Statistical Consultation for EMC-2015-002 Forest Practice Rules Implementation and Effectiveness Monitoring (FORPRIEM) ver. 2.0. and EMC-2015-004 Effectiveness of Road Rules in Reducing Hydrologic Connectivity and Significant Sediment Discharge

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Final Report prepared for the State Board of Forestry and Fire Protection's Effectiveness Monitoring Committee

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Introduction

The California Department of Forestry and Fire Protection (CAL FIRE) is tasked with monitoring compliance and effectiveness of the California Forest Practice Rules in protecting water quality for recently completed Timber Harvesting Plans (THPs) and Nonindustrial Timber Management Plan Notice of Timber Operations (NTMP – NTOs) on California's state and private forestlands. Monitoring focuses on erosion and sediment delivery resulting from timber harvesting and forest roads, as well as post-harvest riparian zone canopy. Previous monitoring efforts have been performed using a random sampling approach among recently completed plans in the three main regions of the state with commercial timberlands (Coast, Cascades, and Sierras) (Cafferata and Munn 2002, Brandow et al. 2006, Brandow and Cafferata 2014). The US Forest Service Pacific Northwest Research Station Statistics Program (PNW Statistics) is advising on the development of a new monitoring plan that will address the range of erosion risk across the forestlands under CAL FIRE's jurisdiction, with specific focus on the highest erosion risk plans and sites.[1]

In preparing this new monitoring plan PNW Statistics has divided the work into four tasks:

1. Evaluate existing risk categories as a method for stratifying plans;
2. Propose a sampling design for selecting plans to be monitored;
3. Propose a sampling design for selecting areas within plans to be monitored;
4. Estimate precision and power using available pilot data.

TASK 1 - Evaluate the Risk Categories as a Method for Stratifying Plans

Background Information

The original risk classification we explored was based on the below algorithm from the EMC-2015-002 Forest Practice Rules Implementation and Effectiveness Monitoring (FORPRIEM) ver. 2.0. Detailed Project Description document (CAL FIRE 2016). CAL FIRE staff developed the algorithm by combining ratings for mean slope, erosion hazard rating, deep-seated landslide rating, and drainage density to create a composite score, similar to that used by McKittrick (1994) in California. This concept for developing a stratified random sample of plans was vetted through the State Board of Forestry and Fire Protection's Effectiveness Monitoring Committee (EMC) in May 2016. The EMC requested that qualified statisticians provide input prior to implementing the second phase for FORPRIEM. This led to the development of a contract with the US Forest Service Pacific Northwest Research Station for the statistical consultation documented in this report.

[1] A detailed statistical review for the Hillslope Monitoring Program (1996-2001) was provided by Lewis and Baldwin (1997).

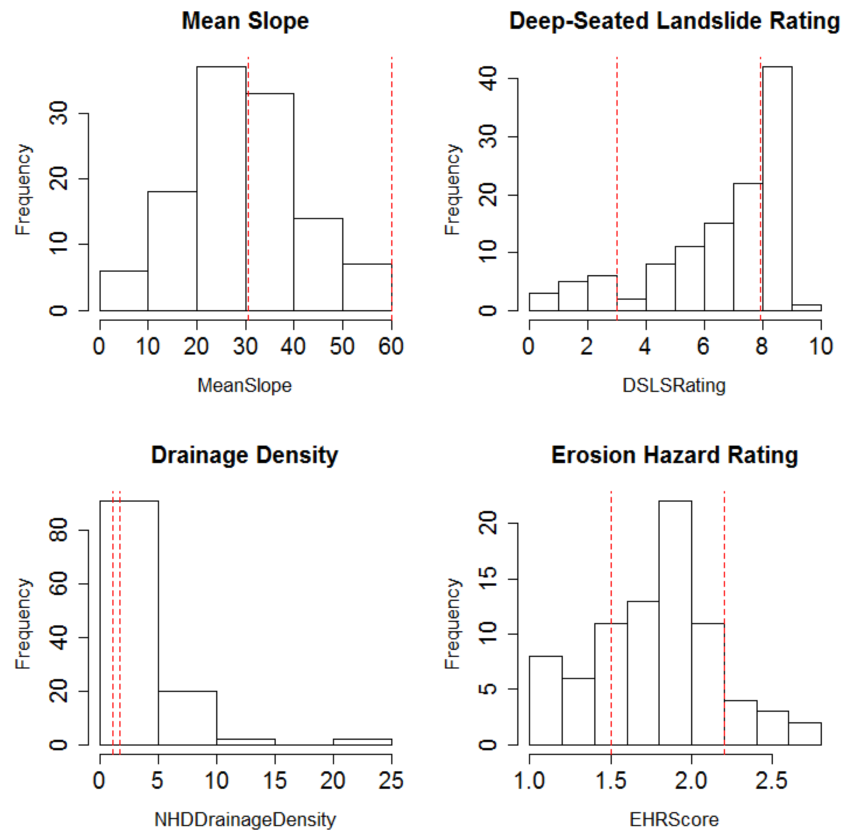
1A. ORIGINAL RISK CLASSIFICATION SYSTEM

Category	High	Moderate	Low
Slope (%)	>60 (3)	30-59 (2)	<30 (1)
Erosion Hazard Rating	>66 (3)	50-65 (2)	<50 (1)
Deep-Seated Landslide Rating	8 to 10 (3)	5 to 7 (2)	0 to 3 (1)
Drainage Density (mi/mi^2)	>1.7 (3)	1.1 to 1.7 (2)	<1.1 (1)
Timber Harvesting Plan Rating	10 to 12	6 to 9	4 to 5

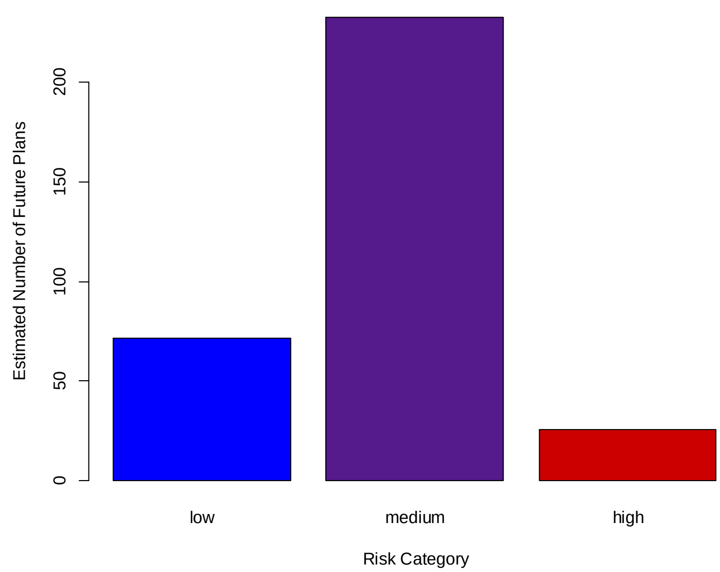
Pilot data from 115 THPs used in the first FORPRIEM monitoring program (Brandow and Cafferata 2014) were supplied to PNW Statistics to analyze risk factors on a plan basis. Average THP data for four risk factors (e-erosion hazard rating (e-EHR), mean slope, drainage density, and deep-seated landslide potential) were provided in detailed spreadsheets.

There were many plans in the pilot data for which erosion hazard was not estimated due to the lack of published soil survey data for large parts of Humboldt and Calaveras counties. Also, there was a very uneven distribution of plans with drainage densities that corresponded to the limits in the table.

