analysis for Transmission Vegetation Management, conducted by PG&E in 2020-2021.

Dr. Larry Costello - Oracle Oak, LLC

Dr. Costello is a former advisor for the University of California Cooperative Extension as well as an adviser to Climate Ready Trees, a study to evaluate the ability of promising but underused species to tolerate stressors of future climates. Dr. Costello is a board certified master arborist. He retired Emeritus from UC in 2011 and started Oracle Oak Nursery in Hopland, CA.

Dr. Greg Dahle - Greg Dahle Consulting, LLC

Dr. Dahle is Program Coordinator for Forest Resources Management and Wood Science and Technology at West Virginia University. He has worked as an arborist in the San Francisco Bay area and served as a consulting utility arborist. Dr. Dahle's research utilizes allometric modeling and tree biomechanics to understanding how urban trees grow and survive environmental loads such as those from snow and ice storms.

Ms. [redacted] - Pacific Gas & Electric

Ms. [redacted] works as a data scientist with PG&E's Public Safety Power Shutoff program. She is currently conducting probability analysis on failure trees on the transmission system and served on the peer review team for the Tree Risk Score Back-Test Analysis for Transmission Vegetation Management, conducted by PG&E in 2020-2021.

Dr. Robert Pefferly - Independent Consultant

Dr. Pefferly's academic career has included professorships and research / teaching positions at universities in the United States, China, and Europe in the fields of Economics, Computer Science, Statistics / Probability, and Mathematics. Over the past twenty years, his professional work has mainly focused upon industrial applications of mathematical modeling and applied mathematics.

Appendix H: Peer Review Recommendations & Formation Environmental Follow-up

During the peer review process, the peer review experts were charged with reviewing Formation's Draft Report for the Targeted Tree Species Study, and asked to provide feedback on data inputs, analytical methods, findings, and any other recommendations related to the TTSS or the PG&E TAT White Paper.

This section provides a summary of the final recommendations from the five peer review experts. The recommendations were compiled into a spreadsheet, categorized by primary topic and presented in tables listed alphabetically by topic. For each topic, the total number of reviewers that commented on the topic and the total number of comments by those reviewers are provided. For example, in the first table below, 2 of 5 peer review experts had recommendations related to abatement outcomes, with a total of 4 comments. Columns include a summary of the reviewer comments / recommendations (Column 1) and corresponding responses from Formation (Column 2) as well as where the recommendation is incorporated into the final report, if applicable (Column 3).

In some cases, reviewers made recommendations that were not related to the TTSS or Formation's analysis. Rather, the recommendations were geared towards PG&E's TAT algorithm or process.

Topic:	**Number of Peer Reviewers This Topic**	**Number of Reviewer Comments**
ABATEMENT OUTCOMES	**2**	**4**
Topic Summary: Formation created a cascade abatement graphic that showed the TAT algorithm ordered by Boolean parameters and parameter scoring. Outcomes at each step of the algorithm included counts of trees abated. One peer review expert provided the following comments: (1) In general, it would be good to give examples of how key data-driven outcomes can be applied. There are some examples, but a good number more would be helpful. Basically, it informs the reader on how the info can be used. (2) Data shows that PG&E is doing a good job of abating obvious unhealthy trees. O&I are being caused predominantly by green, leafy, healthy trees. (3) Recommend PG&E conduct field visits (by SMEs) to validate No Abate by species. Gray pines seem low at 38% abatement rate. (4) Recommend that PG&E consider a category for decline in health vs. alive or dead.	**Formation Response:** (1) TAT Abatement Decision Tree: Figure 2.4 and Table 2.1 are the most granular breakdown of abatement decision-making that we can make with the TAT data. As to how these are used, other than tree abatement, we cannot shed any more insight(s). (2) Retrospective TAT Parameter Crosswalk To O&I Database: Evaluates TAT abatement and conclude with Recommendation 5: "Increase green tree abatement rates for trees with no obvious defects. Consider scored abatements that adds LiDAR metrics for overstrike distance, fall pathways to assets, tree position slope to alignment and canopy exposure to wind." (3) PG&E operations not in our scope (4) Decline in health likely considered in Tree health parameters (e.g., species determined to be of highest risk will be removed when exhibiting minor health or structural issues).	**Referenced in Report:** (1) Section 2.1 (2) Section 2.7 (3) N/A (4) N/A

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
AGGREGATED SPECIES	2	2
Topic Summary: Formation's preliminary recommendations suggested that for some TAT records, species data were collected at the Genus level (Oak) vs. Species level (Live Oak, Black Oak, etc.), creating an aggregated species category that eliminates species specificity necessary to fully interpret abatement parameter trends shown in the analysis. Two panel members suggested that these aggregated species categories should be removed. Species that were referenced as aggregate species were "Oak", "Pine", "Eucalyptus", "Willows", "Cypress", "Pine", "Alder".	**Formation Response:** Section 2.3 TAT Genus and Species Representations was added to fully evaluate species and Genus aggregations. Recommendation 1 was added to "implement a rule set, harmonized with O&I procedures, for TAT to record at species level, with only specified genus allowed as aggregates. Adopt definitions presented in the OEIS Geographic Information Systems Data Standard, version 2.2 in Section 3.4.3 Ignition (Feature Class), page 71." All TAT species and Genus aggregations can be found in Appendix C: TAT Species and Genus Compositions.	**Referenced in Report:** Section 2.3 Section 3.4.3 Appendix C

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
ANALYTICAL METHODS USED IN REPORT	3	7
Topic Summary: Three peer review panel members commented on Formation's analytical methods, stating that (1) "they look rigorous and/or appropriate and that the report represents an extensive evaluation of the TAT data". Conversely, another reviewer suggested that research questions should be presented as a priori unknown and follow a hypothesis test (reject or not). (2) Peer review expert #2 stated that "it needs to be recognized and emphasized that TTSS is a groundbreaking study. Not only is it a unique study (I'm not aware of a similar effort by another utility), it represents a significant, industry-wide step forward in the management of tree-related outages and ignitions. Quality data collection via TAT and subsequent TTSS-type analyses will serve to provide the critical information PG&E needs to effectively manage trees near power lines and markedly reduce outages and ignitions".	**Formation Response:** (1) Thank you (2) Agree	**Referenced in Report:** (1) N/A (2) Appendix J: Literature Citations

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
ANALYTICAL METHODS USED IN REPORT (Cont'd)	3	6
Topic Summary: (3) The third peer review expert offered the following caveats regarding the analysis. • a. Formation's spatial analysis shows concentrations in what look like Tier 2/3 areas where I'm guessing may be population density. • b. The outage-to-EVM circuit spatial analysis (p.58) also sheds light into whether EVM circuits are appropriate given outage history, however, (apologies) I was not able to understand graphics 57a & b very well to be able to distinguish the outages from the buffers. (One suggestion might be to have a graphic that shows just the yellow (>1 mi from EVM) and orange (<1 mi from EVM) outages without the buffers, to be able to see the location of the non-EVM outages better. • c. Might be interesting to see the May-Nov outages (suggested as being 3-5x more ignition prone (p.60)) plotted against EVM circuits as well. • d. The quality of the TAT data collected is the biggest deficiency of the EVM effort – which then compromises the TTSS. It's difficult to move on until assessment data (TAT) and failure data (historical reports) are improved."	**Formation Response:** (3a) Agreed. However, the calculations (e.g., rates of abatement per TAT record, ignitions per outage and TAT records per ignition are not skewed by "concentrations" as these are normalized as Population X/ Population Y). (3b) Due to the spatial inaccuracy of outage and ignition data, it is difficult to present these data given the persistent and sometime large errors. (3c) Agreed. We chose to stay with the defined PG&E wildfire prone period. Note on last comment. (3d) The spatial (locational) quality of the TAT data is the best of all the data we evaluated. However, the O&I and routine work history data contains positional errors that introduce large errors when comparing to the relatively accurately positioned TAT records. See Recommendation 2: Outage and/or ignition investigations should record accurate (dual-phase GPS) positions and be assigned to a EVM circuit span that correlates to geo-rectified and spatially conflated PG&E digital twin vector data. Similar to PG&E Transmission VM, where possible, associate the O&I tree with a LiDAR tree segmentation ID to further improve tree locational accuracy, and future tracking.	**Referenced in Report:** (3a) N/A (3b) N/A (3c) N/A (3d) Section on Recommendations - #2

