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DoD Wildfire Hazard Assessment

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Report

DoD Wildfire Hazard Assessment

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EXECUTIVE SUMMARY

This analysis triaged installations into high, moderate, low, and negligible wildfire hazard based on the number, size, and location of remotely detected fires on or near each installation. This assessment was designed to mitigate the lack of comprehensive and comparable wildfire information with which to determine wildfire exposure across the DoD. Determining wildfire hazard is important in order to properly fund and support wildfire mitigation efforts throughout the military. Recording of wildland fire data has historically been handled at the installation level and the quality and completeness, and often existence of, wildfire data varies dramatically from one installation to the next. This analysis used standardized remote sensing techniques across all installations, producing a systematic, comparable data set that was utilized to triage installations relative to their wildfire hazard.

Eleven years of wildfires were remotely detected for the Air Force, Navy, and Marine Corps installations in the study. This study also leveraged 10 years of previously completed fire detection data from the Army. In all cases, fires were detected using archived Landsat satellite data. Each fire's perimeter was mapped in a Geographic Information System using the differenced normalized burn ratio to differentiate burned from unburned areas. Prescribed fires were identified using a decision tree methodology combined with subject matter expertise and filtered out of the data set, leaving only wildfire perimeters.

The intent of this study was not to account for all, or even most, fires, but rather to create a statistically valid sample of fires across all installations. Ten metrics based on the fire perimeters were measured for each fire and aggregations of the metrics utilizing statistical means clustering to identify like installations was used to group installations. Groups were triaged and individual installations reviewed against their triage designation using expert knowledge.

The analysis was carried out by military branch (Air Force, Army, Marine Corps, and Navy), as well as in a Cross-Branch analysis comparing installations regardless of military branch. The outcome identifies which branches and which installations have the greatest exposure to wildfire hazard.

Of the 145 installations in the Cross-Branch analysis, 13 were triaged into the High wildfire hazard category. An additional 31 were rated Moderate, 40 rated Low, and the remaining 61 were designated as having negligible fire hazard. Please see Table 22 and Table D - 1 for a full listing of final categorizations.

The installations categorized as high had multiple high fire metrics, often in combination with a number of moderate metrics. This separated them from moderate installations which tended to have only one or two high metrics combined with many low metrics, or a number of moderate metrics, but no high metrics. Installations designated as low hazard tended to be dominated by low metrics with few or no moderate metrics. No fires were detected partially or wholly within the installation boundary at installations designated as negligible.

High wildfire hazard installations had many fires every year, numerous large fires, a history of transboundary fires, or all three. These installations represent probable locations of negative wildfire outcomes. Moderate installations varied a great deal in the characteristics of the hazards facing them, making generalizations difficult. The specific threats faced matter when considering how to mitigate them and how difficult, and expensive, that may be.

The wildfire hazard represented by this assessment is relative to the wildfire potential, and mitigation, in place during the time period of the analysis (2004 – 2014). Changes to either the land use (usually the training mission) or mitigation levels can be expected to result in a change in wildfire hazard, though the relationship is not linear and varies substantially between installations based on a wide variety of wildland fire and other factors. In some cases, an installation categorized as anything other than high hazard may

reflect the success of a wildfire mitigation program that reduced wildfire frequency and size enough to prevent it from being categorized higher in this study. Even every high-hazard installation has a wildfire mitigation program in place, some of them very robust, that reduces wildfire frequency and size. Generally speaking, those installations with a high fire hazard were found in particularly fire-prone locations and/or have an active training mission that produces many ignition sources, making wildfire hazard mitigation difficult and expensive.

This assessment is intended to inform national level wildland fire funding and resourcing decisions. However, this analysis applies only to wildfire, it does not address or consider prescribed fire. While this assessment may be used to inform funding decisions, it is important to note that wildland fire, and usually the funds associated with it, include both prescribed fire and wildfire dollars. There are many reasons to fund and implement prescribed fire that have no relation to wildfire risk mitigation, such as maintenance of a desired landscape for training purposes or habit restoration. Thus, installations rated as low or negligible wildfire hazard in this assessment may still require significant wildland fire funding to support their prescribed fire programs.

INTRODUCTION

Wildfire size and severity have increased dramatically over the past several decades (Figure 1), more than doubling in acreage from their averages in the 1980's[1]. The Department of Defense (DoD) is not immune from these trends as they are driven by factors that occur on DoD lands as well. These include long-term fire suppression which leads to a buildup of fuels, climate change which in many portions of the country exacerbates fire weather, and invasive species that can increase fuel continuity and/or fire intensity.

Trends specific to the DoD are currently unknown. Only the Army and Air Force have very recently implemented mechanisms by which to consistently and comprehensively track wildfire occurrence, though even those are hampered by divisions in the responsibility for wildland fire between Natural Resources and Fire and Emergency Services. Decision makers at the national level are generally aware of the largest and most consequential fires, but lack fundamental information about routine fire occurrence. Even at the installation level, typically no one individual is aware of all fires that occur there as they may be reported and/or responded to by more than one entity within the installation.

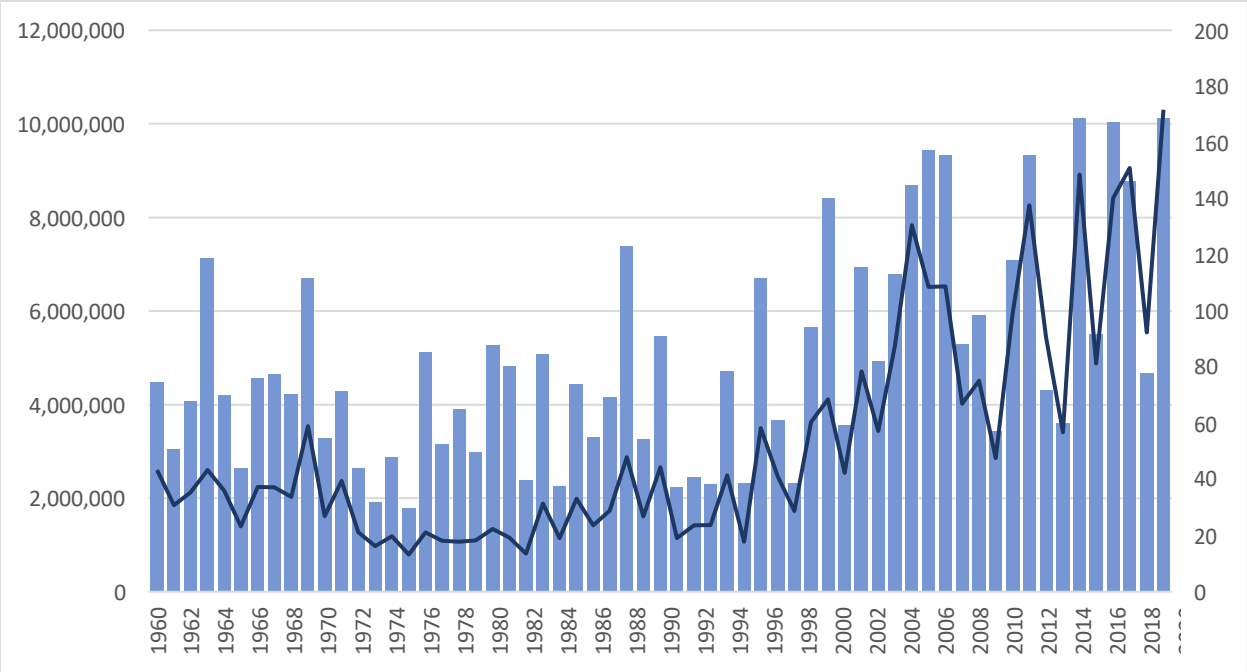


Figure 1. Annual total and annual average acres burned 1960 to 2018. Total burned acreage and average fire size have both increased dramatically in the past two decades.

As a result, the military has limited understanding of its exposure to wildfire. Without metrics with which to measure the scope, acuity, location, or trends of wildfire hazards, either strategically or at the installation level, it is impossible to mitigate those threats. They include potential interruptions to and constraints on the mission, damage to military training assets and defense infrastructure, loss of natural or cultural resources, loss of buildings, as well as damage to neighboring landowners and smoke impacts.

Every wildfire carries with it the potential to do harm. That harm may be damage in the form of one of the above listed examples, but there are many ways that fires can do harm. Each fire that burns represents a hazard in that it has the potential to do harm. The term 'hazard', as used in this study, is in reference to that fact - the potential for fire activity to cause a negative outcome. 'Hazard', as used in this study, does

[1] https://www.nifc.gov/fireInfo/fireInfo_stats_totalFires.html

not account for the values that may have been affected by the fire, it only accounts for the fact that a fire occurred and represents a threat to any value that may exist in that area.

This study used satellite detected wildfire perimeters to determine historic fire occurrence and location. Each of these fires is an example of a realized hazard. From that information we created a set of metrics representing the wildfire hazard at each installation in an effort to estimate wildfire hazard across military branches and at the DoD scale.