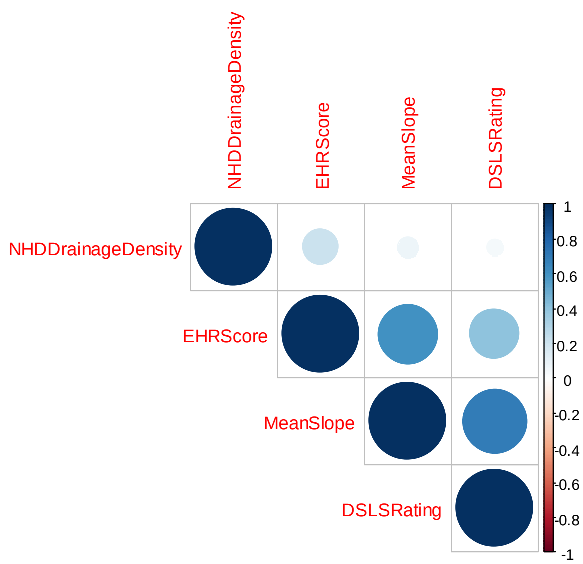
The pilot data were explored using this general scheme. The red, vertical, dashed lines in the figure below represent divisions (moving up the numeric scales on the horizontal axes) between the erosion risk categories (low, medium, and high).

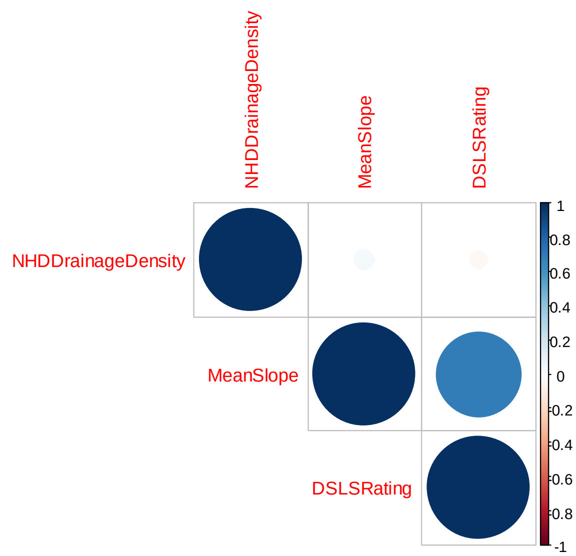


With a slight modification of the drainage density variable, the pilot plans fell out as follows. Note that there were 115 plans in the pilot data and these numbers were then scaled to 330, the anticipated number of study plans in the population to be sampled with FORPRIEM ver. 2.0.



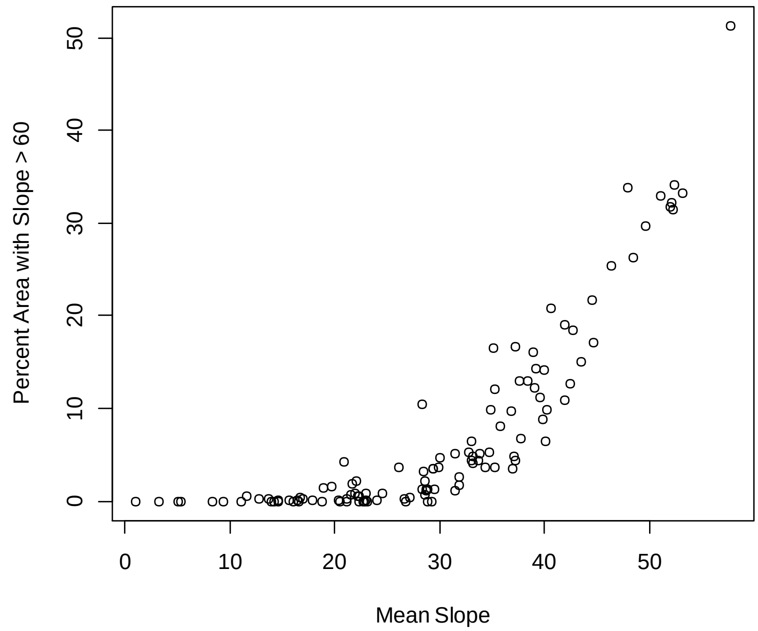
We also wanted to understand how robust the risk stratification system is. In other words, we wanted to understand the degree to which the estimate of risk was based on just one or two variables. To explore which input variables are highly correlated with one another, we created the following correlation matrices.





Mean slope is effectively included in the two hazard rating systems, but it is relatively independent from drainage density. Mean slope is so highly correlated with erosion hazard rating where there are data that we can eliminate erosion hazard and lose little information.

We also wanted to understand whether mean slope is sufficient for estimating percent of the land within a plan that had a very high slope (i.e., >60%). Based on the figure below, mean slope appears adequate for classifying areas with high proportions of very steep land.

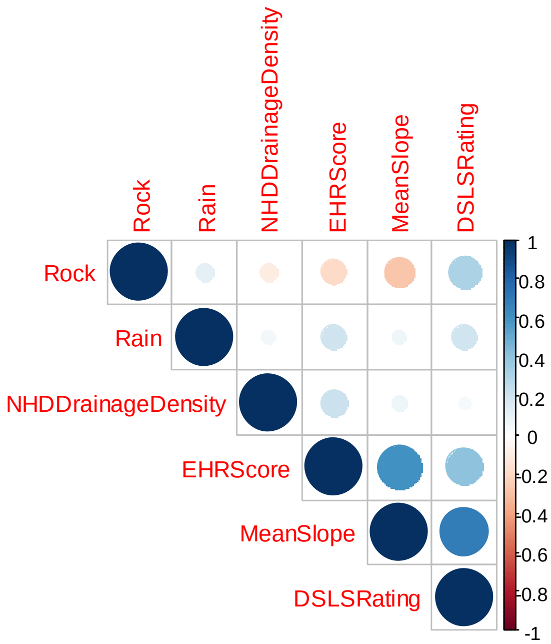


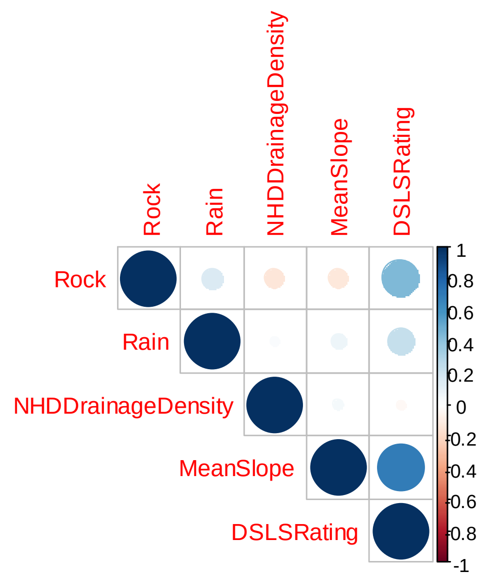
Conclusion from the analysis using original risk strata: There are very few plans classified as high risk and this will make stratification difficult; as well the current system depends heavily on mean slope.

1B. ADDING ROCK STRENGTH AND PRECIPITATION

Our understanding is that CAL FIRE wants to (a) sample all the types of plans, and (b) have a good estimate for those that are assumed as highest risk. We also want the erosion risk stratification system to be robust, and not depend too heavily on one set of highly correlated variables. To better accomplish these goals, we included area-weighted rock strength (Wills et al. 2011) and mean annual precipitation (inches) as potential indicators of erosion.

We explored correlation across the original variables and the proposed additional variables, rock strength and precipitation, with and without EHR score. We established in the above analysis of the original rating scheme that mean slope is adequate for classifying areas with high proportions of very steep land, so we will not include the percent of the area with over 60 percent slope in this analysis.





Conclusion: Mean slope is effectively included in the two hazard rating systems (i.e., e-EHR and deep-seated landslide rating), but it is relatively independent from drainage density and mean annual precipitation. Mean slope is moderately negatively correlated with rock strength. These two additional variables add new information to the rating system that is relatively independent of the original set of input variables. Mean slope is so highly correlated with erosion hazard rating where there are data that we can eliminate erosion hazard rating and lose little information, while also gaining a much higher sample size on which to base future decisions.