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
APPENDICES	2	2
Topic Summary: Peer Review Experts suggested definition clarifications and / or term revisions as follows: (1) Put data samples in appendices (2) Provide a glossary of terms and acronyms. (3) Include TAT Assessment Form	**Formation Response:** (1) Data Descriptions were provided and moved to Appendix A. (2) Glossary added to Appendix I. (3) It is our understanding that the TAT is a software tool vs. a "form". The TAT algorithm and the TAT White Paper were presented to show the "decision tree logic" for abatements.	**Referenced in Report:** (1) Appendix A (2) Appendix I (3) N/A

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
BARK AND BRANCH FAILURES	2	3
Topic Summary: Formation's analysis included trunk and stem failure analysis only as that is what TAT parameters represent. Two reviewers provided feedback regarding bark and branch failure analysis. (1) One peer reviewer suggests "there is a need to address branch failures in future analyses. In the Western Tree Failure Database (WTFD), approximately 40% of failures are branch failures -- and I suspect a similar percentage holds for the PG&E failure database. Although PG&E's line clearance program abates many branches near power lines, a good number of branches remain -- that can (and do) cause O&Is. These need to be included in TAT assessments – and in subsequent reports when a failure occurs. This would provide information regarding species that are prone to branch failure, factors that contribute to branch failure, the occurrence of branch failure relative to trunk and root failures, and the efficacy of line clearance programs".	**Formation Response:** (1) The TTSS scope was to evaluate TAT, which included records that assessed stem and trunk failure potential and compare those to records of vegetation-caused outages & ignitions. Other components of the PG&E EVM program are designed to address overhang clearance that may potentially mitigate branch failures.	**Referenced in Report:** (1) N/A

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
BARK AND BRANCH FAILURES (Cont'd)	2	3
Topic Summary: (2) "I don't know why bark is not considered in codominant stem assessments. It's an easy enough assessment to make – and has a lot of bearing on failure potential". (3) While EVM TAT is focused on fall-ins, my biggest fear is of branch-caused outages since are harder to diagnose. Noticed from this analysis that branch-caused outages were highest frequency cause on high-wind event days (p.47), yielding 1250, compared to next highest cause of ~800. Would be interested to see additional analysis devoted to branch outages/ignitions.	**Formation Response:** (2) Our scope was to evaluate the TAT records provided but will convey this recommendation to PG&E. (3) Agree. Convey to PG&E.	**Referenced in Report:** (2) N/A (3) N/A

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
CASCADE ABATEMENT GRAPHIC	3	3
Topic Summary: Formation created a cascading abatement graphic to depict the TAT algorithm and the effects / outcomes of each Boolean parameter input and final scoring. The graphic provided total tree counts and % of abatements from each parameter input. (1) Two peer review experts (and one PG&E expert) requested clarification on the definition of "not a strike tree" categories and counts. (2) One peer reviewer commented that the graphic was nicely done. (3) One peer reviewer suggested that field reviews be conducted to validate tree defect assessments made by inspectors.	**Formation Response:** (1) "Not a strike tree" represents a tree assigned by the field inspector during the TAT process as a tree that was NOT determined to be a threat to overstrike distribution assets. Formation redesigned the graphic to make this point more clear and recalculated the abatement calculations with the additional categories. (2) Thank you (3) We cannot speak to additional field QC investigations but we convey this comment to PG&E.	**Referenced in Report:** (1) New graphic (2) N/A (3) N/A

Topic:	**Number of Peer Reviewers This Topic**	**Number of Reviewer Comments**
DATA INPUTS & LIMITATIONS	**5**	**13**
Topic Summary: In Formation's Draft report, we noted specific data integrity issues with PG&E enterprise datasets. There were also limitations to the analysis based on the inability to directly compare parameters from the TAT records with those in work management records and/or outage and ignition data. Five panel experts commented on data limitations as being a key area for continued improvement. While some comments were general in nature, specific recommendations for TAT parameters, Outages & Ignitions database, and incorporation of new data include the following: (1) Focused efforts to clean and improve the quality of historical data may significantly increase the value of analysis and data-driven conclusions a. Increasing the accuracy and consistency of new outage and ignition database entries b. improving the overall quality of distribution system geospatial asset data c. cleaning legacy datasets (where possible) d. recording consistent tree attributes across datasets e. improving the ability to relate records describing specific individual trees across all PG&E databases (2) Any new data collection that can be used to verify other data after the fact, like pictures, is welcome a. New database fields (and old ones) might be checked for 'normal' database design conformance – for starters.. b. Ensure that only one question is asked per column (e.g., types of fruit in one column, types of food (milk, veggies, fruit) in another) c. Try to ensure that each question's selection options are clearly mutually exclusive (like avoid options designed like 'terrain' field where >1 option can be true at same time (a. FLAT b. VALLEY c. CREEK d. HILLSIDE)" (3) The TAT white paper states, "Limiting the regression to diameter-to-breast height, height and age (recorded in both datasets) excluded variables that may otherwise impact tree failure as these features were not available within both datasets". Agree, why not assess Tree stand class. Dominate, Co Dominate, intermediate, suppressed and recent work nearby?	**Formation Response:** For this collection of suggestions, which is broad, the final document states data origins, states limitations and assumptions (where appropriate) and makes several recommendations to increase O&I and TAT fidelity and harmonization.	**Referenced in Report:** Section on Final Recommendations

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
DATA INPUTS & LIMITATIONS (Cont'd)	5	13
Topic Summary: (4) The TAT white paper states, "Digitalization accelerates of the inspection process and automates records retention, which decreases inspection time, ensures a system of record on which to further improve the process." Agreed and data should include lidar remote sensing data and harmonization with outage data. (5) "In terms of comparing the databases, there might be value in producing summary tables for select data." (6) Statistical significance (or the lack thereof) could be a product of the data and not a reflection of reality. That said, [TTSS] is presenting a totality of the evidence approach that is correct and should be taken to heart in future abatement processes as well as risk reduction strategies. (7) Regarding the positional errors in the circuit representation for the EVM clear circuits, I'm not sure how that GIS layer was generated, and not sure if this is helpful but wondered whether the EDGIS layer itself is any better or whether work being done by PG&E's LiDAR PMO to conflate LiDAR assets to EDGIS assets might improve the positional representations.	**Formation Response:** Previous page	**Referenced in Report:** Previous page

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
DATA COMPARISONS	2	2
Topic Summary: Formation noted inability to compare parameters across PG&E enterprise datasets. Two panel review experts suggested providing a matrix or summary tables to compare attributes across datasets.	**Formation Response:** Due to the number of fields in the datasets, a graphical display illustrating comparative attributes is not practical for this report.	**Referenced in Report:** Section on Final recommendations

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
DATA COMPARISONS (Cont'd)	2	2
Topic Summary:	**Formation Response:** Instead, we provide an overview of the barriers and a recommendations for improvements. Three barriers exist in comparing TAT and O&I data: • Tree species aggregation • Non-biased position errors • Disparate data fields Final recommendations to resolve these are: • Recommendation 1: Implement a rule set, harmonized with O&I procedures, for TAT records to the species level, with only specified genus allowed as aggregates. Adopt definitions presented in the OEIS Geographic Information Systems Data Standard, version 2.2 in Section 3.4.3 Ignition (Feature Class), page 71. • Recommendation 2: Outage and/or ignition investigations should record accurate (dual-phase GPS) positions and be assigned to a EVM circuit span that correlates to geo-rectified and spatially conflated PG&E digital twin vector data. Similar to PG&E Transmission VM, where possible, associate the O&I tree with a LiDAR tree segmentation ID to further improve tree locational accuracy, and future tacking. • Recommendation 4: Harmonize Outage and Ignition (O&I) data with TAT data parameters. o Fill out all O&I data fields. o To the best extent possible, perform a retroactive TAT analysis on future O&I trees. o Where possible, associate the O&I tree with a LiDAR tree segmentation ID	**Referenced in Report:** Section on Recommendations - #1, #2, #4

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
DEFINITION CHANGES	3	3
Topic Summary: Peer Review Experts suggested definition clarifications and / or term revisions as follows: (1) For TAT Parameters, recommend that PG&E revise minor and no wound thresholds. Minor Wounds: "No Wounds" - By this definition; a 6 ft wide 2 in long wound is classified as no wound. I would think that a 6 ft wound would be classified as a potentially important wound. (2) Suggest using the term slenderness (height:diameter ratios) which provides additional insight into failures. The research team might consider if a tree threshold for instability exists for a given species of collection of species. The threshold of 100 has been shown in the literature for pines. Additionally, are there interactions between slenderness and decay, insect or other defects. (3) The term "severe lean" is used to identify the direction of lean – away from or toward a power line. Seems to me that a better term should be found for this parameter – severe lean doesn't do it. Perhaps lean direction? Lean risk?	**Formation Response:** (1) This would be for PG&E to consider. (2) Given our definition is specific to our mathematical analysis, we maintain the H:DBH term. See Section 3.3 Height to DBH Ratio as a Scored Parameter for Selected Species. Final species and thresholds are presented, generally align to literature and are data driven using O&I and TAT data. (3) This would be for PG&E to consider for future TAT improvements.	**Referenced in Report:** (1) N/A (2) Section 3.3 (3) N/A