Though not every fire can be detected in via satellite, this methodology produced detection rates that were comparable across installations, making it useful for inferring meaningful comparisons across all 145 installations included in the study. It is not the intent of this study to produce a complete accounting of all wildfires on DoD managed lands, nor should the data contained herein be used for that purpose. It can, however, be used to compare installations and DoD branches. The comprehensive and comparable methodology used across all installations facilitates those comparisons and was used to triage wildfire hazard within and across military branches.

The resulting data is intended to aid in strategic national wildland fire management planning. By understanding where the fire hazard lies within each military branch and within DoD as a whole, fire managers can focus resources on those installations where fire mitigation is most necessary. The information in this study does not allow for installation-level management decisions, but can bring into focus the big picture of where the potential for fires exists. DoD managers can then focus their efforts on those locations, using more detailed information to determine which installations are most likely to benefit from increased fire mitigation and what mitigation measures may be most appropriate. Conversely, this study can point out locations where the fire hazard is lower and where fire mitigation may not be as necessary.

METHODS

Data Development

STUDY AREA

A set of 145 installations from across the Air Force (40 installations), Army (54 installations) Navy (37 installations), and Marine Corps (14 installations) were selected and approved for inclusion in this study in coordination with Legacy Service Level managers and the Legacy Resource Management Program. These installations represent virtually all of the training capacity of the DoD, as well as numerous other functions.

Installation boundaries were acquired from Common Installation Picture data (Air Force), Legacy Service Level Managers (Navy and Marine Corps), and Army Mapper (Army). For the purposes of this assessment, these boundaries are considered the definitive extent of each installation. We created a five-mile buffer polygon around each installation boundary. This five-mile buffer, including the area within the boundary, represented the study area for each installation.

STUDY PERIOD OF RECORD

An 11-year study period of January 1, 2004 through December 31, 2014 was utilized for the Air Force, Navy, and Marine Corps. This study leveraged previously completed data compiled for the Army that spanned a 10-year period from January 1, 2005 through December 31, 2014. The Air Force, Navy, and Marine Corps were analyzed on their 11 year study period for the within-branch analyses, and the Army using its 10 year study period. The one year shorter period of record for the Army data limited the Cross-Branch analysis to the 10 year period of 2005 – 2014.

FIRE DETECTION

Fires were detected using Landsat Level-1 satellite data products, courtesy of the U.S. Geological Survey Earth Resources Observation and Science Center[2]. Each Landsat image contains seven to eleven spectral bands, ranging from blue to mid-infrared. Landsat data are commonly used to monitor vegetation health, including to map the effects of wildland fires[3]. We delineated fire perimeters using processes developed by the national Monitoring Trends in Burn Severity (MTBS) program[4]. A summary of these methods follows.

Normalized Burn Ratio (NBR) is a surface reflectance-derived spectral index that highlights changes in vegetation due to fire and disturbance. For Landsat data products, NBR is given by:

$$NBR = \frac{NIR - SWIR}{NIR + SWIR} \quad (1)$$

[2] U.S. Geological Survey, 2017. Product Guide: Landsat Surface Reflectance-Derived Spectral Indices, Version 3.5. U.S. Department of Interior. Available from: https://landsat.usgs.gov/sites/default/files/documents/si_product_guide.pdf. Accessed 12/1/17.

[3] NASA Landsat Science. 2016. http://landsat.gsfc.nasa.gov/. Accessed 11/14/16.

[4] Eidenshink J., Schwind B., Brewer K., Zhi-Liang Z. Quayle B. Howard S. 2007. A project for monitoring trends in burn severity. Fire Ecology 3(1).

where *NIR* denotes the near-infrared Landsat spectral band (Band 4 for Landsat 4–7; Band 5 Landsat 8) and *SWIR* denotes a shortwave-infrared Landsat spectral band (Band 7 for Landsat 4–8). Pre- and post-fire NBR images were differenced to generate the differenced NBR, or dNBR:

$$dNBR = NBR_{pre} - NBR_{post} \quad (2)$$

where *pre* indicates a pre-fire satellite image and *post* indicates a post-fire satellite image.

We delineated fire perimeters through a combination of automated fire perimeter identification and heads-up digitizing of the fire-induced land cover change, as indicated by the dNBR images. We followed fire detection methods developed by the MTBS program, with two key differences. First, MTBS begins its detection process with known fire locations, whereas we did not have *a priori* knowledge about fire dates or locations. Second, MTBS detects fires greater than 1,000 acres in size in the western U.S. and 500 acres in the eastern U.S., whereas we digitized all visible fire perimeters in the Landsat-derived dNBR images (30-meter resolution), regardless of how small.

We also acquired MTBS detected fire perimeters. This helped ensure the largest fires were accounted for in our fire perimeter data.

There are known limitations to these satellite-based detection methods. Small fires, low-severity fires, and fires under canopy may not be detected. Additionally, cloud cover can mask fires, though usually only when cloud cover obscures the fire area for multiple sequential satellite passes. Additional information about these methods is available from the MTBS program[5].

After completing our Landsat-based fire detection process and acquiring MTBS data, we cross-referenced fires we detected against those detected by the MTBS program and removed duplicates, defaulting to the MTBS perimeter and attribute data where matches were found. We also utilized spatial fire data provided by installation-level wildland fire programs. We cross-referenced our Landsat detected perimeters and the MTBS detected perimeters against the installation-provided fire perimeters, identifying duplicates. When we found duplicate fires between our dataset or MTBS detected fires and installation-provided fires, we substituted the installation-provided perimeter geometry. Attributes from the installation data were added to the our standardized attributes to provide more context in the dataset deliverable, but those attributes were not used in any analysis in this study. We did not add fires from installation data that were not detected via our Landsat-based fire detection process or by MTBS in order to ensure the sampling methodology was consistent across installations as installation provided data varied in availability, consistency, and comprehensiveness.

DATA ATTRIBUTION

We assigned each fire a location (inside, outside or crossing the installation boundary), detection date, fire type (prescribed fire, wildfire, or unknown), and data source ('MTBS'; 'TM', detected through our Landsat-based dNBR methods; or 'IS', installation-provided perimeter). The fire detection date was defined as the date of the Landsat image on which the fire was detected. Landsat passes over each location on a 16-day return interval, and fire detection dates are limited to the dates of available imagery.

Cloud cover or smoke from current burns can obscure Landsat images partially or completely, occasionally making fire detection difficult or impossible. Fires that are missed on one pass for these reasons may not

[5] https://www.mtbs.gov/mapping-methods

be detected until a month or more after it has burned, and detection dates associated with Landsat-derived fire perimeters should be considered rough estimates.

The location of the fire was assigned using ESRI ArcGIS spatial selection functions to determine whether the perimeter of the fire was entirely inside the installation boundary, entirely outside the installation boundary, or crossed the installation boundary.

The distinction between prescribed fire and wildfire followed a standard set of criteria based on shape, size, recurrence, land cover, and region as shown in Table 1. A level of error is inherent in determining fire type from fire perimeter data alone. We used two installations with high quality installation provided data to test the level of accuracy, one from the southeast, where prescribed fire is frequent, and one from the west, where wildfire is often more frequent. We selected installations with at least 150 fire perimeters that included data identifying whether the fire was a prescribed fire or a wildfire, were greater than 50 acres in size, and had been detected by Landsat as well as being included in the installation provided data. This limited installations available for selection to only three outside of the Southeast. Fort Hood was selected to represent the West and Fort Jackson was selected to represent the Southeast.

One hundred fires were selected at random from each installation's supplied data per the criteria listed above. Without any data or *a priori* knowledge, a fire analyst then used only the fire's fire perimeter in order to determine the fire type. The fire analyst also used other available data including roads, aerial imagery from Google Earth and Bing, the locations of training areas and ranges, and the locations of other detected fires. The fire analyst approached the determination in two ways: the first strictly followed the guidelines in Table 1, and the second supplemented those guidelines with professional judgement.

This small test indicated a good degree of accuracy, on average greater than 80%, in the ascription of fire types to fire perimeters using these methods. Full results are indicated in Table 4 in the Results. On occasion, fires defied classification as a wildfire or prescribed fire, and in these cases were classified as 'unknown'. This resulted in three categories – wildfires (WF), prescribed burns (RX), and unknown (UNK). Prescribed fires and unknown fires were then removed from the analysis dataset.

We generated fire frequency layers for each installation over the full study period at 10-meter resolution within the extent of each installation's five-mile boundary buffer, including all fire types (RX, WF, and UNK). Three fire frequency rasters are included in each installation's geodatabase, representing frequency of (a) wildfires, (b) prescribed fires, and (c) total fires, including wildfires, prescribed fires, and fires of unknown type.

Data Analysis

The analyses presented in the section below were based on the data described above. The analyses were intended to estimate the hazard posed by wildfires, and, therefore, were based only on wildfire occurrence, ignoring RX and UNK fires. Prescribed fire is used by many installations for a variety of reasons, including wildfire mitigation and ecosystem management. These were not included because a successfully implemented prescribed fire is, by definition, controlled and managed to produce positive benefits. Under these constraints, no prescribed fire should cause significant damage to any resource, and therefore is not considered a hazard if successfully implemented. Escaped prescribed fires are considered wildfires and were included in this study.