1C. PROPOSED REVISIONS TO RISK RATING SYSTEM

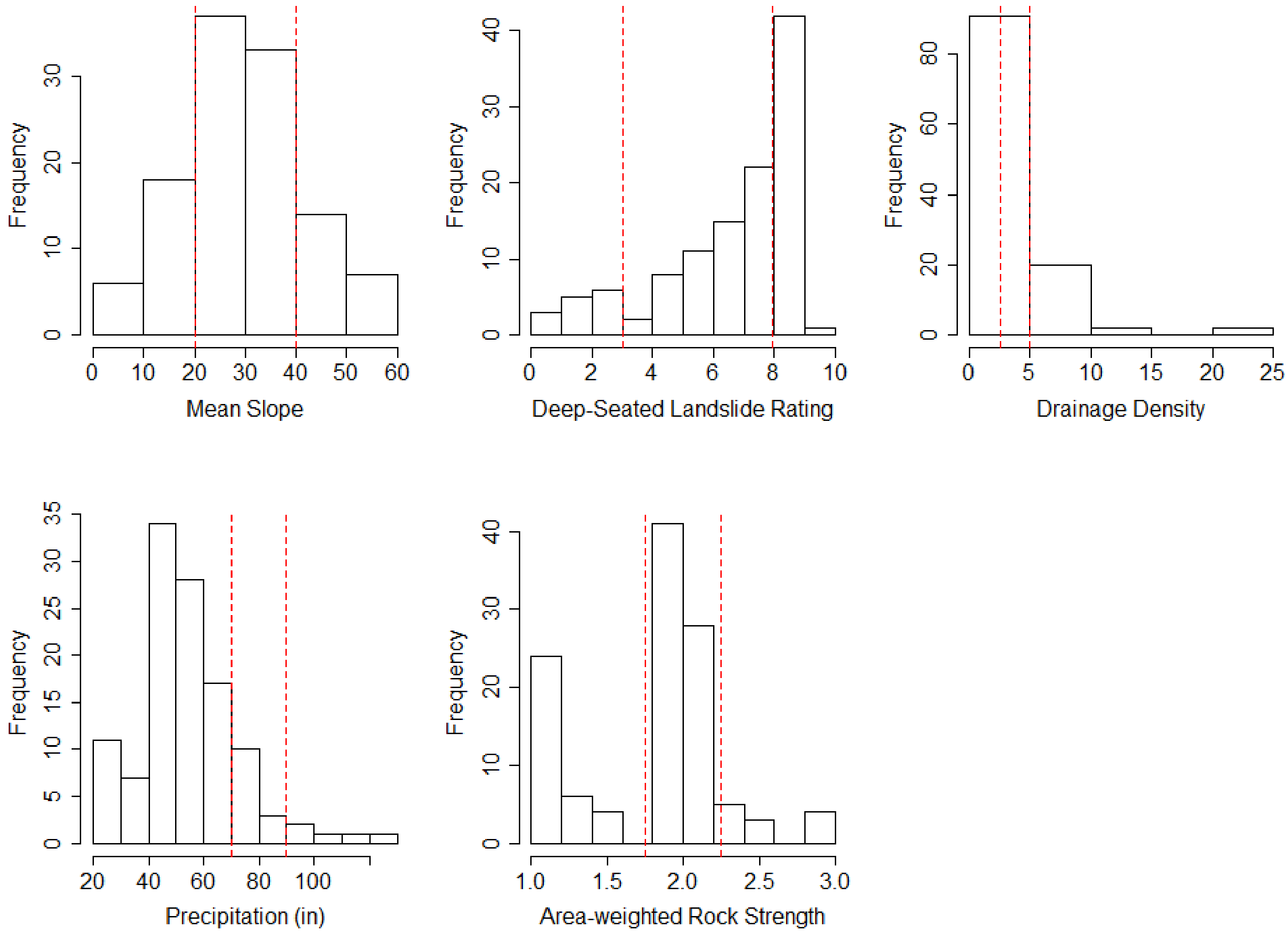
The goals of the risk rating system revisions are as follows:

1) Allow for a sampling scheme that produces samples that balance the dual needs of being representative of the population of THPs and NTMP – NTOs, and identifying high-risk plans for increased monitoring.
2) Identify a strata of the highest risk plans that can be sampled.
3) Produce a robust and transparent system in which any one variable does not drive the rating system but which, instead, is based on multiple data inputs with a clear mechanistic relationship to erosion risk.

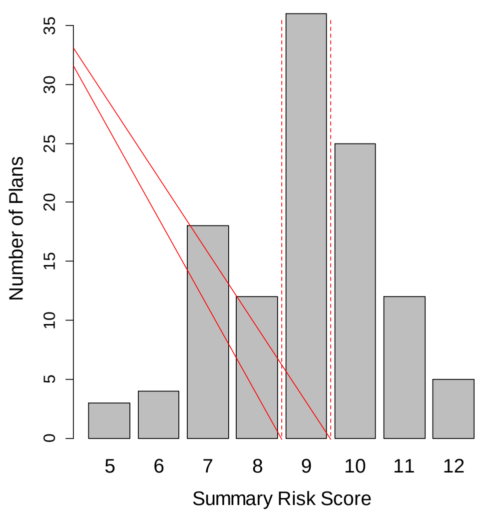
The revised risk rating system is displayed in the following table.

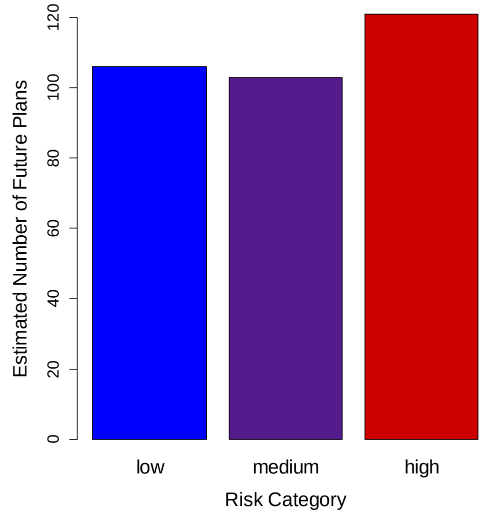
Category	High	Moderate	Low
Slope (%)	≥ 40 (3)	20-40 (2)	< 20 (1)
Deep-Seated Landslide Rating	≥ 8 (3)	3-8 (2)	< 3 (1)
Drainage Density (mi/mi^2)	≥ 5 (3)	2.5 - 5 (2)	< 2.5 (1)
Area-weighted Rock Strength	≥ 2.5 (3)	1.75 - 2.5 (2)	< 1.75 (1)
Mean Annual Precipitation (in)	≥ 80 (3)	40 - 80 (2)	< 40 (1)
Timber Harvesting Plan Rating	10 to 15	8 to 10	5 to 8

The following figure displays the proposed system visually using the pilot data.