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
ECOREGION ASSIGNMENTS	2	3
Topic Summary: During check in meetings with PG&E, Formation was asked to analyze TAT records associated with EcoRegion assignments vs. PG&E administrative boundaries. Following its analysis, Formation recommended that PG&E adopt EcoRegion assignments to improve its assessment, study and mitigation of trees located in similar ecosystems. Two panel experts provided feedback on this topic. (1) Suggest additional analysis for calculating species % in each ecoregion. (2) Enhancement of TAT's RSFRR parameters using ecoregions instead of PG&E administrative regions. Agreed --- it's much more reasonable to consider ecosystem-based regions where species and environmental conditions are connected. This will help TAT assessments and management strategies be more precisely targeted. (3) Improve Figure 115 - Overlapping ecoregions on PG&E admin districts is confusing and hard to read. Suggest making 2 figures – one with ecoregions and one with admin districts.	**Formation Response:** (1) Species composition was expanded from using 1 year of routine work history records to using 8 years (2013-2020), comprised of 35 million records. This is virtually all of the relevant data available for calculating species composition in the ecoregion boundaries. (2) Agreed. Recommendation 6 is to use EPA Level III Ecoregions to aggregate Regional Species Fire Risk Rating scores. Use multiple years of data. Update annually. (3) Two new maps were created to illustrate the EcoRegions and PG&E administrative boundaries as separate maps.	**Referenced in Report:** (1) N/A (2) Section on Recommendations - #6 (3) Section 3, Figure 3.2

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
EVM CLEAR ANALYSIS	4	4
Topic Summary: Formation presented the results of its EVM Clear Analysis which we found that between 9/152019 to 6/6/2021, of 259 ignitions that 11 (4%) had occurred on EVM clear circuit segments, while 248 (96%) had occurred on non-EVM clear circuit segments. Panel members provided the following recommendations. (1) One note, I fully understand concentrating on ignitions here, yet a proportion of the outages that did not cause ignitions could have ended up as ignitions. It might be worth investigating the outages vs EVM using this proportionality to add more data points to your analysis? (2) Regarding the EVM Clear database - recommend continued analysis that incorporates records up to December investigation records, and update this work. (3) Maybe interesting view to consider these % of outages relative to line miles EVM cleared vs EVM not cleared yet. (4) Is there any usefulness in considering outage-to-line-miles relationship in an area – like maybe there are more outages because there is more conductor	**Formation Response:** (1) Outages would have increase sample size. These were not considered but could be in future analysis. Further, there will be one additional fire season to build sample size. (2) We constrained the analysis to the defined fire season only. Full year analysis will increase sample size. (3) Agreed. Proportionality to EVM clear vs. non-clear would be a good way to normalize results. (4) See #3	**Referenced in Report:** (1) N/A (2) N/A (3) N/A (4) N/A

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
EVM CROSSWALK ANALYSIS	1	2
Topic Summary: Formation presented the results of its EVM Crosswalk analysis to compare TAT parameters to parameters in the outage & ignition database to "back test" TAT tree health parameters with tree failure parameters. One peer review expert commented on the inability to analyze overhanging branches in this EVM Crosswalk analysis. From TAT White Paper - "There is little available data from which to estimate how many of these historical overhanging branch failures could have presumably been avoided if the EVM program were in operational use at the time."… (1) Peer reviewer recommends getting VM Reliability Data from Reliability program, its broken in to Overhang, Facility Protect, Limb Failure, Etc.. This data showed nearly 50% improvement over the first 5 years of VM Reliability Program. (2) Overhanging branches are a key abatement target on nearly all species. Need to study it.	**Formation Response:** (1) The TTSS scope was to evaluate TAT, which included records that assessed stem and trunk failure potential and compare those to records of vegetation-caused outages & ignitions. Other components of the PG&E EVM program are designed to address overhang clearance and facility protect that may potentially identify and mitigate branch failures. (2) There was a brief discussion on overhanging branch analysis in the EVM Crosswalk Analysis. It was provided in the DRAFT Report but not included in this FINAL Report. Below is the statement from that analysis: With respect to overhanging branches in the HFTD areas, approximately 20.91% of all outages and 18.97% of all ignitions in the historical O&I database were recorded as having been caused by an overhanging branch. Amongst HFTD branch failures only, 68.76% of those outages and 64.82% of ignitions were attributed to overhanging branches. There is little available data from which to estimate how many of these historical overhanging branch failures could have presumably been avoided if the EVM program were in operational use at the time. In areas where EVM inspections and tree work can eliminate all or most overhanging branches, that could presumably mitigate up to the approximately 20% of overall HFTD outages and ignitions historically caused by overhanging branches and the targeted removal of overhanging branches in the EVM program should result in a meaningful reduction of O&Is as these branches are removed. It should also be noted that these are estimates of presumed past performance, which may not necessarily be predictive of current and future performance. The best way to evaluate the true effectiveness of the EVM TAT will be to collect detailed, accurate, and consistent data regarding outages, ignitions, and EVM TAT tree inspections along with corresponding tree work over time, which may then be more rigorously assessed once one or more complete fire seasons follows the verification of EVM work.	**Referenced in Report:** (1) N/A (2) N/A

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
EVM EFFECTIVENESS	**1**	**2**
Topic Summary: Formation discussed the inability to identify a specific tree across datasets, tracking from TAT record to work management record to outage & ignition database. As a result of this limitation, determining EVM Effectiveness requires alternative approaches. Further, it was determined that not enough time had elapsed to study specific regions to show a decrease in vegetation-caused outages and ignitions. One panel member had comments on this section. (1) Recommend that PG&E shorten the time between TAT records and worked trees (estimated to currently be approximately 12 months). (2) With regard to this Formation statement about following a tree across datasets, “Impossible to determine (in the data) with certainty whether or not any particular tree designated for abatement by the EVM TAT has in fact been removed”, the expert suggested to PG&E that this needs to be remedied.	**Formation Response:** (1) This is a PG&E operational matter. Obviously, the programmatic velocity between abatement decisions and tree removal should be a priority. (2) We agree.	**Referenced in Report:** (1) N/A (2) N/A

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
FIGURE CAPTIONS	1	2
Topic Summary: Formation provided a number of graphics and illustrations to convey results of analysis and describe findings. Two panel members provided feedback on some of those graphics. (1) Many figure captions don't give enough info that a reader needs to know to understand what's in the figure. More descriptive info would be very helpful. For example, Fig. 2 caption gives a figure title, but no descriptive info. Yes, there is descriptive info in the text, but a synopsis should be in the caption. (2) p. 48, Fig. 39: Why are branch, trunk, and root failures listed as causes of failure? They are types of failure, not causes.	**Formation Response:** (1) Formation has rewritten captions where appropriate to improve descriptions. (2) Agree. They were listed as "cause" on the figure because that is the name of the field containing that information in the PG&E database (i.e., what happened to the tree which caused the outage). We will revise the figure to use a more appropriate title for this context.	**Referenced in Report:** (1) N/A (2) N/A

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
LIDAR DATA	3	4
Topic Summary: While Formation did not have an opportunity to incorporate the Distribution LiDAR data received in December 17th, 2021 into its analysis, our team referred to its experience with LiDAR and the results of the PG&E TVM Tree Risk Scoring Back Testing project as evidence for making the recommendation to incorporate LiDAR data into tree assessments to further evaluate strike potential. The use of highly accurate and precise active remote sensing technologies (e.g., airborne and mobile LiDAR) are recommended to facilitate improved accuracy and consistency in determining which trees have the potential to strike PG&E distribution assets in the event of a root or stem failure, as well as the ability to	**Formation Response:** Note: Referencing the PG&E 2022 WMP, in 2021 PG&E "continued to expand the utilization of ground-based LiDAR datasets in Routine VM for distribution lines in HFTD areas. To scale this effort to regions with HFTD lines, VM Technology has mapped out the locations of Routine Inspections (VM Projects) and developed a data pipeline to deliver the LiDAR Detections to VM Operations approximately 30 days following collections".	**Referenced in Report:** Next Page Note: Reference Appendix J: PG&E WMP 2022