Table 1. Criteria used to differentiate wildland from prescribed fires. Criteria were applied in the order listed, with criteria higher in the list overruling criteria lower in the list. The fire analyst occasionally used professional judgement to override these criteria when the rule set did not lead to a clear conclusion.

Criterion	Wildfire	Prescribed Fire
Recurrence - Shape	Fire perimeter does not recur	Fire in approximately the same area and approximately same shape and size as another fire in the data.
Shape	Irregular borders that do not conform well to roads, streams, or prescribed fire burn units. Less than 85% of the fire perimeter is bounded by roads/streams/burn unit perimeter, usually much less.	Bounded by roads, streams or conforms to prescribed fire burn units. Roads/ streams/burn unit perimeters bound at least 85% of the burn perimeter. Streams are less likely to be used to contain prescribed fires in the west than other regions of the country.
Size	< 5 acres	Fires < 5 acres are typically not prescribed fires
Land Cover	Fires on live-fire ranges are more likely to be wildfires than fires in other portions of the same installation.	Fires on live-fire ranges are less likely to be prescribed fires than fires in other portions of the same installation
Recurrence - Neighbors	Other fires in the immediate vicinity are overwhelmingly wildfires	Other fires in the immediate vicinity are overwhelmingly prescribed fires.
Timing - Neighbors	Fires not bounded on one or more sides by another fire in the same year.	Fires bounded on one or more sides by another fire in the same year.
Region	More likely in the West	More likely in the Southeast

HAZARD METRICS

Wildfire hazard was defined as a composite of multiple fire characteristics that varied between installations. It depended on the number, frequency, and size of fires, as well as their location on or off the installation. One installation may have many small fires, while another has infrequent, but large fires. The goal of this analysis was to consider the metrics that describe wildfire hazard, determine the magnitude of each metric in groups of installations with similar metric values, and triage the installations based on exposure to each metric. Decision makers can use this triaged listing of installations to identify those that require support, and act accordingly.

The metrics used to determine the wildfire hazard for each installation are listed in Table 2. Numerous additional metrics were initially calculated for consideration, but they were not found to provide unique or meaningful information relative to the metrics listed in Table 2. The metrics used addressed questions such as "how many fires occur at an installation?", "how many large fires occur?", "how many fires occur in a typical year?", "how much of the total installation acreage burns?", "how likely is a fire to cross the installation boundary?", and others that are useful descriptors of the wildfire hazard at an installation. These metrics are abbreviated throughout this study as noted in Table 3.

Installations where no on-installation or transboundary fires were detected within the analysis period were removed from subsequent analyses and assigned an installation triage category of negligible. It is not possible to claim there is no fire hazard at these installations as any vegetation can theoretically burn. However, these installations lacked any detectable fires resulting in a zero for all hazard metrics.

Table 2. Fire hazard metrics. Each of the items below reflects an aspect of the overall wildland fire hazard to an installation that can be directly detected or calculated from detected data.

Metric	Use
Total count of all wildfires inside the installation	The total count of detected wildfires that fall wholly within the installation boundary over the study period. This provided an indication of the total fire load. This captured outlier years of very high or very low counts of detected fires, as well as typical year fire loads.
Median count per year of wildfires inside the analysis area	The median count of detected wildfires within the installation's 5-mile buffer, including inside the installation. This was an indication of the regional fire load. Installations with high values represented a location where fires were likely to ignite and spread to a detectable size. The median was used because it is less influenced by outlier years of extremely high or low detected fire counts than the mean, though this resulted in installations with low overall counts receiving a median of zero as in most years there were no fires.
Total count of large wildfires inside the installation	The number of fires greater than 300 acres in size, occurring wholly within the installation boundary. This measure was an indicator of the potential for a large fire inside the installation.
Proportion of all wildfires inside the installation that are large	The proportion of detected wildfires wholly inside the installation boundary that were at least 300 acres. This reflected the likelihood, should a fire ignite, that it would become large. An installation with few fires, all of which grew to be large, had a different type of fire hazard than an installation with many fires, but few that grew to a significant size.
Total count of wildfires inside the installation close to the boundary	This was defined as on-installation fires that occurred within 0.5 miles of the installation boundary, but did not cross the boundary. Being close enough to the boundary that they could easily cross the boundary under the right conditions, these represented a potential for transboundary fires and their associated consequences.
Total count of transboundary wildfires	The number of fires that crossed the installation boundary. This is an aspect of problematic fires, as transboundary fires are universally undesirable. Transboundary fires indicated installations where there are significant difficulties in controlling wildfires and/or potentially inadequate controls on wildfire ignition timing and location. A fire burning off of an installation is generally considered a more egregious situation than a fire burning onto an installation, but in this study, there was no capability for determining whether these fires ignited on or off of the installation.
Median fire size across the analysis area	The median fire size provided a metric of area burned by each fire occurring within the analysis area, with larger median sizes indicating a larger potential for negative outcomes. This metric was calculated using all wildfires in the analysis area, whether they were wholly inside or outside the installation, or crossed the installation boundary. The entire fire extent was used, including any portion that extended outside the analysis area, as long as some portion of the fire was inside the analysis area.
90th percentile fire size across the analysis area	The 90th percentile fire size indicated the potential for extreme wildfire on or near an installation. The period of this study was too short to provide a great deal of confidence in this metric as very large fire events are rare, but it nonetheless captured a snapshot in time of exposure to major wildfire damage. This metric was calculated using all wildfires in the analysis area, whether they were wholly inside or outside the installation, or crossed the installation boundary.
Total wildfire acreage within the installation boundary	This was calculated as the total installation acreage burned by detected wildfires over the study period inside the installation. Wildfires occurring wholly within the installation were considered in their entirety, whereas only the portion of transboundary fires inside the installation was used. If an area burned multiple times, the acreage was counted multiple times. An example of this would be an impact area that burned in multiple years. This value indicated the demand on firefighting resources, as each fire requires time and effort to suppress.
Overall proportion of installation area burned by wildfire	The proportion of the installation burned by wildfire over the 10 year study period. Unlike the total wildfire acreage metric, above, the Overall Proportion of the Installation Burned metric counted fires occurring repeatedly in the same location (areas with overlapping fires) only once. Thus, between two installations of the same size, the installation that had most of its wildfires occurring within one impact area, for example, would have a lower value for this metric than the installation that experienced fires burning across different locations. A greater proportion equates to a greater probability of valued resources being impacted. It also indicates the predictability of fire at an installation, which is conducive to suppression effectiveness.

Table 3. Fire hazard metric abbreviations used throughout the document.

Fire Hazard Metric	Abbreviation
Total count of all wildfires inside the installation	TC *(Total Count)*
Median count per year of wildfires inside the analysis area	MC *(Median Count)*
Total count of large wildfires inside the installation	TCL *(Total Count Large)*
Proportion of all wildfires inside the installation that are large	PL *(Proportion Large)*
Total count of wildfires inside the installation close to the boundary	TCC *(Total Count Close)*
Total count of transboundary wildfires	TCT *(Total Count Transboundary)*
Median fire size across the analysis area	MS *(Median Size)*
90th percentile fire size across the analysis area	90^{th} PS *(90^{th} Percentile Size)*
Total wildfire acreage within the installation boundary	TA *(Total Acreage)*
Overall proportion of installation area burned by wildfire	PAB *(Proportion Area Burned)*

ANALYSIS

After each value was calculated for each installation, the values for each metric were evaluated for outliers using Grubbs' test at α=0.01. Outlier status was determined for each dataset independently (i.e. Air Force, Army, Navy, Marine Corps, and Cross-Branch) as the dataset composition impacts the outlier test and varied among datasets. This means that an installation that was an outlier in one branch may not have been an outlier in the Cross-Branch analysis. Outliers can skew the data, resulting in erroneous analysis results and obscuring differences between non-outlier installations.

After identification, outliers were removed from further relative analyses. Once removed, the outliers were assessed subjectively on a case by case basis. All outliers identified in this analysis were at the high end of each metric's spectrum, no outliers were identified at the low end of any metric.

Because the goal of this analysis was to assess the wildland fire hazard among installations relative to each other, we normalized the remaining, non-outlier installation values for each metric on a 0-1 scale. This analysis was based on satellite-detected fires. It is important to recognize that not all fires can be detected remotely, and it was not this study's intention to detect every fire, or even most fires. The purpose was to create a consistent and comparable sample set of data across all installations that was representative of fire activity.

Normalizing the data allowed categorization of the *relative* wildfire hazard among installations. With this relative measure, it was possible to compare them to one another on a proportionate scale. The absolute values of each comparative metric, therefore, were not relevant. Rather, it was the relationships between installations that were important. Therefore, all results were provided in relative terms with the maximum installation value for any metric being 1 and all other installations scaled (normalized) off of the maximum observed value. This also allowed comparison among metrics with different units, such as count and area.

We used K-means clustering to group the non-outlier installations by metric similarity. After clustering, the Kruskal-Wallis and Dunn's post hoc tests were used to determine the statistical validity of each metric for separation among clusters. Results from both post hoc tests were evaluated for significance at α=0.1; full results are shown in Appendix A – Kruskal-Wallis and Dunn's Test.