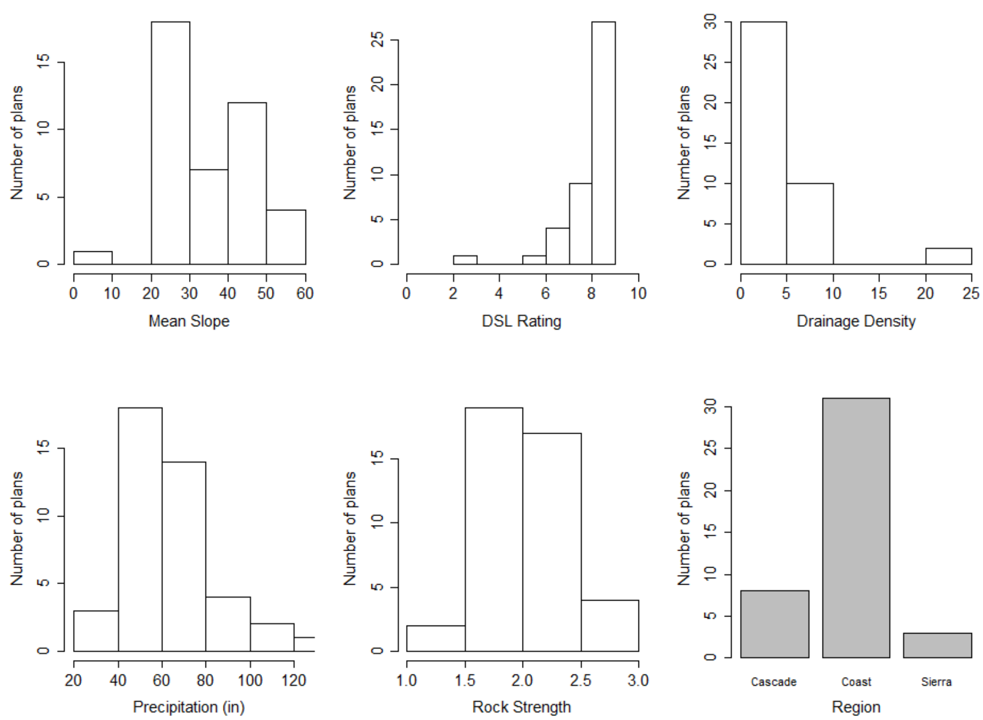


The total score for each plan will be a summation of the five inputs, with each risk category having a possible score of 1, 2, or 3. The maximum score is 15, indicating a high level of risk for all 5 input variables. In the pilot data, approximately 1/3 of the plans had a score of 10 or higher and approximately 1/3 had a score of 8 or lower, so an even distribution of plans was easy to identify. A plan in the high erosion risk strata could have a 2 in all of the component ratings, a 2 in all and one or more 3's, or it could have several ratings of 3 and a few ones. The histogram below displays the cut-offs and the bar chart below estimates the number of plans when scaled to the expected 330 plans. This projection assumes that sufficient numbers of plans are available in each of the three risk categories.

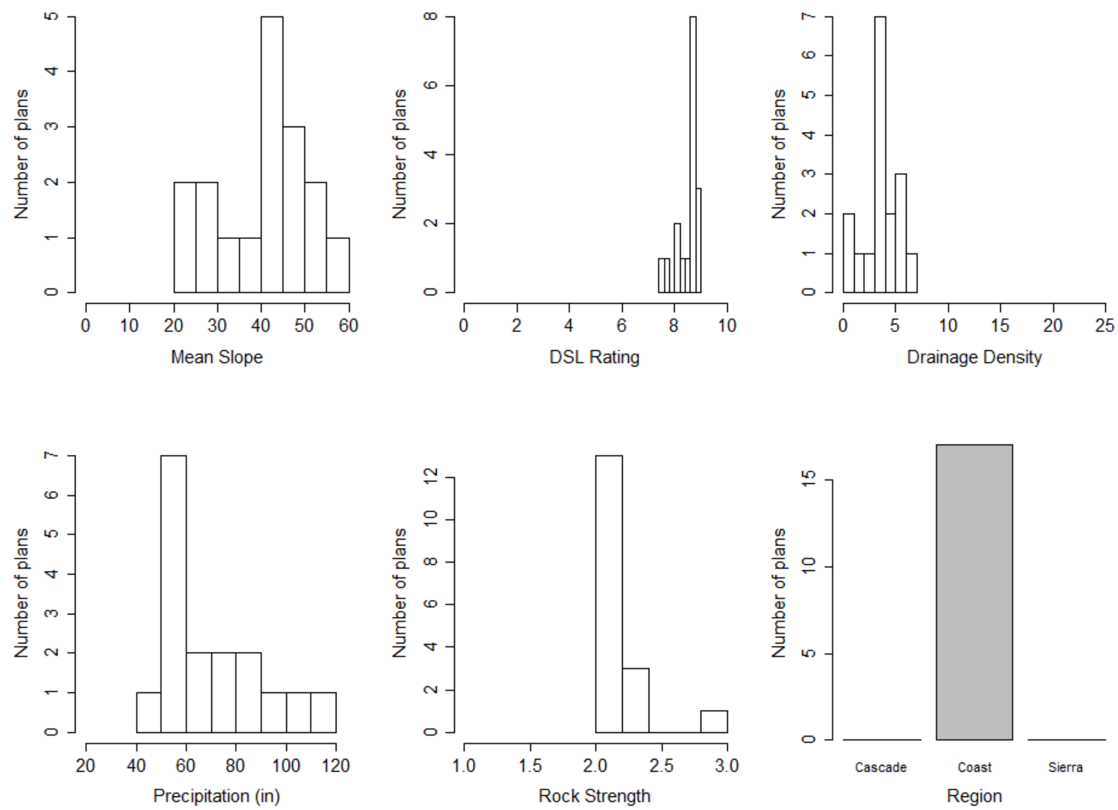




What is the composition of input data for the plans identified as highest risk with the pilot data (n=42)?



If we subset even further to just the 17 plans with a score of 11 or greater, we see the following distribution of input variables:



Recommendation: Use all five input variables, with reasonable cut-off values, and sum to a total risk score, without weighting any one input variable more than another. Consider all plans with a total score of 10 or higher as high risk. This provides a transparent and relatively robust method for characterizing risk. The method is repeatable and portable. For the pilot data, this method identified about a third of plans with the highest risk; these plans came from all three regions and included a range of input data.

TASK 2 - Propose a Sampling Design for Selecting Plans to be Monitored

We assume that the pilot data are representative of the approximately 300 plans that will be evaluated as part of FORPRIEM ver. 2.0. There are two main choices for developing a statistically valid sampling plan which is fairly robust to errors in input data, transparent, easy to explain, and easy to conduct analyses on after data collection. We would also like the plan to accommodate issues with access.

Options:

A. Sample all plans with a score of 10 or higher. With remaining resources, take a random sample of all plans that score below 10.

   Pros: Ability to make a statement about erosion risk for all plans that have a higher degree of risk; ability to collect a census of other information about these plans; some representation across all regions, and an ability to compare higher risk plans across regions; some ability to make inference to all plans.

   Cons: This is only one definition of risk and the sampling design is highly dependent on it; the ability to make inference to all plans is limited.

B. Sample all plans that score 11 or higher. Create a stratified sample of remaining plans (all plans with scores 10 or lower).

   Pros: Ability to make a statement about a small set of highest risk plans; adequate ability to make inference to all plans.

   Cons: This is only one definition of risk and the sampling design is highly dependent on it. There is little representation of higher risk plans across all regions.

We recommend Option A. Option A would meet the goal of better data on erosion potential at higher risk plans while still collecting some information about effectiveness and erosion across all plan types. The majority of erosion comes from a small proportion of sites (e.g., Durgin et al. 1988, Lewis and Rice 1990, Rice and Lewis 1991), and this plan would put a great deal of effort in the higher risk plans where that sediment production is most likely.

Sub-dividing the largest plans

In order to better assess large THPs (e.g., >1000 acres), we strongly recommend that the largest plans be split into smaller units such that the small units are somewhat homogenous in terms of erosion risk. Each smaller unit would be evaluated separately in the above sampling plan. The splitting of the largest plans would accomplish two goals. First, higher erosion sub-areas of large plans would be identified rather than lost in the process of calculating average scores over larger areas. Second, each acre of land would have a more similar chance of being selected in the randomized part of the selection.

TASK 3 - Propose a Sampling Design for Selecting Areas within Plans to be Monitored

In the first version of FORPRIEM, CAL FIRE chose the monitoring areas within a plan by selecting a random 660 foot road segment, two associated road watercourse crossings, and a random 200 foot Class I or II watercourse and lake protection zone (WLPZ) segment (Brandow and Cafferata 2014). Road segments were divided by hand into 660 foot segments on the plan map and one was randomly selected. The two watercourse crossings that were within the random road segment or closest to this road segment were evaluated if they were available within the plan boundary.

In line with goals to identify the highest risk parts of the landscape, we have designed a new approach, similar to the approach for selecting plans, for ensuring the part of the highest risk area is evaluated while also allowing all areas within a plan to have a chance of being evaluated. Essentially, we will again stratify on estimated risk.