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
LIDAR DATA (Cont'd)	3	4
Topic Summary: calculate other LiDAR-derived parameters relevant to understanding tree failure, such as overstrike, topographic & tree height exposure, slope and aspect to wire, and estimating fall path obstructions. (1) Using LiDAR to detect and classify failure trees would be awesome. (2) Agree to using LiDAR and would recommend that Formation incorporate LiDAR analysis into further analysis. Need to consider vegetation segmentation routines to account for co-dominant gray pines (3) Seems to be a worthwhile endeavor – although I have to say that I don't have expertise in remote sensing and don't know the limitations of the technology.	**Formation Response:** (1) Agree. (2) Agree. Vegetation segmentation is a critical step in the use of LiDAR data to identify and analyze individual trees, regardless of the species. (3) Thank you *See Recommendation 5: Increase green tree abatement rates for trees with no obvious defects. Consider scored abatements that adds LiDAR metrics for overstrike distance, fall pathways to assets, tree position slope to alignment and canopy exposure to wind.	**Referenced in Report:** (1) N/A (2) N/A (3) N/A *Section on Recommendations - #5

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
LITERATURE CITATIONS & BENCHMARKS	2	4
Topic Summary: Two panel review experts commented on benchmarking tools for tree risk assessments. Discussions ensued during peer review meetings regarding literature searches and UVM benchmarks. The following comments were made: (1) Please reference other literature that are utility and tree failure related. Are any other utilities doing these types of work… TAT, failure trees, etc. (2) Consider reference from ISA BMP Tree Risk Assessment 2020. John Goodfellow - author.	**Formation Response:** All: We have expanded our literature review and referencing. That said, it is difficult to find germane and contemporary publications in this specific area. This is especially true in the gray literature (industry or internal non-published documents). That said, our body of literature citations can always be expanded.	**Referenced in Report:** All: Appendix J

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
LITERATURE CITATIONS & BENCHMARKS (Cont'd)	2	4
Topic Summary: (4) From the TAT White Paper, "The benchmark assessment tools collect considerably more data than the PG&E Tree Assessment Tool with a materially longer estimated average assessment time which makes them difficult to assess large tree populations". Should consider new approach to TAT, and staffing in Tier 2 & 3 areas. (4) From the TAT White Paper, "The benchmark assessment tools are designed for urban forestry and do not specifically seek to mitigate wildfire threats". Note that the tools are used to address public safety threats.	**Formation Response:** Previous page	**Referenced in Report:** All: Appendix J

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
RECOMMENDATIONS FOR FUTURE ANALYSIS	3	7
Topic Summary: The peer review panel was charged with making overall recommendations for extended or additional analysis that may be useful to PG&E to further understand parameters or species-specific trends that would enhance or improve its TAT or other recommendations that would assist PG&E with continuous process improvement to its EVM program. (1) A comprehensive Data Dictionary listing what data elements are available in each database as well as form and distribution summary statistics for each data element. It is difficult to know what questions can be answered without a thorough view of what data is available. In addition, any future researchers and industrial data scientists will require bench-marking and a comprehensive Data Dictionary would be invaluable.	**Formation Response:** (1) Data Descriptions for a review of data employed. A true data dictionary (or better yet metadata for each database) would be helpful for any future investigator.	**Referenced in Report:** (1) Appendix A

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
RECOMMENDATIONS FOR FUTURE ANALYSIS (Cont'd)	3	7
Topic Summary: (2) Using Shannon Meta-metrics to measure the quality of the information contained in PG&E TAT data would be extremely beneficial. (Section A.2.7) (3) Using a Multiplicative TAT Model in place of the current Additive TAT Model would be a direct measure of inherent risk and provide more intuitive results (Section B.1.2) that could be objectively measured. (4) Replacing the RSFRR Metric with its two Q components would identify species risk more effectively. (Section C.2.5) (5) A Literature Review of best practices concerning the DBH Metric would be beneficial. (Section C.2.6) Current research shows that DBH conditioned upon canopy cover, species, soil conditions, distance to electrical assets, etc. provides more accurate assessments of risk. (6) Interested in more analysis regarding slope & hillside…maybe actually the lower slope category is more predictive? (7) Is it useful to isolate parameters (e.g., slope and terrain) and analyze them independent of other parameters? Seems to me that more than one factor comes into play when a failure occurs – wind, saturated soil, slope, dense crown, shallow root system, and nearby disturbance all can combine to cause a root failure. Focusing on dense crown independent of the other causal factors does not provide a full assessment of causal factors.	**Formation Response:** (2) We are not familiar with Shannon Meta-metrics, but we are always happy to explore/learn new analytic methods. (3) We did not (and could not) evaluate the TAT model algorithm, as the basis for computation and threshold is not explicit in the TAT white paper. (4) This could be. We demonstrate that Recommendation 6 (Use EPA Level III Ecoregions to aggregate Regional Species Fire Risk Rating scores. Use multiple years of data. Update annually) increases abatement rates and improves the TAT abatement distribution relative to legacy O&I for select species. Future investigations should conder improvement that build on this recommendation. (5) This is a well-reasoned point. Future analysis should consider H:DBH in relation to other parameters (stand, canopy soils, etc.) (6) The PSPS Transmission Back Testing effort employed LiDAR metrics and accurately located to the tree failures. This comprehensive effort found that slope and terrain (when evaluated independently) are very weak predictors of outages. (7) Formation's analysis for TAT parameters relations strength found slope and terrain to be the weakest of the TAT parameters in affecting abatement outcomes. It is logical that multiple factors (involving slope and terrain) contribute to vegetation-caused outages.	**Referenced in Report:** (2) N/A (3) N/A (4) Section on Recommendations - #6 (5) N/A (6) Appendix J: Tree Risk Back Testing Report reference (7) N/A

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
SPECIES & SEASONALITY STUDIES	3	4
Topic Summary: The TTSS Peer review experts provided several comments (both in peer review meeting discussions and recommendations) regarding TAT seasonality studies. (1) Figure 54 suggests that in the spring TAT collectors found more Abate trees. Did you / should you test to see if there was a relationship between time of year for data collection and % of Abate trees? (2) The report walked through the annual seasonality of the outage vs ignition data sets. To be clear, identifying and abating the trees that might fail in the winter (outside of fire season) will likely lead to a reduction in the outages and ignition in the fire season simply by removing three with high likelihoods of failure. It might be worth adding them into some of the analysis. (3) Ignitions data shows seasonal differences in addition to species differences. Should we study seasonality? (4) Seasonal analysis is complex in terms of analyzing species physicality. Micro climates, soil conditions and variable seasonal timelines all come in to play. The study would not be the same from year to year. Should not study seasonality.	**Formation Response:** (1) We did not explore abatement rate and seasonality. (2) It follows that ignitions would vary seasonally by species. That said, we did not study ignition rate by species seasonally (or monthly). (3) This would be for PG&E to consider but the EVM program and this study primarily address vegetation potentially impactful to wildfire season. (4) Thank you for this comment.	**Referenced in Report:** (1) N/A (2) N/A (3) N/A (4) N/A

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
SPECIES SPECIFIC ABATEMENTS	**3**	**4**
Topic Summary: Formation conducted multiple analyses focused on identifying species-specific parameter trends. Peer review experts had several comments regarding species parameters. (1) Consider making TAT forms specific for species. If an assessor is inspecting a Doug fir, a form with attributes specific for Doug fir may help make the assessment more useful. This could be done fairly easily with electronic forms – as I presume are being used. For example, a blue oak does not likely need HT:DBH values – as would Doug fir or Ponderosa pine. (2) Do we know what characteristic of gray pine led to an abatement decision? Dead? Wounds? Lean? It would be good to have "species failure profiles" for each of the "bad actors". This would help guide assessors when conducting inspections. (3) From the TAT White Paper "*AWRR also more aggressively targeted the removal of ten tree species based on their history of causing outages and/or ignitions in HFTD during wildfire season*". Peer reviewer suggested, "Not certain that Ponderosa Pine is a wildfire risk, typically associated with snow load failures". (4) Related to assessments in the field - select species that has an auto populate parameters associated with that species only. Also, a lot of TAT records collected in 15 month timeline is commendable amount of work.	**Formation Response:** (1) Preconfiguring a pre-populating the TAT forms makes sense and would potentially speed inspection cycles. (2) No, but the RSFFR for gray pines increases the TAT abatement rate to 38%, above other species. Formation did conduct species failure profiles for the EcoRegion Analysis - Appendix D. (3) Agree. Formation took a data-driven process in assessing legacy O&I species populations. Similarly, PG&E applied a data-driven approach to assignment of the Regional Species Fire Risk Ratings. All O&I data shows that Ponderosa Pine species have a high frequency of vegetation-caused O&I. However, Ponderosa Pines are ranked low in the RSFRR which was derived using O&I vegetation failure data for wildfire season months only. The high frequency of O&I for Ponderosa Pines is likely attributed to winter storm outages (possibly snow loading). (4) A TAT auto-populate feature that selects some parameters by species could potentially facilitate improved targeting. Some species-specific analysis conducted by this team that could be incorporated in this auto-populate feature are H:DBH by species, RSFFR and EcoRegion by species.	**Referenced in Report:** (1) N/A (2) Appendix D: EcoRegion Analysis (3) (4)