We evaluated the characteristics of each group of installations identified by the K-means algorithm, and assigned an initial wildfire hazard classification (low, moderate, high) to each group. Installations where no fires were detected anywhere inside the study area were assigned to a 'negligible' category. Installations where all detected fires were wholly outside the installation boundary, but within the 5-mile buffer around the installation boundary, were also assigned to the negligible category.

We then individually reviewed installations against their group classification, incorporating additional wildfire characteristics calculated in this assessment (those that weren't pertinent to the entire dataset),

supplemental information external to this analysis, and expert knowledge. We used these to subjectively refine the classifications, and make adjustments to individual installations as needed, rather than rely exclusively on the K-means clustering. All outlier installations were assessed individually, utilizing all available information in the study, supplemental information external to this analysis, and expert knowledge, and placed into a triage category.

The Marine Corps dataset was too small for statistical clustering. Only nine installations had detected fires occurring within or across their boundary. In this case, we evaluated each installation individually using the same process as for outlier installations.

CORRELATIONS WITH INSTALLATION SIZE

Several metrics in this study could be sensitive to installation size. These include metrics related to wildfire size and transboundary fire probabilities. For example, a large fire occurring completely within the installation boundary may be expected to be more common at a large installation, as large installations are more capable of containing large fires than small installations. Conversely, at small installations, the likelihood of a large fire crossing the boundary is greater. Wherever a consideration like this became relevant, a simple linear correlation analysis was run on the installation size against the metric in question in order to test for correlates. We did not find any metric in this study to be strongly correlated with installation size, though there were several with moderate levels of correlation. These are noted in the results.

RESULTS AND DISCUSSION

Fire Detections

A total of 20,912 fires were digitized from the dNBR Lansat images. Of these, 5,291 were determined to be wildfires, with the remaining 15,621 determined to be prescribed fires. Of the wildfires, 1,046 were entirely outside the installation boundary, but at least partially within the 5-mile buffer, and 113 were transboundary fires, leaving 4,132 wildfires across the 145 installations that were entirely within the installation boundary.

Fire Type Validation Assessment

Fires were correctly ascribed to prescribed fire or wildfire using strict conformance with the rule set described in Table 1 85% of the time in the Southeast and 71% of the time in the West (Table 4). Using the rule set and professional judgement in combination, performance improved in both regions to 87% and 78% respectively. Performance in the Southeast may have been better because prescribed fires occur regularly and the ability to detect multiple fires burning the same general location repeatedly is a strong indicator a prescribed fire and helps to more effectively determine which fires are prescribed burns.

This level of accuracy was considered sufficient for the purpose of separating wildfires from prescribed fires. Any fire not classified as a wildfire was removed from the analysis dataset and was not considered in any of the results below.

Table 4. Fire type determination accuracy assessment results

Installation (Region)	Rule Set Conformance Percent Correct	Rule Set and Professional Judgement Percent Correct
Fort Jackson (Southeast)	85	87
Fort Hood (West)	71	78

Air Force Results

FIRE DETECTIONS

Forty Air Force installations were included in this analysis. An initial pass through the data revealed 14 installations with no detected fires occurring anywhere inside the installation or within the 5-mile buffer, and an additional 3 installations that only had detected fires occurring wholly outside the installation. We categorized these installations as having negligible hazard within the scope of this analysis, and removed them from further comparative analyses.

The 14 installations with no wildfires detected anywhere (on-installation or within the buffer) over the entire study period are shown in Table 5. Also shown are the 3 installations whose detected fires only occurred wholly outside the installation boundary, and the remaining 23 installations with at least one wildfire detected on-installation.

The five installations identified as outliers are indicated with asterisks in Table 5. These were removed from the cluster analysis and evaluated independently per the methodology of this study.

Table 5. List of Air Force installations where fires were detected, were only detected wholly outside the installation boundary, or were not detected at all during the study period 2004 - 2014. Outliers are marked with an asterisk.

At Least One Fire Detected On Post	No Fires Detected On Post, at Least One Fire Detected Off Post in Analysis Area	No Fires Detected Anywhere in Analysis Area
BARKSDALE AFB	JB CHARLESTON	CHEYENNE MTN AFS
ARNOLD AFB	LITTLE ROCK AFB	COLUMBUS AFB
AVON PARK AFR*	TINKER AFB	DOBBINS ARB
BARRY GOLDWATER AFR*		GRAND FORKS AFB
BEALE AFB		HOLLOMAN AFB
CAPE CANAVERAL AFS		HOMESTEAD ARB
DARE COUNTY BOMBING RANGE*		JB ELMENDORF RICHARDSON
EGLIN AFB HURLBURT AFB*		JB LANGLEY FORT EUSTIS
ELLSWORTH AFB		JUNIPER BUTTE BOMBING RANGE
HILL AFB UTTR		MACDILL AFB
JB CAPE COD		NEW BOSTON AS
JB MCGUIRE DIX LAKEHURST		ROBINS AFB
JB SAN ANTONIO		WESTOVER ARB
KIRTLAND AFB		WRIGHT PATTERSON AFB
MELROSE AFR		
MOODY AFB GRAND BAY		
MOUNTAIN HOME AFB		
NTTR		
PECR		
SAYLOR CREEK BOMBING RANGE*		
TYNDALL AFB		
USAF ACADEMY		
VANDENBERG AFB		

FIRE HAZARD METRICS

The figures below show the rescaled values for each metric listed in Table 2. These are the scaled values excluding Avon Park AFR, Barry M Goldware AFR, Dare County Bombing Range, Eglin/Hurlburt AFB, and Saylor Creek Bombing Range, all of which were identified as outlier installations.

The greatest TC was detected at JBMDL (Figure 2). There was a notable decrease in fires detected between JBMDL and the installation with the second highest TC, Melrose AFR, where the number of fires detected was also high. After another substantial drop to Kirtland AFB, the next three installations had moderate counts. Lower counts were detected at another 9 installations, and 3 installations had no wildfires detected wholly within their boundaries (Mountain Home AFB, Ellsworth AFB, and JBSA).

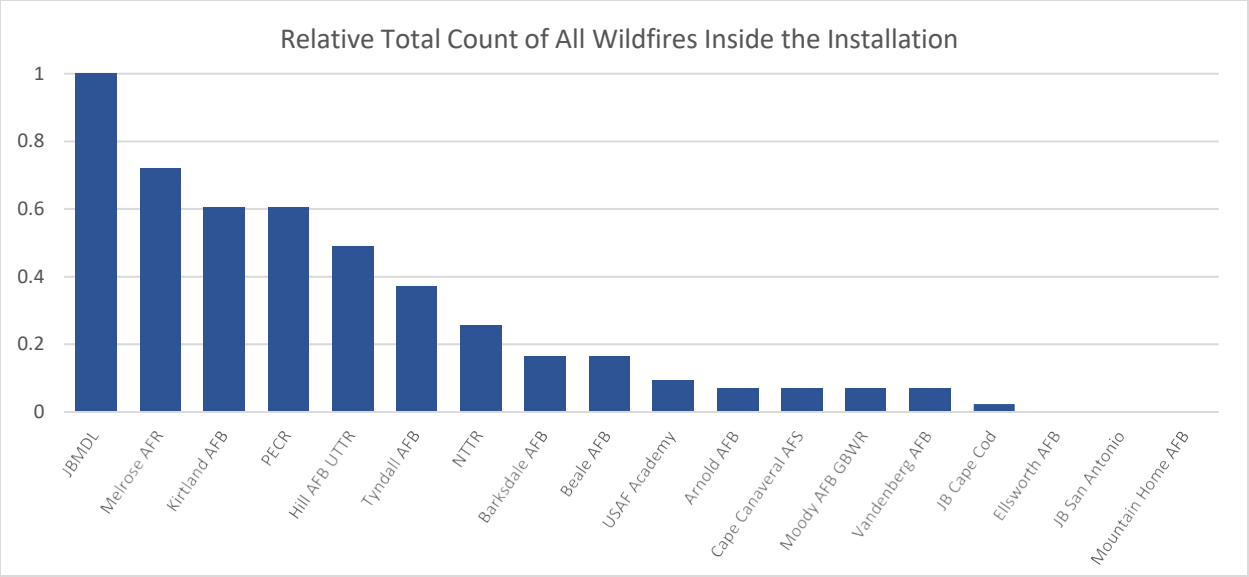


Figure 2. The relative total count, across the entire study period, of detected wildfires whose perimeters were entirely contained within the installation boundary 2004 – 2014. Data have been rescaled relative to the maximum detected count from JBMDL after removing the outlier installations from the calculation.

The greatest MC was also at JBMDL (Figure 3). There were 11 installations with some wildfire activity expected each year (25 – 50% of the median count at JBMDL), and 6 installations whose median count of detected fires within the analysis area was 0, indicating that more often than not, those installations and their surrounds would not experience a wildfire in a given year.