Step 1: With GIS, create a population of road segments of similar lengths and relatively homogenous hillslope. Attribute each segment with hillslope and an indicator as to whether there is a watercourse crossing. If road surface is known, the segment will be attributed with road surface for future work but road surface will not figure in the sampling scheme.

Step 2: Divide the population of road segments into three strata:

A. Roads with no watercourse crossings
B. Roads on hillslopes <50% with watercourse crossings
C. Roads on hillslopes >50% with watercourse crossings

The cut-off of 50% was chosen to correspond with regulatory standards. Initial GIS analyses suggest that sufficient road segments exist within each of the strata. During the final sample selection process, it will be essential to calculate the proportion of total roads within each of the three strata.

Step 3: Select one random road segment (and one of the watercourse crossings in that segment if there are more than one) from A, B, and C. If there are no road segments in one of these strata, only two segments are selected, one from each of the remaining strata. If there are only roads in one of these strata, two road segments will be selected from that strata.

In this way, we will have a representative sample from each strata (across plans) and at least two watercourse crossings in most plans. The population of roads selected for this FORPRIEM ver. 2.0 monitoring can also serve as the sample of roads for the EMC-2015-004 project (Effectiveness of Road Rules in Reducing Hydrologic Connectivity and Significant Sediment Discharge). The advantage is that it is already a stratified sample and the data for the road rules monitoring and the FORPRIEM ver. 2.0 work can be collected in the same sampling trip.

Identifying riparian Class I or II WLPZ segments

For identifying riparian Class I or II WLPZ segments, we will create a population of all watercourse segments that are within a ¼ mile of selected roads using GIS. One watercourse segment will be randomly selected for canopy cover measurements. Note that inference can only be made to accessible stream reaches, i.e. watercourses that are within a ¼ mile from a road, but this population will be clearly defined. Through a GIS analysis, it is possible to compare landscape attributes of inaccessible to accessible watercourses.

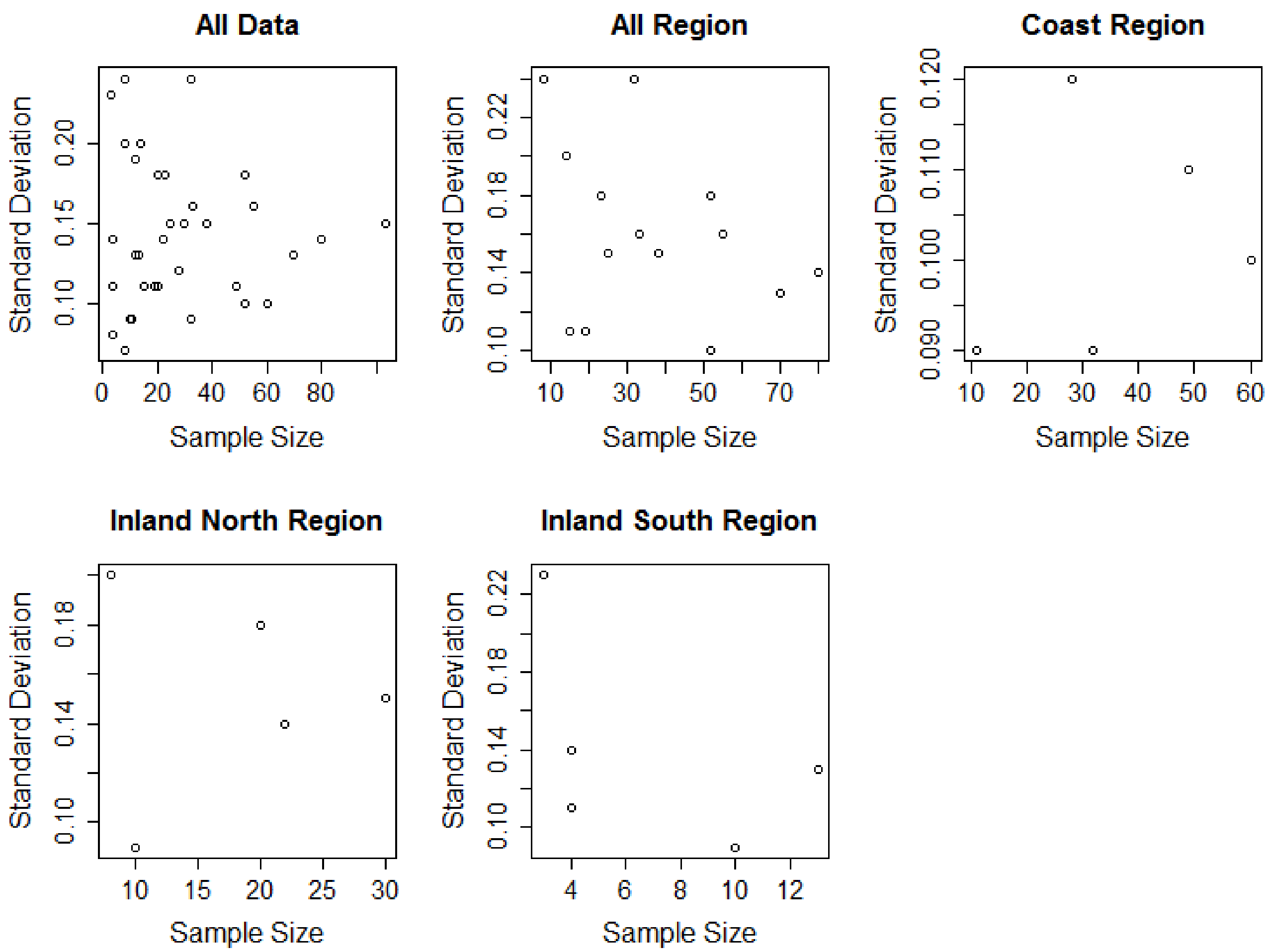
Using this approach, watercourse segments will be selected based on the roads which are selected randomly from areas with > 50% hillslope and < 50% hillslope gradients. Past data have revealed that plans are generally in high compliance with Forest Practice Rule canopy cover requirements. This sampling scheme appears sufficient to continue this type of post-harvest monitoring. It is efficient because the watercourse will be nearby to the road segment being sampled. If there are no stream segments within a ¼ mile of the selected road segment, the road segment will be extended out by one mile in each direction and again searched for Class I or II watercourses. This process can be repeated until possible stream segments are identified.

TASK 4 - Estimate Precision and Power using Available Pilot Data

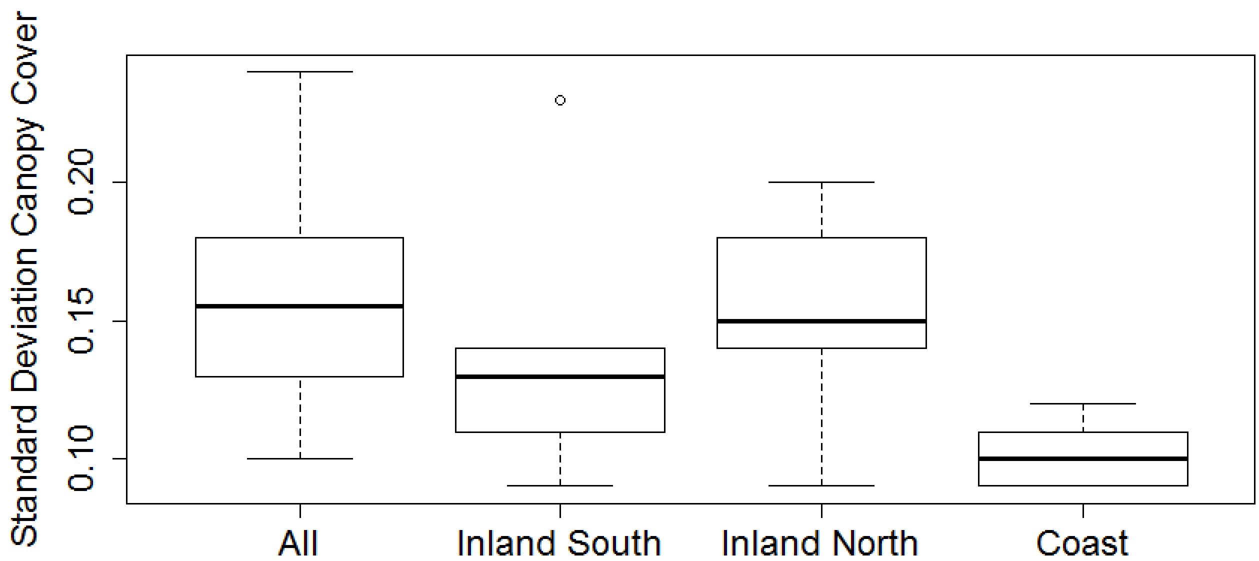
Summary mean canopy closure, standard deviation of canopy closure, and sample size were provided on April 7, 2018. We used these data in several ways to provide guidance for statistical estimation and testing.