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
STRIKE TREES	**2**	**3**
Topic Summary: Regarding Strike Trees & Non-strike Tree Populations, peer review experts provided feedback for PG&E regarding the TAT algorithm and consideration of strike trees. (1) Is the TAT 640,501 number - all trees tall enough to strike the lines, does it include trees too short or too far away to be considered as potential strike trees? Yes. I feel this is important to clarify, especially seeing the statement that 82% of TAT trees were rated as not requiring abatement. Curiously, can this number (84%) be extrapolated to the 8 million trees within 'strike distance' of power lines announced on Jan 4 2022? (2) Why are "not strike trees" included in the dataset? If they are out of strike range, they are not a concern. No target = no risk. (3) Although young trees may not be "strike trees", they should not be ignored in TAT assessments. A young Doug fir may not be a strike tree initially, but it will be eventually. Does PG&E want to wait until it becomes a strike tree to consider it for abatement? If a process to deal with future "bad actors" is not in place, then it should be considered. Why not do some preventative abatement?	**Formation Response:** (1) No. TAT has evaluated a relatively small number of trees in EVM corridors and is spatially and temporally confined to the 1st year of TAT inspections. It is fair to expect for strike tree abatement rates to change as the TAT record population increases and other areas (ecoregions) become more represented. (2) It was simply a judgement call to account for all trees in the TAT database. These do not factor into any succeeding analysis or recommendations. (3) We did not consider this as a TAT programmatic option. Due to the volume of trees to address across its system, the highest risk trees at the time of assessment are considered to be the priority.	**Referenced in Report:** (1) N/A (2) N/A (3) N/A

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
TAT ALGORITHM	**3**	**4**
Topic Summary: Peer Review Panel experts provided some general TAT Algorithm Recommendations for PG&E (1) In general, wonder if useful to looking for interaction effects among variables (if not already in part of analysis I haven't gotten to) (2) TAT methodology needs to be looked at closer. There's some confusions regarding terms. (3) Recommend reordering Boolean parameters (4) Lean seems to be factored in twice – in Boolean as "severe lean" and Tree Health as degree of lean. If "yes", the first lean assessment negates the second, but if "no" then is second lean assessment meaningful?	**Formation Response:** **All: We agree that the TAT algorithm can be improved (as with any algorithm). But, more important is to back test the algorithm against O&I prevention. We recommend addressing data compatibility issues between TAT parameters and O&I database and updating analysis with current TAT and O&I records from June 2020 - 2021.**	**Referenced in Report:** All: N/A

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
TAT EFFECTIVENESS	**2**	**3**
Topic Summary: Peer Review Panel experts provided a few general TAT Effectiveness Recommendations and Comments for PG&E. (1) Impressed with the number of TAT records - significant effort by PG&E (2) EVM and TAT represent significant steps forward in the effort to reduce outages and ignitions. Results to date give reason for optimism (as noted in the study): For the 21-month period studied (2019-2021), 259 ignitions were reported -- and only 4% were found on clear-circuit segments, while 96% occurred on non-clear segments. Furthermore, it is estimated that 32% of ignitions and 20% of outages would have been avoided due to TAT. These results speak for themselves: EVM and TAT work! (3) Clearly, what TAT has produced to date represents a very good start – but it is not an end point. Improvements and refinements can and should be made. Implementing recommendations listed will significantly improve TAT and help PG&E achieve its goal of substantially reducing outages and ignitions.	**Formation Response:** All: We agree	**Referenced in Report:** All: N/A

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
TAT INSPECTOR TRAINING	3	7
Topic Summary: Peer Review Panel experts provided general feedback for PG&E regarding TAT Inspector Training & Experience (1) Do we know what role assessor variability plays in assessment decisions? Perhaps not a lot in the Boolean process, but in the scored section (health and environment) I would think it plays a role. Should this be addressed? (2) Who were the "champions" that tested? Qualifications background experience? It is quite clear that abatement in the field is a difficult and arduous task that requires highly trained individuals and asset allocations. Even if it is just a contractor with a chainsaw - properly felling a tree is a trained skill-set. Whatever can be done to reduce abatement subjectivity should be the focus such that Field Staff have clear directions in Boolean Abate or Do Not Abate outcomes. (3) From the TAT White Paper, "and increase consistency of inspection results. The final tree assessment tool will then be digitalized to enable worker processes and automate data collection." Peer reviewer states that this is a limiting factor… subjective decisions and experience of inspector. (4) From the TAT White Paper, "The benchmark assessment tools are generally more reliant on individual SME subjective input". Peer reviewer states, this is the key difference to have experienced and credentialled personnel making decisions…. (5) From the TAT White Paper, "When a tree is inspected with EVM TAT Model". Peer reviewer states, "I recommend pilot on hand selected PI with multiple credentials (CA, RPF, TRAQ, US, Other).. Vs. Non credentialed PI". (6) In addition to a training program, a study of the TAT process is recommended -- to determine what needs to be improved – and how to improve it. The establishment of a review team to identify deficiencies and recommend improvements would expedite the upgrade needed to TAT. (7) PG&E should consider developing a rigorous training program for TAT assessors -- and collectors of failure data. Such a program could include a manual/guide, classroom and field instruction, testing, and possibly certification. A focus on data collection methods (form improvements, refinement of terms) and species ID and defect ID is recommended.	**Formation Response:** (1-7) Formation did not assess the training or supervision of TAT inspectors. We convey these peer review comments to PG&E for consideration. PG&E 2022 Wildfire Mitigation Plan describes their existing training program for Senior Vegetation Management Inspectors (SVMI). - WMP 2022 Reference is shown in Section 7.3.5.6 Improvement of Inspections	**Referenced in Report:** (1-7) N/A Appendix J: Literature Citations

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
TREE ENVIRONMENT: ETA	2	2
Topic Summary: In our draft report, Formation provided the results of analysis on ETa, precipitation and SPI and potential correlations with TAT parameters. The results showed no correlation with individual tree health parameters and a small correlation with tree (alive vs. dead). The resolution of the data (regional-level) was thought to be a contributing factor of these results. Peer reviewers offered the following comments: (1) While Et data may provide insight into tree health, additionally explanatory power might come from using precipitation accumulated over multiple years as successive stressful years can significantly influence tree health. (2) Did you look at ETa relationships at the species level? I could see that some species are more susceptible to ET decline.	**Formation Response:** (1) & (2) Based on review comments Section 3.4 Climate Data to Evaluate Trends in TAT Recorded Dead Trees was redone and focus on future investigations that consider species level relationships and employs the higher resolution PG&E meteorology data. See Recommendation 9: Create a stress index model for PG&E tree health and mortality. Employ the PG&E climate database to evaluate temperature, precipitation, evapotranspiration and other environmental trends to evaluate relationships affecting TAT trees health and mortality. Consider both multivariate parameterized analysis and machine learning. Develop an framework that is recursive, and constantly learning/training from incoming new data.	**Referenced in Report:** (1) & (2) Section 3.4 Section on Recommendations - #9