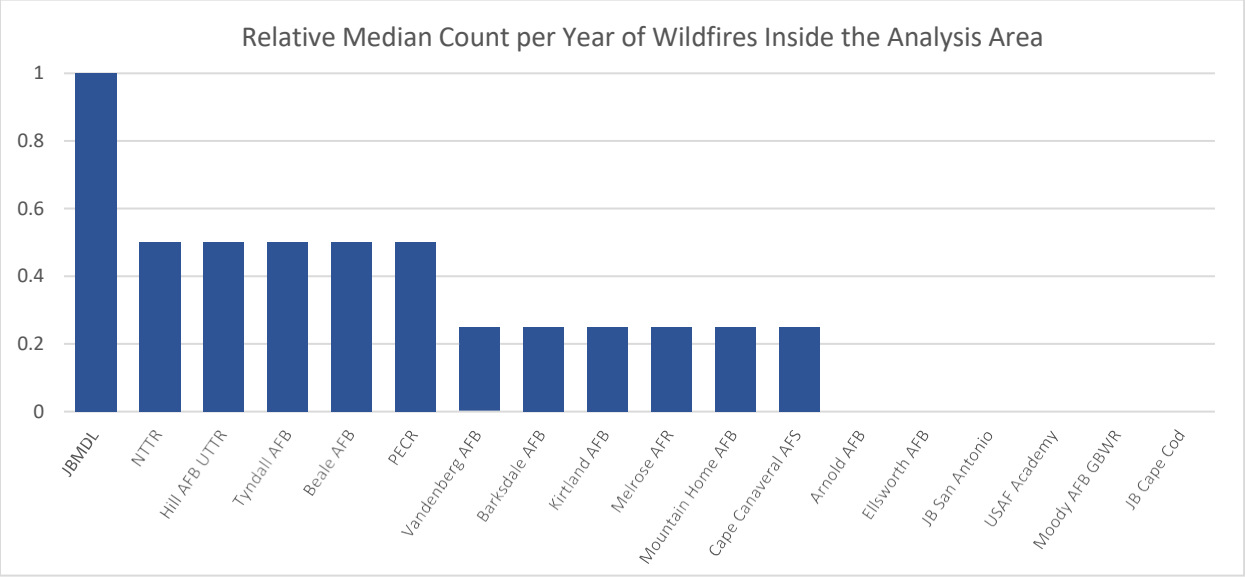


Figure 3. The relative median count per year of detected wildfires within the analysis area 2004 – 2014. Data have been rescaled relative to the maximum detected median count from JBMDL after removing the outlier installations from the calculation.

The highest TCL was at Hill AFB/UTTR (Figure 4). Elevated counts were also detected at JBMDL and NTTR. Lower counts of large fires were detected at 6 additional installations, and 9 installations had no large fires detected wholly within their boundary.

Correlation may be expected between the large fire counts and installation size because this metric is a count of large fires whose perimeter is entirely contained within an installation's boundary. All else being equal, large fires are more likely to be transboundary fires, rather than entirely contained within the installation, at small installations than at larger installations. Although many installations with the smallest large fire counts were, indeed, some of the smaller installations, there was only moderate correlation between installation fire size and detected large fire counts wholly within the installation boundary amongst Air Force installations. We concluded that on-installation large fire counts were more than a proxy for installation size.

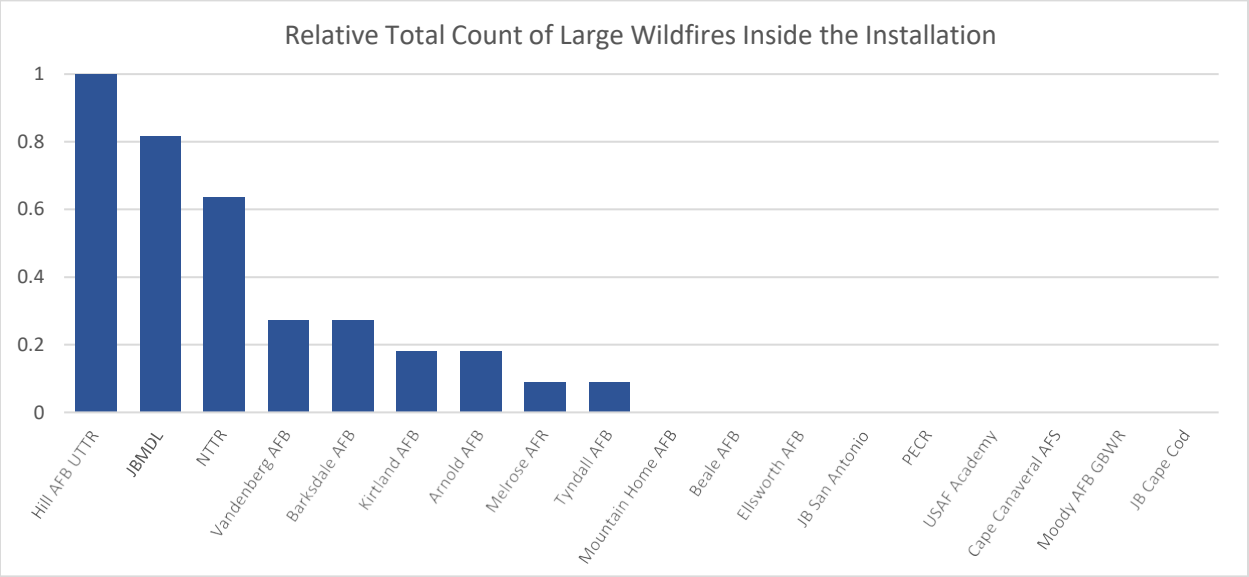


Figure 4. The relative total large fire (> 300 acres) count, across the entire study period, whose perimeters are entirely contained within the installation boundary 2004 – 2014. Data have been rescaled relative to the maximum detected count from Hill AFB/UTTR after removing the outlier installations from the calculation.

Vandenberg AFB had the highest PL (Figure 5). Although a high large fire proportion in conjunction with a small total count of wildfires does indicate the potential for significant fire growth, it can also be skewed by the small sample size of the total fire count. Both Vandenberg AFB and Arnold AFB, with the two highest PL metric values, each had only 3 fires over the 10 year study period. All of those at Vandenberg AFB and 2 of the 3 at Arnold were greater than 300 acres. Although potentially interesting, the results from only 3 fires should not be used to infer that future fires at Vandenberg AFB and Arnold AFB will also grow to over 300 acres. Generally, greater meaningfulness can be attributed to large fire proportions (high or low) that are derived from larger total counts of on-installation wildfires, such as at Hill AFB/UTTR or JBMDL.

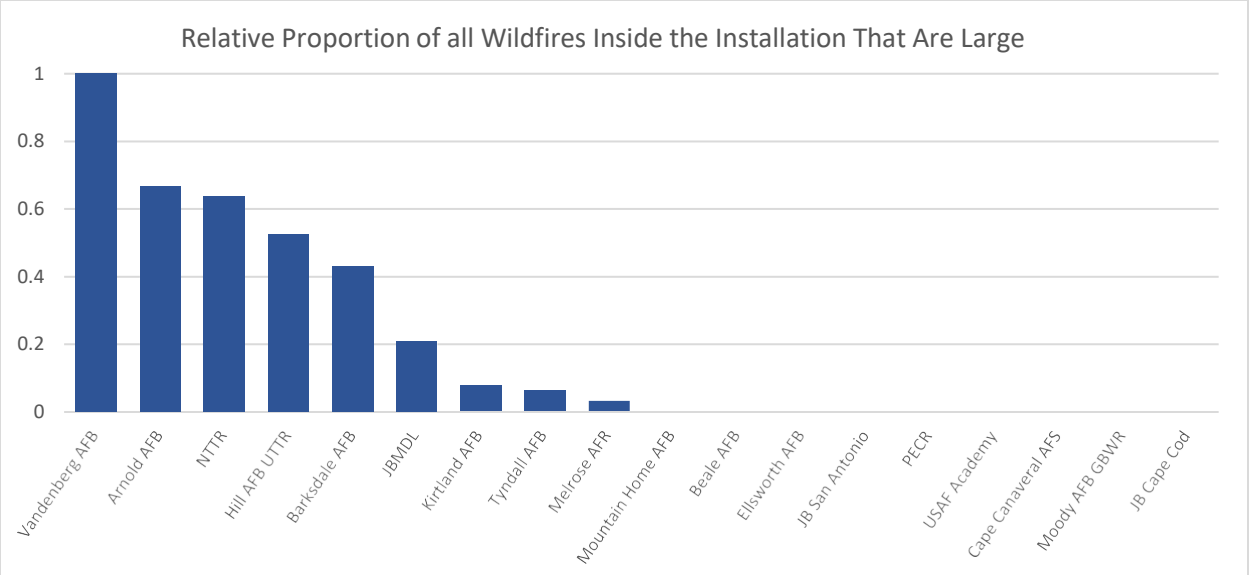


Figure 5. The relative proportion of detected wildfires whose perimeters are entirely contained within the installation boundary that were at least 300 acres 2004 – 2014. Data have been rescaled relative to the maximum proportion from Vandenberg AFB after removing the outlier installations from the calculation.

The highest TCC was at Tyndall AFB (Figure 6). In addition to Tyndall AFB, there were 4 other installations with high or moderate TCC, 8 installations with low values, and 5 installations with no on-installation fires detected within 0.5 miles of the boundary.