4A. EXPLORING VARIABILITY OF CANOPY COVER ACROSS PAST DATA

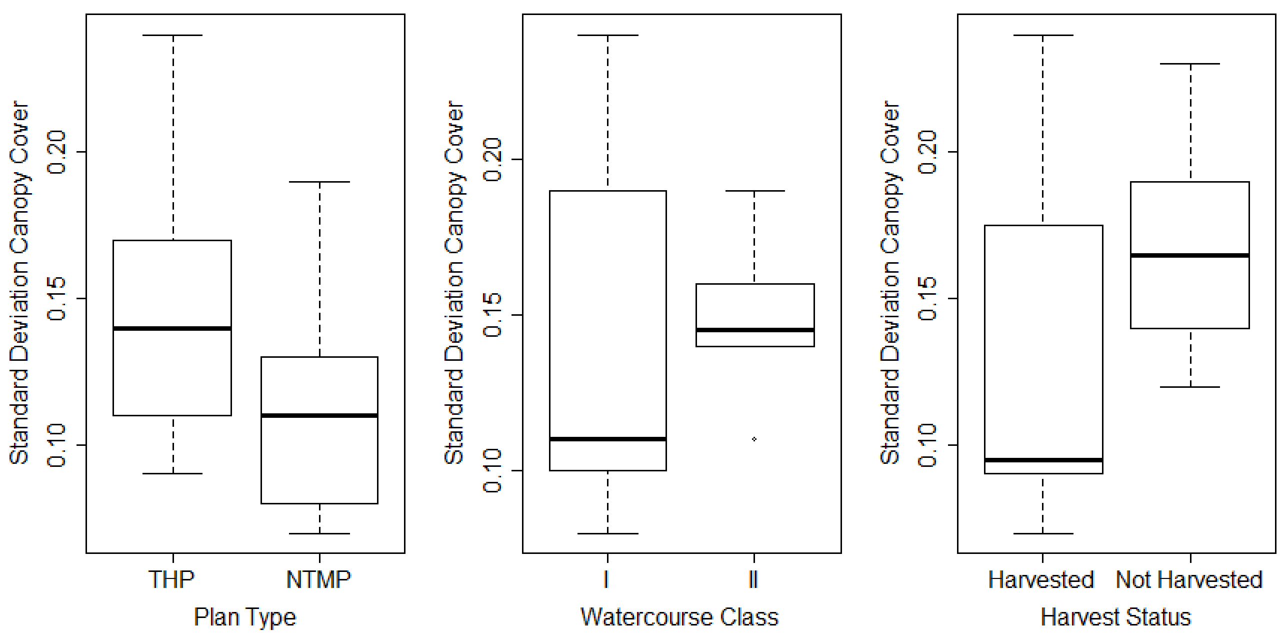
First we examined whether there was a relationship between sample size and standard deviation for all of the data or for any one region. We also compared variability in the data across regions and potential comparisons of interest.



Conclusion: There was no relationship between sample size and standard deviation of the data.



However there were substantial differences in variability of the data (standard deviation squared) across regions and across various comparisons of interest. For planning purposes, it is useful to know where the data are likely to be more variable (more samples required for a given level of precision) or less variable (fewer samples required for the same level of precision).



Conclusion: Canopy cover is somewhat less variable on the coast and in the inland south, as well as for NTMP- NTOs, on Class I watercourses, and in harvested areas, although in all cases there is considerable variability across pilot datasets.

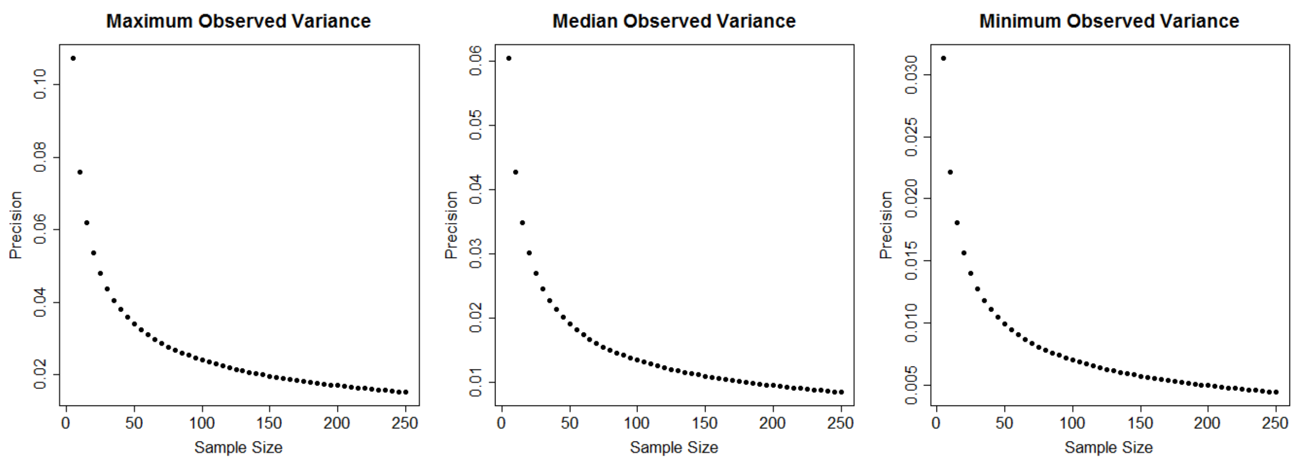
4B. PRECISION OF CANOPY COVER ESTIMATES UNDER THREE SCENARIOS

There is interest in understanding how precise the estimate of mean canopy cover is likely to be. We used the pilot data for canopy cover to estimate precision as a function of sample size for three cases: the maximum observed variance in the pilot data, the median observed variance in the pilot data, and the minimum observed variance in the pilot data. Together, these curves offer a range of estimates from worst case to best case for how precise estimates of canopy cover are likely to be as a function of sample size.

The standard error of the mean is a useful estimate of precision and can be calculated from observed standard deviation and sample size. The formula for standard error of the mean is:

$$\sigma_{mean} = \frac{\sigma_{population}}{\sqrt{n}}$$

For the following graphics, the estimate of precision (y-axis) is represented as 1 standard error of the mean.



Conclusion: There are fairly large differences in how precise estimates will be depending on which pilot data are used. For any particular future study, it may be possible to guess whether the data are likely to be closer to the maximum, minimum, or median variability here using early data or by exploring the boxplots in section 4B.