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer
TREE ENVIRONMENT: SLOPE & TERRAIN	**3**	**4**
Topic Summary: Peer review experts provided feedback for PG&E on a number of Tree Environment Factors including Slope, Terrain, Soil, Area Disturbance and Multivariate causes. (1) From the TAT White Paper, Area Disturbance: "This attribute to the only subject component of the PG&E Tree Assessment Form. Internal and external SMEs, combined with academic reach, indicated that areas of significant disturbance (e.g. logging) indicate a highly likelihood of future tree failure". Peer review expert suggests increase need to remove/mitigate. (2) Analysis of interaction effects of variables, including possibly looking into adjusting score weighting for TAT_terrain and TAT_slope combination -- noticed from the analysis that a. 45% of outage records were on a hillside b. 71% of outage records were on a slope<=15 degrees c. the scales of the normality histograms for 'hillside' suggest that most frequent slope entry for hillside is <15. Can you further evaluate multivariate conditions regarding 'hillside+slope<15' associated with outages? (3) The data set (O&I) is large >30,000 and 72% of failures and ignition were on low slopes 0-15 degrees). I agree this is surprising, but I am not sure why it is inconclusive. Could the inclusion of soil type and soil moisture help here? (4) Can the soil type or soil moisture conditions be evaluated in the O&I dataset so that root failures can be further investigated?	**Formation Response:** (1) In essence, these EVM corridors are worked annually. A key metric, in addition to the TAT area disturbance parameter) is front row tree fall paths to assets. Every year through routine tree removal work or EVM TAT abatements, PG&E creates new front row trees that can strike assets. LiDAR is especially suited at determining this parameter risk metric (PG&E Transmission VM Tree Risk Score Back Testing). (2-4) The research identifies slope or terrain (when assessed independently) to be weak predictors of tree failure. The TAT algorithm outcomes show Slope and Terrain as very weak parameters for abatement decisioning. Based on our analysis and other PG&E internal research, we feel that these parameters are accurately treated in the TAT algorithm and should remain minimally-weighted parameters. Restating: The PG&E TVM Tree Risk Back Testing effort study involved LiDAR metrics that supported accurate location of tree failures. This comprehensive effort allowed us to appropriately evaluate the surrounding tree environment and found that slope and terrain (when evaluated independently) are very weak predictors of vegetation-caused outages. Further, our analysis for TAT parameter relations strength found slope and terrain to be one the weakest of the TAT parameters in affecting abatement outcomes.	**Referenced in Report:** (1-4) N/A

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
TREE ENVIRONMENT: WIND	**2**	**8**
Topic Summary: In our draft report, Formation provided the results of analysis on the TAT wind parameter. The results showed that wind had no significant affect on the abatement decision outcome, an unintended result (according to PG&E SMEs). To determine whether wind should have a higher weighting in the TAT algorithm, Formation provided additional analysis on vegetation-caused outages with wind reported as a contributing factor. Formation also produced several new wind parameter models as a recommendation to the TAT model improvements. (1) The recommendation to replace wind metric looks important given the analysis. Also, thoughtful replacement approaches are suggested, including one that may reduce risk by combining models. However, I wondered if the metrics might be somewhat arbitrary if only winds associated with outages are considered -- for example, setting the cut off at the average vs other value of max daily windspeed for high wind/low wind zone (p.50) in model 2. Similarly, wondered whether to choose a cut-off of 20 or 59 outages for wind model Approach A, given how close the difference in median windspeed was for the above & below the thresholds in the (useful) sensitivity analysis on p.40. (2) A threshold of 9.5 m/s was set for separating the wind data into High vs Low (pg 50). This equates to 21 mph which is not that heavy of a wind, the Beaufort Scale would label this as a Fresh Breeze. It is not until around 40 mph (approx. 17-18 m/s) that twigs begin to break. Can you use three or more categories (one example could be: Low <9.5 m/s, medium 9.5-17 m/s, high >17 m/s)? (3) You set a threshold of 9.5 m/s for separating the wind data into High vs Low (pg 50). This equates to 21 mph which is not that heavy of a wind, the Beaufort Scale would label this as a Fresh Breeze. It is not until around 40 mph (approx. 17-18 m/s) that twigs begin to break. Can you use three categories (Low <9.5 m/s, medium 9.5-17 m/s, high >17 m/s)? (4) Utilizing three or more categories for wind speed beyond the High vs Low as the 9.5 m/s threshold is low for heavy winds; The wind event count threshold set to 59, please consider analyzing using 18 or 40.	**Formation Response:** (1-4) The current TAT model employs a wind score parameter that has negligible effect on abatement decision-making. That is where we started in the process of creating an improved wind risk parameter for future TAT applications. The models developed are data driven and based on NOAA wind data and PG&E O&I. We were surprised to find that relatively low wind speeds (~21 mph) were correlated with ≥59 O&I EVM events per day. In consultation with PG&E meteorology SMEs, we learned that this this wind speed is consistent with their public safety power shutoff threshold. Such independent agreement in results, given two very different methodologies and data sets, gave us confidence in our wind risk score models. The two models increase scored tree abatements by 4,026-7,414. That said, we know that our proposed models can be further improved. At a minimum, the TAT should use the higher resolution PG&E meteorology data for the next generation TAT wind risk model parameterization. See recommendation #7.	**Referenced in Report:** (1-4) Section 3.6 Section on Recommendations - #7:

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
TREE ENVIRONMENT: WIND	3	8
Topic Summary: (5) I wondered if a Poisson or OLS model of outage counts vs counts of max daily windspeed bin (including windspeed counts on non-outage days) over a desired period (perhaps system wide) might be able to represent the relationship of windspeed to outages in a way that is grounded in windspeed frequency. The relationship would be expected to show the outage counts going up relative to count in windspeed bin. I am wondering if such an approach might reduce possible arbitrariness in setting a cut-off, and retain the influence on outages of windspeed at lower levels. Of course, there are pros and cons to keeping the effect at the lower windspeed level, but in general I'm a little worried about overlooking fails at lower windspeeds. Once a coefficient is developed for each bin is developed, then might be able to apply this to the count of local max windspeed to create the wind map, understanding there might be some effects of scaling down to lower windspeed bin counts. (6) I'm generally interested in wind analyses and, and, as I think another participant mentioned, effects of wind, temperature, precipitation together across time would be appropriate to study. (7) FE Recommendation: Replacement of current non-significant wind-scoring methodology with data-driven wind-scoring methodology. Agreed – Formation made a good case for this change. An increase in abatements and reduction in outages and ignitions should follow.	**Formation Response:** (5) Recommendation 7: Replaced existing wind model scoring methods with a wind event driven representation that captures where wind driven outages and ignitions are more likely, using either model proposed. The "Simple Model" will result in more net abatements and may be more conservative. PG&E meteorology data should also be considered as it has higher temporal and spatial resolution and is used across several important PG&E programs. (6) PG&E Meteorology developed a climatology model that may have this analysis. Will convey this recommendation to PG&E. (7) Thank you	**Referenced in Report:** Previous page

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
TREE HEALTH: GENERAL	**3**	**6**
Topic Summary: (1) In Fig. 3, "minor wounds" is listed under "Tree Health" – but changes to "major wounds" in Boolean tree health. Not sure why "minor wounds" would be of interest. Was this explained? (2) Codominance – your second bullet item ends with "increased risk of failure". The Tree Risk Assessment (TRA) Best Management Practices (BMP) and Utility TRA BMPs use the term "likelihood" instead of "risk", as risk is a combination of likelihood of an event and the potential consequences. (3) The term "tree health" is used to include both health and structural issues with trees. Tree health and tree structure are associated, but health does not mean structure (and vis-versa). A healthy tree can have serious structural deficiencies, while an unhealthy tree may have insignificant structural issues. These terms should be clearly defined. (4) Formation may want to consider adding photos to the final report – particularly for management readers who may not be familiar with some/many of the tree conditions referred to in the report. (5) From TAT White Paper: "Poor tree health was highly correlated with tree failure". Yes, but these are not the trees causing ignitions.	**Formation Response:** (1-4) Similar to our answer to PG&E operations and TAT inspector training, we did not consider these to be in our scope. Instead, we evaluated the data in the TAT records as collected by inspectors and developed into TAT outcomes. We did not consider the thresholds or range(s) of severity when assessing TAT tree health Boolean or scored parameters. Given comments 1-4, perhaps a team of certified utility arborist and other PG&E SMEs should review these to determine if these are appropriate, standardized and conservative and if the reviewers' comments warrant further analysis on • wound categories • codominance • tree health definitions • addition of photos • healthy trees vs. poor tree health. (5-6) These points are valid and identify a critical TAT deficiency/bias that requires resolution. See the discussion in Section 2.7 Retrospective TAT Parameter Crosswalk To O&I Database in the final document where we take this issue head on. This section is included in its entirety below: Comparing the TAT Historical Effectiveness values for both ignitions and outages to the cumulative TAT 56% abatement rate, suggests that these four Boolean parameters over represent their combined abatement contribution to the TAT model. Consider that a median of 31.6% and 20.4% of historical ignitions and outages, respectively, had features that the TAT model would have identified and abated. Yet, 56% of the TAT abatements are coming from these same parameters, suggesting an over-abatement. It is potentially a good outcome, as it is conservative.	**Referenced in Report:** (1-4) N/A