The long, skinny shape of Tyndall AFB plays a role in this result. Not including the barrier island, which is largely unburnable, the installation is only approximately 2.5 miles wide at its widest point. Therefore, a large proportion of the installation lies within 0.5 miles of the installation boundary. Further, as Tyndall is almost completely surrounded by water, there is little opportunity for a fire to burn off of the installation, largely eliminating the meaningfulness of this metric for that particular installation. None of the other installations ranked highly by this metric have that same issue.

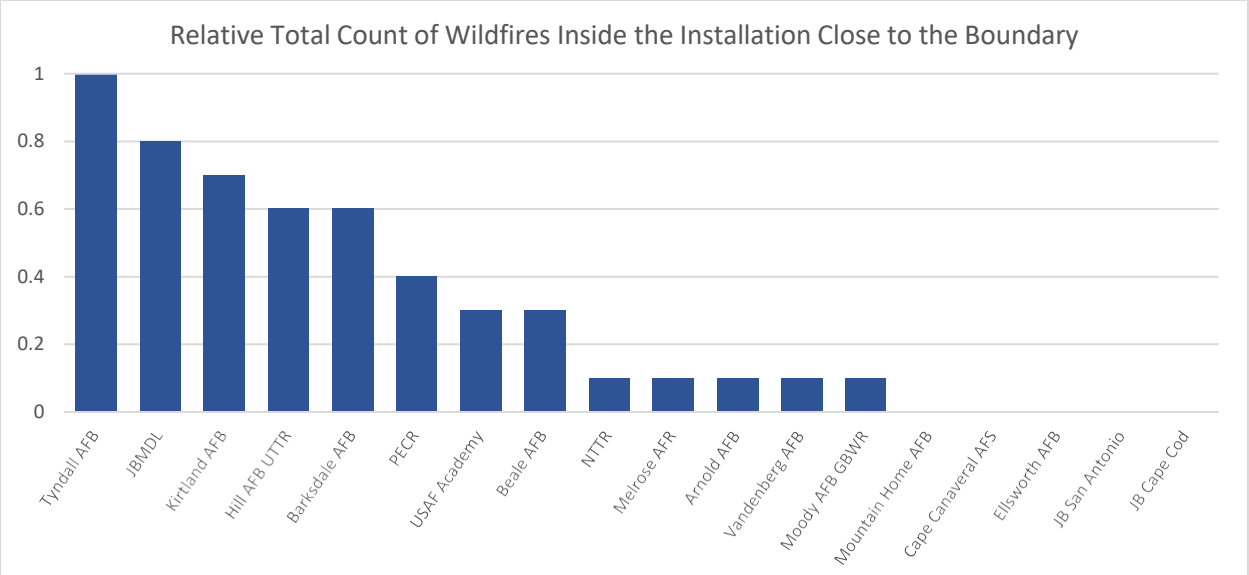


Figure 6. The relative total count of on-installation detected wildfires whose perimeters, while entirely contained within the installation boundary, extended within 0.5 mi of the installation boundary 2004 – 2014. These fires did not cross the installation boundary. Data have been rescaled relative to the maximum detected count from Tyndall AFB after removing the outlier installations from the calculation.

NTTR had the highest TCT, with Hill AFB/UTTR a close second (Figure 7). Only 6 other installations had any detected transboundary fires. All else being equal, smaller installations would be expected to have higher transboundary wildfire counts, as the likelihood of being close enough to the boundary to cross it increases as installation area decreases. However, there was little correlation between installation area and transboundary fire counts, implying that other factors were driving this metric, and making it more meaningful to this analysis.

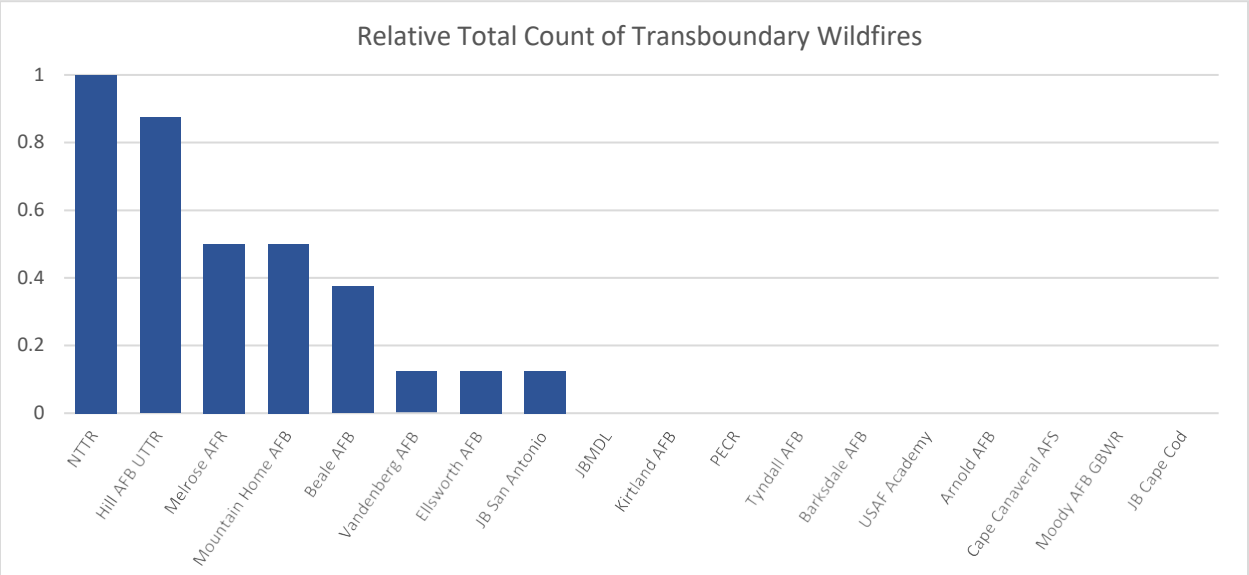


Figure 7. The relative total count of detected wildfires that extend across an installation's boundary 2004 – 2014. Data have been rescaled relative to the maximum detected count from NTTR after removing the outlier installations from the calculation.

The largest MS detected within any analysis area was at Ellsworth AFB (Figure 8). Of the 7 installations with the greatest median fire sizes, however, 4 had fewer than 10 fires detected in the analysis area over the study period, including Ellsworth AFB which had only one detected fire. Similar to the PL metric, the MS metric is more robust when calculated from a larger number of detected fires. This result makes it less reliable and makes it difficult to make conclusions about the likelihood of large fires occurring in the future. However, there were 20 or more fires detected at Mountain Home AFB, Hill AFB/UTTR, and NTTR, giving good confidence in those results.

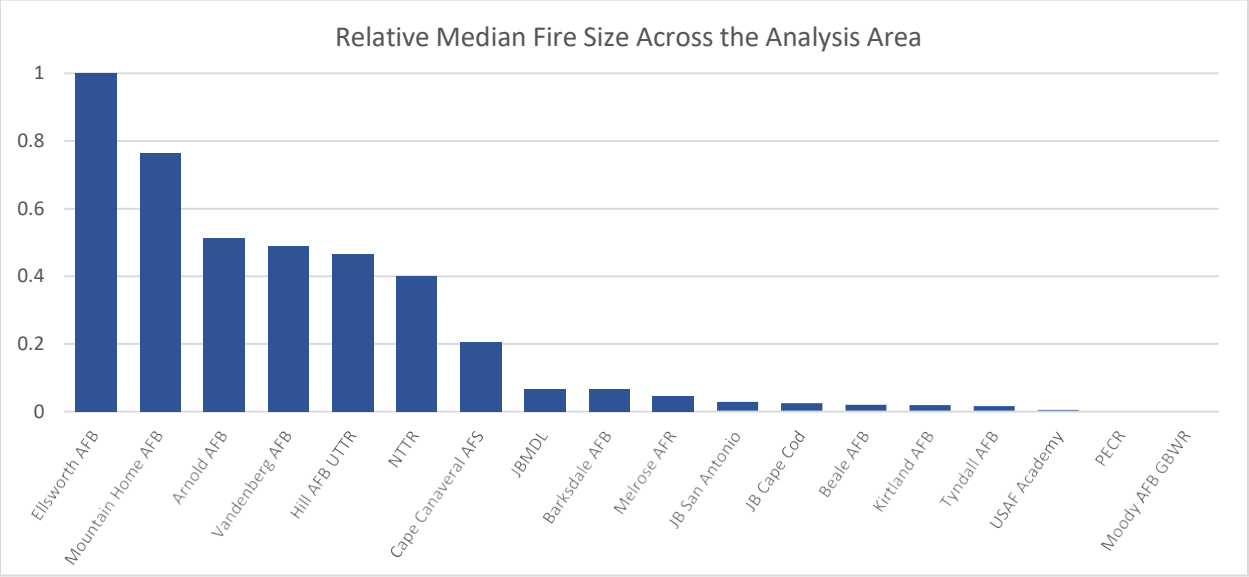


Figure 8. The relative median fire size of detected wildfires occurring anywhere in the analysis area 2004 – 2014. Data have been rescaled relative to the maximum detected median fire size from Ellsworth AFB after removing the outlier installations from the calculation.