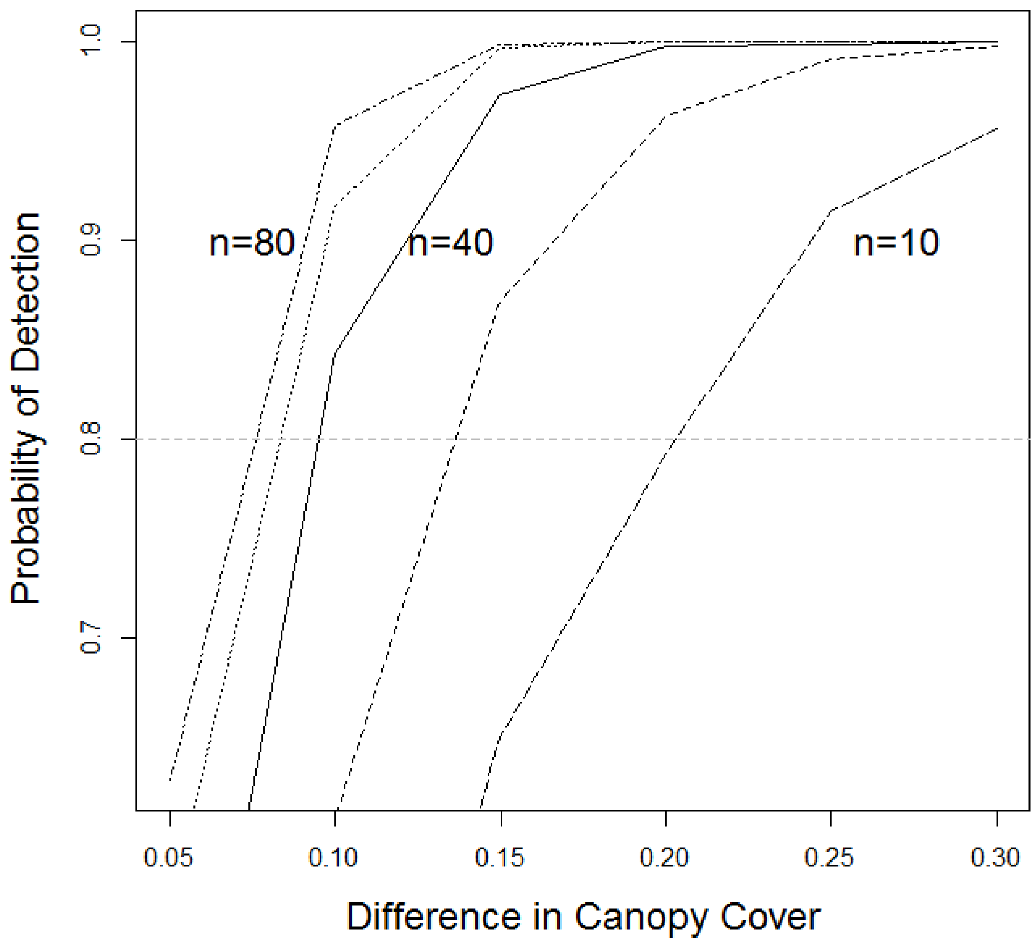
4D. POWER CURVES FOR EXAMPLE COMPARISONS

Statistical power is used in hypothesis testing to help users understand how good future data are likely to be at detecting true differences between two populations. We normally assume that the estimated variation in the sample data is the true variation. In this case, because there is so much variability in past data, we provide three power curves. The first power curve uses all the data and the second considers the best and worst case scenarios in terms of variability in the data. Statistical power estimates can be used to explore how many samples might be needed to quantify the before/after component of the Roads Rules Effectiveness Monitoring Study (EMC-2015-004) or to compare any two groups of plans.

These canopy closure data come from mining the original FORPRIEM monitoring report from 2014. The standard deviations and medians vaguely suggest deviations from normality. Sample sizes are generally not generous. We have not differentiated between Timber Harvesting Plan (THP) data and Nonindustrial Timber

Management Plans (NTMP – NTO) data. Generally, the goal of a study design is to achieve at least an 80% chance of detecting a difference if it is there. To visualize this goal, we include a dashed horizontal line for reference. Power analyses for canopy cover cannot be extrapolated to other types of data.

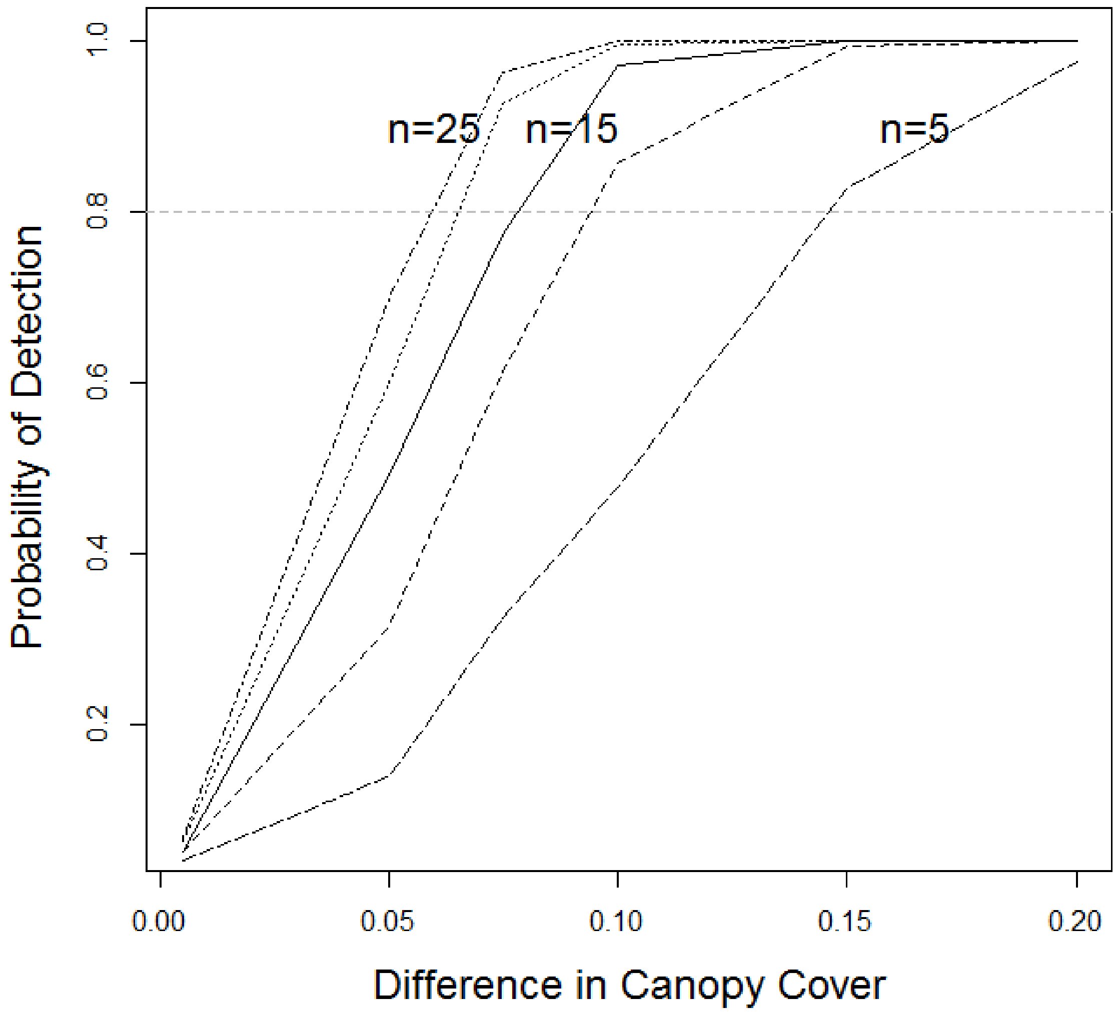
Combining all observations of canopy cover from all regions and both types of plans, we see the following statistical power estimates for a test comparing canopy cover across two groups of plans. In this first analysis, we choose a random observation of canopy cover and its associated standard deviation for each simulation.



Sample sizes are per group, so a sample size of 40 would include 40 plans in each of two groups of plans. Power simulations are for samples sizes of 10, 20, 40, 60, and 80 plans in each of two groups. Unlabeled lines describe n=20 and n=60.

Conclusion: This graph indicates that (for example) for a sample size of 40 THPs or NTMP-NTOs, for which canopy cover data are not particularly unusual, you have adequate power (traditionally speaking, about 80%) to detect a difference in canopy cover just under 10% if it does exist.