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
TREE HEALTH: GENERAL (Cont'd)	3	6
Topic Summary: (6) From TAT White Paper: "However, it must be recognized that in complying with 18-10-007, the risk posed by trees exhibiting no health or structural issues remains unmitigated. Trees in this category were responsible for 76 percent of the May-Nov vegetation outages in HFTD 2012-2019 and 82 percent of the HFTD vegetation ignitions for the same time frame." Very concerning, needs further evaluation.	Formation Response: But, the question remains, with the other 44% TAT parameter abatement outcomes, how are the outstanding non-prevented outages (79.6%) and ignitions (68.4%) being addressed. Would the remaining abatement parameters have sufficiently captured and abated these legacy outages and ignition? The TAT white paper (PG&E Vegetation Tree Assessment Tool Development and Application, November 19th, page 5) notes that 76% of fire season outages and 82% of ignitions originate from 'green trees' with "no health or structural issues." "In keeping with the direction provided in 18-10-007, the TAT does not direct removal of trees that have no signs of health issues or structural defect. However, it does provide a species wildfire risk rating based on regional outage and ignition data taking into account the frequency of the species in the population. Only species determined to be of highest risk will be removed when exhibiting minor health or structural issues. Species with lower risk require a greater degree of health or structural issues to result in removal... However, it must be recognized that in complying with 18-10-007, the risk posed by trees exhibiting no health or structural issues remains unmitigated. Trees in this category were responsible for 76 percent of the May-Nov vegetation outages in HFTD 2012-20191 and 82 percent of the HFTD vegetation ignitions for the same time frame." Thus, 24% and 18% of outages and ignitions, respectively, occur from trees with outward defects (such as those represented in the four TAT Boolean parameters. When compared to these values, we see better alignment to the HFTD historical effectiveness results (31.6% and 20.4%, respectively). Yet, if we add in Tree Mortality, 80% of the TAT abatements are coming from trees with health or structural issues that qualify for abatement under the Boolean portion of the TAT. We see an imbalance. There is an opportunity to add other tree parameters to the TAT model that include risk factors to assets for trees, regardless of health and structural issues. A large body of work (much of it conducted by PG&E) employs LiDAR metrics, such as overstrike distance, fall pathways to assets, tree position slope to alignment and canopy exposure to wind. These metrics have been demonstrated to mitigate risks from all trees, including green trees. Further, these parameters can be calculated and applied without increasing field inspection duties (Reference PSPS Back Testing Phase III Results). Adding LiDAR metrics is a proven way to speed VM program operational velocity, automate and standardize assessments and include green trees into the TAT model. That said, it is not trivial and warrants a master plan for EVM adoption. The benefit PG&E enjoys is that PG&E invented, operationalized, and maintains the largest LiDAR VM program in N. America.	Referenced in Report: (5-6) Section on Recommendations - #4 & #5

Topic:	Number of Peer Reviewers This Topic	Number of Reviewer Comments
TREE HEALTH: STEM HEIGHT to DBH RATIO	3	3
Topic Summary: Regarding the Stem Height to DBH Ratio analysis, the following comments were provided by three peer reviewers. (1) The tree height to diameter ratio refers to the ratio derived by a tree's height divided by the diameter-at-breast- height of its trunk (Figure 83), with both measurements being in the same units. Consider looking at species by age class… Dominate, Codominant, Intermediate, Suppressed as in traditional forestry to draw themes, and conclusions. (2) FE Recommendation: Addition of tree height to diameter ratios. Agreed – this is a reasonable addition to TAT assessments – especially for many conifers. A refined protocol for assessing multi-stem trees will be important to include, however. For instance, the gray pine shown below may not fit into a typical slenderness assessment – with multiple stems (which is typical for gray pine). How does an assessor evaluate DBH:Ht on this tree? Note that 3 stems/branches have failed on the tree (yellow arrows) – all of which would have caused an outage or ignition if they landed on a power line. Perhaps a good reason to minimize the occurrence of gray pine next to power lines??? (3) "There is no surprise that stem diameter was a strong predictor of stem breakage. This is well known in the literature, and it is good to see it hold true here. Additionally, the relationship between stem breakage and Stem Height:DBH ratio, has also been seen in the literature and other non-peer reviewed studies. One thought, if you want to simplify the Stem Height:DBH name, you might use "Slenderness" as it is common in the literature for both trunks and branches. Furthermore, do you know if the variables (height and DBH) were measured or estimated? If estimated, do you feel the estimates are better or worse after a tree has failed compared to a standing tree? Additionally, there are a number of journal articles that suggest a slenderness of 100 is a threshold for instability in pines."	**Formation Response:** (1) We agree that H:DBH can be further evaluated with more granularity in future investigations. That said, the added TAT scored H:DBH parameter adds 3,845 new tree abatements (to the existing abatement population), nearly all of which are 'green trees' exhibiting no health or structural issues. (2) PG&E would need to develop field guidance for TAT inspectors regarding how to measure H:DBH for selected species. (3) We assumed that height and DBH are measured, not estimated. Instead of using a fixed threshold across species (e.g., H:DBH>100), we employed a data driven approach for each species using the 60th, 70th and 85th percentile for scoring. Looking at Table 3.1, you can see that these threshold are variable and species specific. These threshold can be assessed and changed before final implementation into the TAT model.	**Referenced in Report:** (1) N/A (2) N/A (3) Section 3, Table 3.1

Appendix I: Glossary of Terms

Boolean	A binary variable, often Yes/No or True/False
Canker	Infectious disease that grows on trees, killing the underlying wood
CIMIS	California Irrigation Management Information System
Conk	Mushrooms that appear around the base of a tree, usually indicative of a rot-inducing disease
CPC	Climate Prediction Center
CPUC	California Public Utilities Commission
Ecoregion	Spatially defined zones where ecosystem characteristics are generally homogenous
EDGIS	Electric Distribution Geographic Information Systems
EMC	Environmental Modeling Center
EPA	Environmental Protection Agency
EPA Level III Ecoregions	Ecoregions are areas where ecosystems (and the type, quality, and quantity of environmental resources) are generally similar. They are designed to serve as a spatial framework for the research, assessment, management, and monitoring of ecosystems and ecosystem components. Level III is comprised of 105 ecoregions across the continental US. There are 12 EcoRegions that intersect the PG&E service territory.
ETa	Actual Evapotranspiration - the sum of evaporation from the land surface plus transpiration from plants and trees.
EVM	Enhanced Vegetation Management
EVM Clear	A phase in the Enhanced Vegetation Management Program that indicates a segment of a distribution line have completed pre-inspection and tagged trees have been worked (trimmed or removed). Quality control teams verify and report EVM Work Verification Status as one of the following: Pass, Fail, Ready for Verification.
Fall-In Tree	A tree that has the potential to strike a powerline if it were to fail (based on its height and proximity to the asset). In outage and ignition databases, a fall-in (or failure) tree is a tree that failed and struck the asset, causing an outage and/or ignition.
GIS	Geographic Information System
GPS	Global Positioning System

GSFC	Goddard Space Flight Center
H:DBH	Tree Height to Diameter Breast Height Ratio
HFTD	High Fire-Threat District. CPUC designated areas where there is an increased risk for utility associated wildfires.
HUC	Hydrologic Unit Code
LAI	Leaf area index (LAI) indicates the amount of leaf area in an ecosystem. LAI is a critical parameter for understanding terrestrial ecological, hydrological, and biogeochemical processes.
Lat/Lon	Latitude and Longitude
LiDAR	Light Detection And Ranging – a method of determining distance by measuring the time lapsed between targeting an object with a laser beam and the return of the beam to the receiver
NASA	National Aeronautics and Space Administration
NCEP	National Centers for Environmental Prediction
NED	National Elevation Dataset
NERC	The North American Electric Reliability Corporation (NERC) is a not-for-profit international regulatory authority whose mission is to assure the effective and efficient reduction of risks to the reliability and security of the grid.
NLDAS	North American Land Data Assimilation System
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
O&I	Outage and Ignition
OEIS	Office of Energy Infrastructure Safety
OHD	Office of Hydrological Development
PET	Potential Evapotranspiration
PRC	Public Resources Code
PRISM	Parameter elevation Regression on Independent Slopes Model
QA/QC	Quality Assurance / Quality Control - QA/QC is the combination of quality assurance the process or set of processes used to measure and assure the quality of a product and quality control, the process of ensuring products and services meet a specified standard.