The largest 90th PS was at Mountain Home AFB (Figure 9). High 90th PS values were also found at Hill AFB/UTTR and NTTR. Like the MS metric, the 90th PS metric is more robust when calculated from a larger number of detected fires in the analysis area. Here, more than 10 fires were detected within the analysis area at all of the top 5 installations.

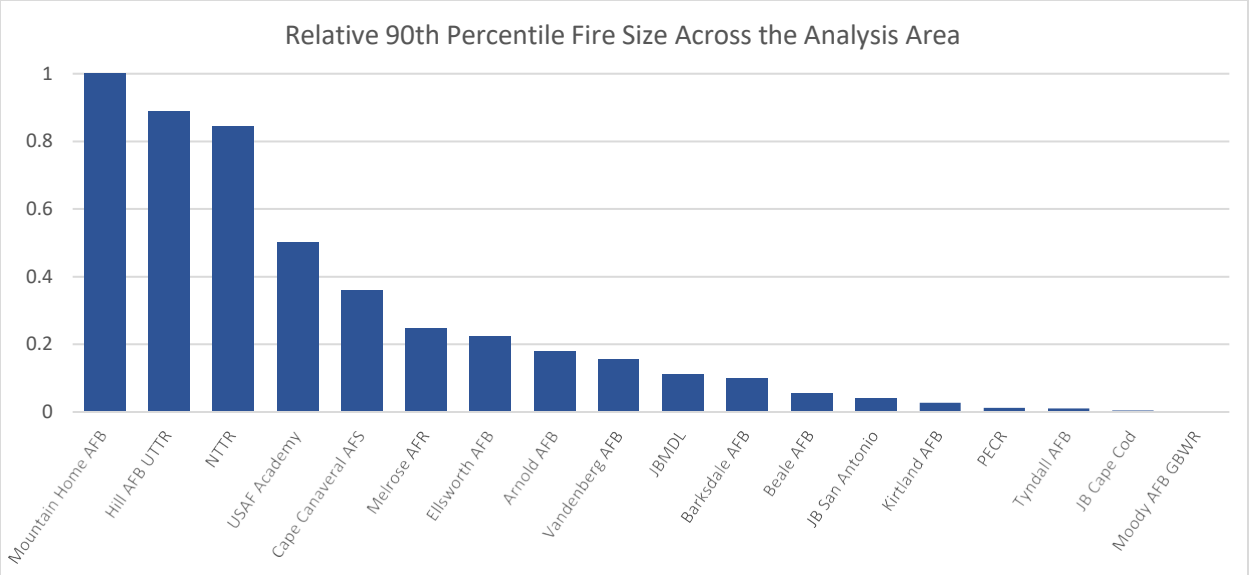


Figure 9. The relative 90th percentile fire size of detected wildfires occurring anywhere in the analysis area 2004 – 2014. Data have been rescaled relative to the maximum detected count from JBMDL after removing the outlier installations from the calculation.

The largest TA was found at Hill AFB/UTTR, followed closely by NTTR (Figure 10). The distribution showed a distinct separation between the total acreages of the upper 2, middle 2, and lower 14 installations. Although larger installations do have a greater potential capacity for total wildfire acreage than smaller installations, the relationship between installation size and total acreage is weak, indicating other factors were driving this metric, and substantiating its usefulness as an indicator of wildfire hazard.

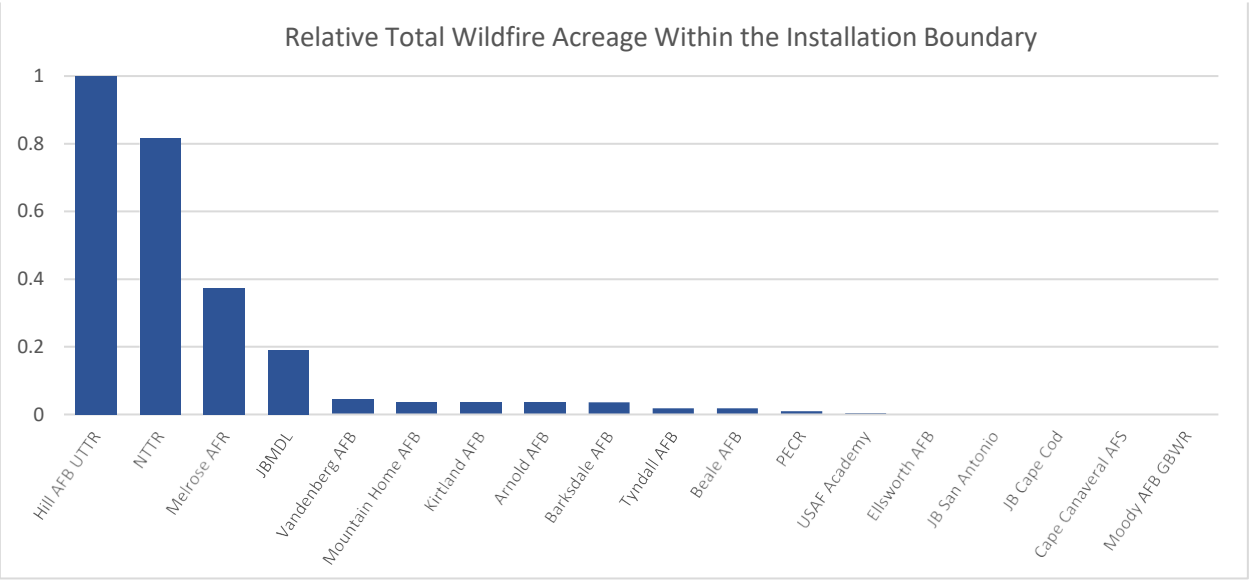


Figure 10. The relative total acreage of detected wildfires, or portions of detected wildfires, occurring on-installation 2004 – 2014. Data have been rescaled relative to the maximum detected count from JBMDL after removing the outlier installations from the calculation.

Melrose AFR had the largest PAB (Figure 11). Mountain Home AFB and JBMDL also had elevated proportions of their acreage burned in wildfires (55% and 51% of the Melrose AFR proportion respectively). The proportion of Hill AFB/UTTR that burned was considerably lower, at 23% relative to

Melrose AFB, though much of UTTR is unburnable salt flats and when considering that, the PAB for Hill AFB/UTTR is quite high. The PAB of the remaining 14 installations decreased gradually, but were all at the low end of the spectrum. There was no relationship between installation size and proportion burned.

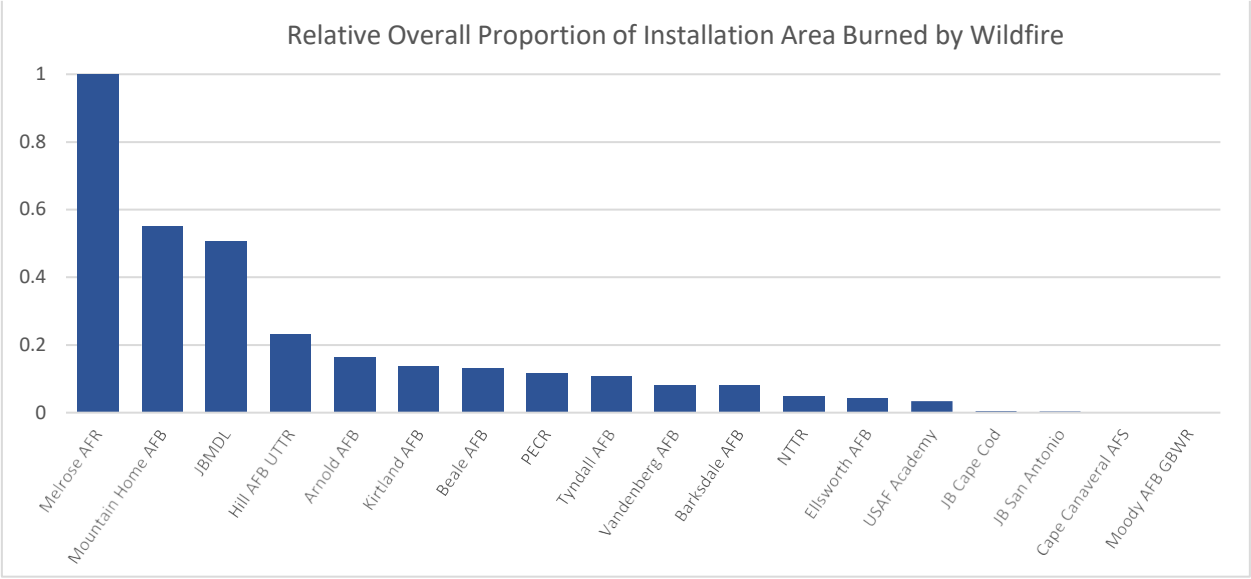


Figure 11. The relative unique acreage burned by wildfires, or portions of wildfires, occurring on-installation, normalized by that installation's area 2004 – 2014. Data have been rescaled relative to the maximum proportion from JBMDL after removing the outlier installations from the calculation.