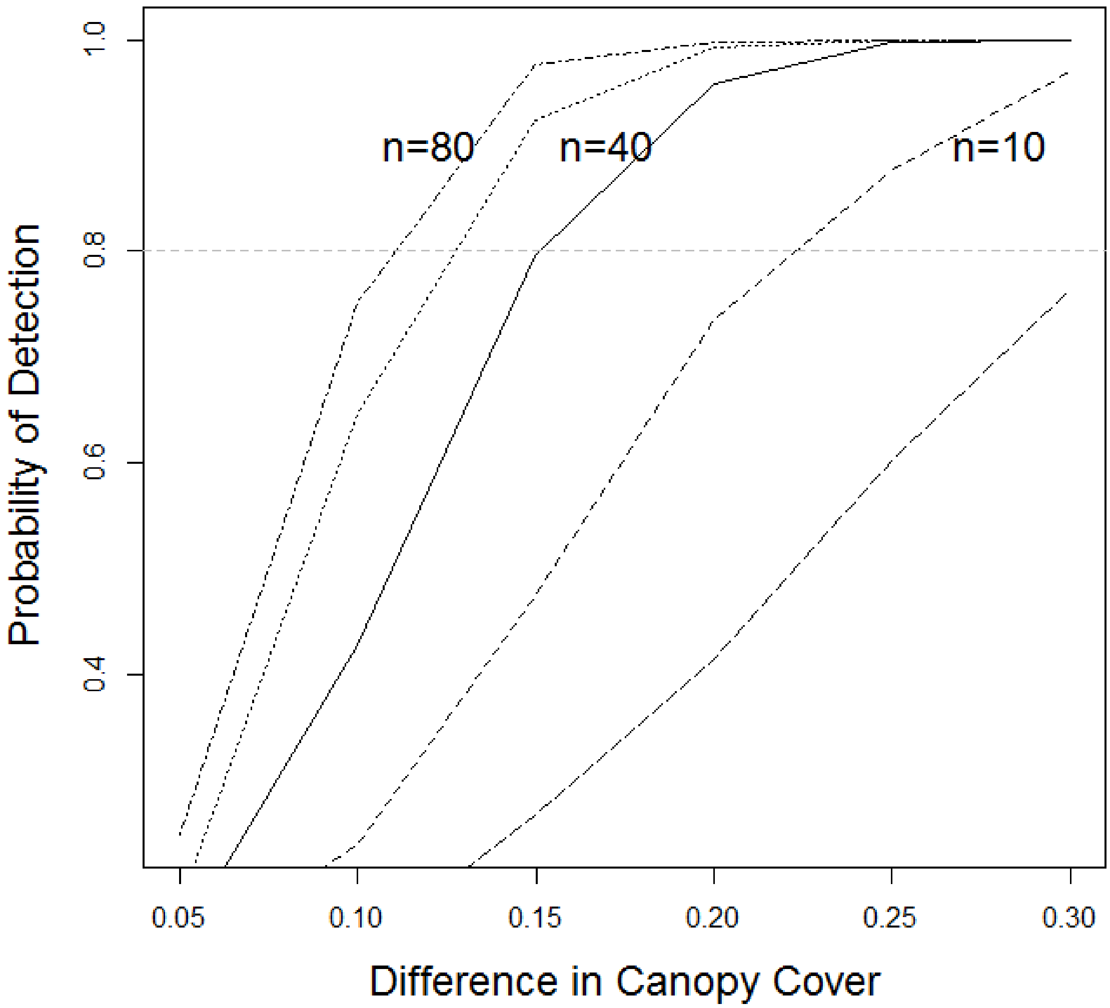
For the best case scenario, we choose a random canopy cover for each simulation but the lowest observed standard deviation (0.07).



Power simulations are displayed for samples sizes of 5, 10, 15, 20, and 25 plans in each of two groups. Unlabeled lines describe n=10 and n=20. The very strong shift in estimated power simply indicates just how sensitive statistical power is to the variability in the observed data.

Conclusion: In the best case scenario in which there is very little variability in canopy cover across samples, a sample size of 15 would have enough power to detect a difference of 0.07 if it existed 80% of the time. Note that a sample size of 5 plans in each category is clearly too small for useful inference even though the estimated power looks sufficient for small differences. With such a small sample size, you would not be sure that the observed data are really as low in variability as the pilot data.

For the worst case scenario, we choose a random canopy cover for each simulation but the highest observed standard deviation (0.24).



Power simulations are displayed for samples sizes of 10, 20, 40, 60, and 80 plans in each of two groups. Unlabeled lines describe n=20 and n=60. This analysis demonstrates that sample sizes of only 10 plans in each group are very risky and even sample sizes of 20 may yield little useful information. However, even in the worst case situation, a sample size of 60, as planned, will be useful for comparing two categories of plans and have a good chance of detecting differences of about 0.10 in canopy cover. Improvements are still possible if you were to increase the sample size to 70 (not shown) or even 80 plans.

Summary of Study Plan Recommendations

1. Drop Erosion Hazzard Rating (EHR) as a criterion for assessing erosion class (details on p. 7), and include Area-weighted Rock Strength and Mean Annual Precipitation (inches) as additional criteria for assessing erosion class (details on p. 6-7).
2. Split large THPs (those greater than 1000 acres) into separate, smaller, homogeneous sub-plans for sample-selection purposes (details on p. 12).
3. Modify erosion risk rating system and sum rating levels for each plan (unweighted). Sample all High-risk plans (using a cut-off risk score of 10 or higher to define High risk), and randomly sample among the remaining Moderate- and Low-risk plans (details on pgs. 8, 11-12):

Category	High	Moderate	Low
Slope (%)	≥ 40 (3)	20-40 (2)	< 20 (1)
Deep-Seated Landslide Rating	≥ 8 (3)	3-8 (2)	< 3 (1)
Drainage Density (mi/mi^2)	≥ 5 (3)	2.5 - 5 (2)	< 2.5 (1)
Area-weighted Rock Strength	≥ 2.5 (3)	1.75 - 2.5 (2)	< 1.75 (1)
Mean Annual Precipitation (in)	≥ 80 (3)	40 - 80 (2)	< 40 (1)
Timber Harvesting Plan Rating	10 to 15	8 to 10	5 to 8

4. For selecting measurement points within plans, subdivide roads into relatively homogeneous, similar-length segments. Using the hillslope and watercourse- crossing attributes group the road segments into three strata (details on page 13) from which measured road segments will be selected:
   A. Roads with no watercourse crossings;
   B. Roads on hillslopes <50% with watercourse crossings;
   C. Roads on hillslopes >50% with watercourse crossings.
5. To select Class I or II WLPZ segments, create a population of watercourse segments that are within one-quarter mile of available roads in the plan area and randomly select one watercourse segment near selected road. Complete GIS analyses to quantify and compare population of stream segments near roads to all stream segments (details on p. 13).
6. Sample size will depend on available resources at the disposal of CAL FIRE and the BOF's desired level of precision (details on p. 17-20).

Summary of Statistical Work Conducted for the BOF and CAL FIRE

- Simulation and evaluation of pre-existing risk evaluation algorithm using available pilot data.
- Development of alternative risk evaluation algorithm using available pilot data.
- Simulation and evaluation of revised risk evaluation algorithm using available pilot data.
- Application of survey design principles to develop a system for selecting plans to be monitored.
- Application of survey design principles to develop a system for selecting areas within plans to be monitored.
- Simulation study, using available pilot data of expected precision in canopy cover estimates, including multiple variability scenarios.
- Power analyses, using available power analyses and a simulation study, for comparing canopy cover across groups of plans or in a before/after study context.

References

Brandow, C.A. and P.H. Cafferata. 2014. Forest Practice Rules Implementation and Effectiveness Monitoring (FORPRIEM) Program: monitoring results from 2008 through 2013. Monitoring Study Group Report prepared for the California State Board of Forestry and Fire Protection. Sacramento, CA. 121 p. plus Appendix. http://www.bof.fire.ca.gov/board_committees/monitoring_study_group/msg_monitoring_reports/forpriem_report_final_022715.pdf

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