RFP	Request for Proposal
ROWs	Rights-of-Way - the land (often a corridor) used by a public utility for conveyance of a power or gas line.
RSFRR	Regional Species Fire Risk Rating
SCR	Score
SEB	Surface Energy Balance
SL-Factor	Slope Length & Steepness Factor
Slope aspect	Slope is the percent change in elevation over a certain distance. Aspect is the orientation of the slope. In the context of utility assets, aspect is the orientation of the slope to the powerline (sloping towards or away from).
SME	Subject Matter Expert
SPEI	Standard Precipitation-Evapotranspiration Index
SPI	Standard Precipitation Index
Strike Tree / Not a Strike Tree	A strike tree is a tree that has the potential to strike a powerline, based on its height and proximity to the asset.
TAT	Tree Assessment Tool
Tree Height to DBH Ratio	Ratio derived by a tree's height divided by the diameter-at-breast-height of its trunk
TTSS	Targeted Tree Species Study
TWI	Topographic Wetness Index
UAV	Unmanned Aerial Vehicle
USGS	US Geological Survey
VDA	Vargha and Delaney's A Statistical Measure
VM Work History	Vegetation Management Work History is a database of records documenting work performed to trim or remove trees along a utility corridor.
WRF	Weather Researching and Forecasting Model
WRF-ARW	The Weather Research and Forecasting (WRF) Model is a next-generation mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting applications. The WRF system contains two dynamical solvers, referred to as the ARW (Advanced Research WRF) core and the NMM (Nonhydrostatic Mesoscale Model) core.

Appendix J: Literature Citations

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Appendix K: Formation Environmental TTSS Team Bios

[redacted], MS
SR. REMOTE SENSING & DATA SCIENTIST

M.S., ECOSYSTEM SCIENCE & MGMT
TEXAS A&M UNIVERSITY

Mr. [redacted] is a Senior Remote Sensing Scientist with over 10 years of experience using remotely-sensed data and geospatial technologies to solve problems and inform decision-making with respect to a wide variety of ecological applications. Mr. [redacted] is a LiDAR expert with a strong background in geospatial programming and the development of analytical algorithms using R and Python. He has developed numerous customized data analysis and manipulation tools to solve complex remote sensing problems and to ensure geospatial data are highly accurate as input to scientific analysis.

[redacted], MBA
UVM PROGRAM MANAGER & GEOSPATIAL CONSULTANT

MBA - REGIS UNIVERSITY
B.S., LAND USE / GIS
METRO STATE UNIVERSITY

Ms. [redacted] is a Senior Geospatial Consultant with more than 14 years of experience in the environmental and remote sensing industries. Her primary focus is on the application of remote sensing data and analytics solutions for utility vegetation management teams. As a program manager, Ms. [redacted] works with clients to identify solution gaps and data integration challenges that are barriers to program objectives. Ms. [redacted] supports the PG&E Transmission Vegetation Management team and serves as a SME for its LiDAR Technology Program, contributes to the PG&E Wildfire Mitigation Plan (TVM LiDAR content) and assists with data requests and reporting for OEIS and other regulatory or programmatic needs.

[redacted] MS
ENGINEER & DATA ANALYST

M.S., CIVIL & BIORESOURCE ENGINEERING
OREGON STATE UNIVERSITY

Mr. [redacted] is an engineer, developer and data analyst with more than 20 years of expertise with analyzing remote sensing and environmental data. Beginning with the 2010 NERC alert, Mr. [redacted] has led teams in the development and implementation of industry-leading analytics and visualization tools to leverage geospatial data and create actionable frameworks for utility vegetation management teams. Mr. [redacted] also has experience in the development of data process improvements for UAVs, cluster computing & processing, cloud data handling, machine learning frameworks, geospatial analytics and end user tools for desktop, web and mobile apps.

CHUAN-SHIN CHONG, MS
REMOTE SENSING ENGINEER

M.S., ELECTRICAL ENG.
*FOCUS ON SENSORS
IOWA STATE UNIVERSITY

Mr. Chong is a Senior Remote Sensing Developer with over 18 years of experience in applying geospatial and remote-sensing technology in forestry, ecological and environmental industries. His expertise is in developing analytical solutions utilizing a variety of data from commercial satellite data, UAV and airborne LiDAR and other environmental data. Mr. Chong is an expert in manipulating large datasets, automating image analysis techniques, analyzing time series data, and developing custom algorithms to evaluate multi-variate environmental trends, such as drought impacts on tree species and tree mortality.

[redacted], PH.D.
DATA SCIENTIST

PH.D., PHYSICS
UNIV. OF CALIFORNIA
DAVIS, CA

Dr. [redacted] is a Data Scientist with experience in physics and mathematical critical-thinking and problem-solving. He provides overarching scripting support and algorithm development in the Python programming language. Dr. [redacted] is also skilled in providing support in Frequentist/Bayesian statistics and machine learning applications using large GIS data sources, including but not limited to LiDAR and satellite imagery. He specializes in classification and regression model creation and the evaluation of said models through industry standard metrics and hypothesis testing.

Formation Environmental TTSS Team Bios (Cont'd)

BRIAN SCHMID, MS
PRINCIPAL MANAGING PARTNER
SOIL & PLANT SCIENTIST

M.S., SOIL SCIENCE
B. S., AGRONOMY
IOWA STATE UNIVERSITY

Mr. Schmid is a Managing Partner at Formation and a Principal Investigator. Mr. Schmid has over 18 years of experience as a quantitative agronomist (plant scientist) and soil scientist, specializing in the application of remotely sensed data and techniques to quantify land surface conditions pertaining to wetland vegetation, soil science, precision agriculture, and other environmental objectives. Mr. Schmid manages several large-scale programs for the Imperial Irrigation District, LADWP, CADWR and is a technical / testifying expert for drought impact on wetland vegetation in the Atacama Desert of Chile, South America.

BEN CHENG, PH.D.
SR. REMOTE SENSING
& DATA SCIENTIST

PH.D., HYDROLOGICAL SCI.
UNIV. OF CALIFORNIA
DAVIS, CA

Dr. Ben Cheng is a Sr. Remote-sensing Scientist with over 22 years of experience focused on deriving plant biophysical attributes (LAI, water content, chlorophyll, and physiological stress) from remotely sensed data. He is highly skilled in retrieval of land surface parameters, including plant biochemical, biophysical and physiological properties from LiDAR, multispectral, hyperspectral and thermal data acquired at field, airborne and spaceborne levels. Dr. Cheng served on multiple NASA missions and projects to utilize remote sensing observations to monitor and model eco-hydrological and environmental processes.

TYLER RITCH, PH.D.
ATMOSPHERIC SCIENTIST

PH.D., METEOROLOGY
SAINT LOUIS UNIVERSITY
ST. LOUIS, MISSOURI

Dr. Ritch is an Atmospheric Scientist specializing in wind modeling in the planetary boundary layer using the WRF-ARW weather model. His work focuses on the analysis and prediction of severe wind events relating to utility risk management using ensemble probabilistic forecast techniques. Dr. Ritch worked on the recent Tree Risk Scores Back Testing Analysis project, evaluating wind events associated with each vegetation-caused transmission line outage in the study. The resulting analysis was used to isolate trends corresponding various wind parameters with failure trees.

GEORGE PAUL, PH.D.
GEOSPATIAL SCIENTIST

PH.D., AGRONOMY &
SYSTEMS MODELING
KANSAS STATE UNIVERSITY

Dr. Paul is a biophysically-oriented Systems Scientist with extensive experience in field measurements, remote sensing, and numerical modeling of soil, plant, and hydrologic processes. Dr. Paul has 12 years of experience focused on modeling spatio-temporal aspects of soil-water-plant-environment processes and their interactions with a changing climate. This includes extensive experience in analyzing large spatial datasets including weather, soil, satellite, and surface energy flux datasets. Most notably, Dr. Paul led the technical development of the first statewide evapotranspiration monitoring framework for the CA DWR.

MICHAEL ASPINWALL, PH.D.
PHYSIOLOGICAL ECOLOGIST

M.S., FORESTRY
NC STATE UNIVERSITY
PH.D., FORESTRY
NC STATE UNIVERSITY

Dr. Aspinwall is a Physiological Ecologist with extensive research dedicated to understanding how plants respond to environmental change in the long-term via adaptation and short-term via plasticity/acclimation. Mike also has a long-standing interest in examining the factors that influence ecosystem responses to environmental change; both in terms of diversity and function. Mike focuses on studies and research that are fundamental in nature but have implications/applications for natural and managed ecosystems (including forests), as well as model development. Prior to joining Formation, Dr. Aspinwall served as Assistant Professor, School of Forestry and Wildlife Sciences, Auburn University.

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