INSTALLATION CLUSTERS

The above metrics characterize individual aspects of fire hazard for each installation, but making overall conclusions utilizing 10 separate characteristics across numerous installations is difficult. The results in Table 6 utilize the output from the K-mean clustering after Avon Park AFR, Barry M. Goldwater AFR, Dare County Bombing Range, Eglin AFB and Hurlburt AFB, and Saylor Creek Bombing Range were excluded due to their outlier values for one or more metrics. Each group contains installations that are more alike to each other than they are to installations in other groups. In addition to facilitating prioritization among installations, the groupings also identify installations that share common hazard characteristics.

The means of each group for each metric are shown in Table 7. The highest group mean was 0.938, Group G's TCT. At 0.908, Group G also had the second highest mean value for TA. Low group means also reflect a shared trait. For example, the Group A mean for TC was 0.000, indicating there were no fires detected within any of the installation boundaries in Group A. There were numerous zero values and near zero values, indicating installations where the metric was very unlikely to be detected.

For this analysis to be valid, the within-group variability must be considered when evaluating the significance of the differences among them. The Kruskal-Wallis post-hoc test found that all variables, except the 90th PS, provided statistically significant differentiation among clusters. Full results of pairwise tests for significance (Dunn's Test) are in Appendix A – Kruskal-Wallis and Dunn's Tests.

Table 6. Air Force installation groups formed by K-means clustering, after excluding the outlier installations which have high, outlier values for many metrics. Here, the outlier installations are identified in their own group.

Group ID	Installations
A	ELLSWORTH AFB
	MOUNTAIN HOME AFB
B	ARNOLD AFB
	VANDENBERG AFB
C	MELROSE AFR
D	JB SAN ANTONIO
	JB CAPE COD
	CAPE CANAVERAL AFS
	MOODY AFB GRAND BAY
	USAF ACADEMY
E	JB MCGUIRE DIX LAKEHURST
F	BARKSDALE AFB
	BEALE AFB
	TYNDALL AFB
	KIRTLAND AFB
	PECR
G	NTTR
	HILL AFB UTTR
Outliers	AVON PARK AFR*
	BARRY GOLDWATER AFR*
	DARE COUNTY BOMBING RANGE*
	EGLIN AFB HURLBURT AFB*
	SAYLOR CREEK BOMBING RANGE*

Table 7. Air Force group means for each wildfire hazard metric.

	A	B	C	D	E	F	G
Relative Total Count of All Wildfires Inside the Installation	0.000	0.070	0.721	0.051	1.000	0.381	0.372
Relative Median Count per Year of Wildfires Inside the Analysis Area	0.125	0.125	0.250	0.050	1.000	0.400	0.500
Relative Total Count of Large Wildfires Inside the Installation	0.000	0.227	0.091	0.000	0.818	0.109	0.818
Relative Proportion of all Wildfires Inside the Installation That Are Large	0.000	0.833	0.032	0.000	0.209	0.114	0.580
Relative Total Count of Wildfires Inside the Installation Close to the Boundary	0.000	0.100	0.100	0.080	0.800	0.600	0.350
Relative Total Count of Transboundary Wildfires	0.313	0.063	0.500	0.025	0.000	0.075	0.938
Relative Median Fire Size Across the Analysis Area	0.882	0.500	0.046	0.053	0.066	0.025	0.433
Relative 90th Percentile Fire Size Across the Analysis Area	0.612	0.167	0.245	0.181	0.110	0.041	0.866
Relative Total Wildfire Acreage Within the Installation Boundary	0.019	0.041	0.374	0.001	0.189	0.023	0.908
Relative Overall Proportion of Installation Area Burned by Wildfire	0.296	0.123	1.000	0.009	0.506	0.114	0.140

Although K-means clusters are often described using the group mean, the range of values within a group for each metric is also informative. The mean and distribution of each group's values for each metric are shown in Figure 12 –Figure 21. Categorized wildland fire hazard was assigned after evaluating these means and distributions for each group among the metrics.

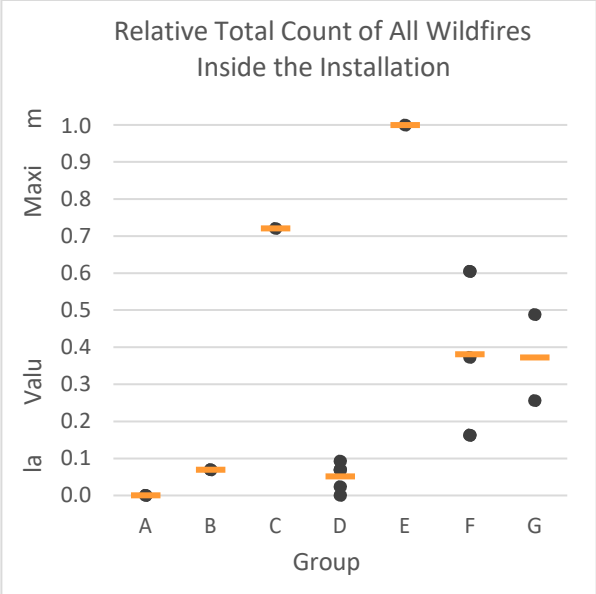


Figure 12. Clusters of the relative total count of detected wildfires whose perimeters are entirely contained within the installation boundary. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

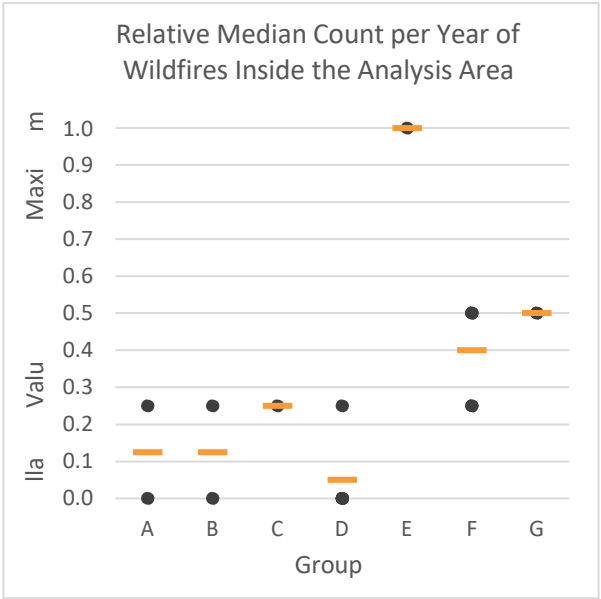


Figure 13. Clusters of the relative median count per year of detected wildfires within the analysis area. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

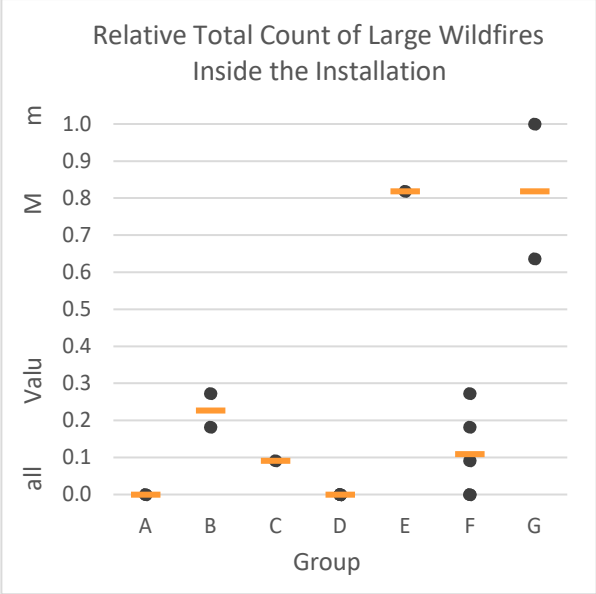


Figure 14. Clusters of the relative total large fire (>300 acres) count whose perimeters are entirely contained within the installation boundary. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

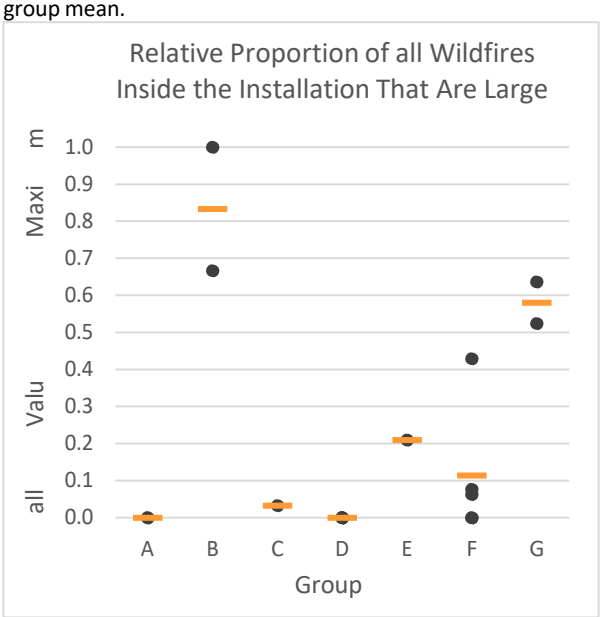


Figure 15. Clusters of the relative proportion of detected wildfires whose perimeters are entirely contained within the installation boundary that were at least 300 acres ("large"). Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

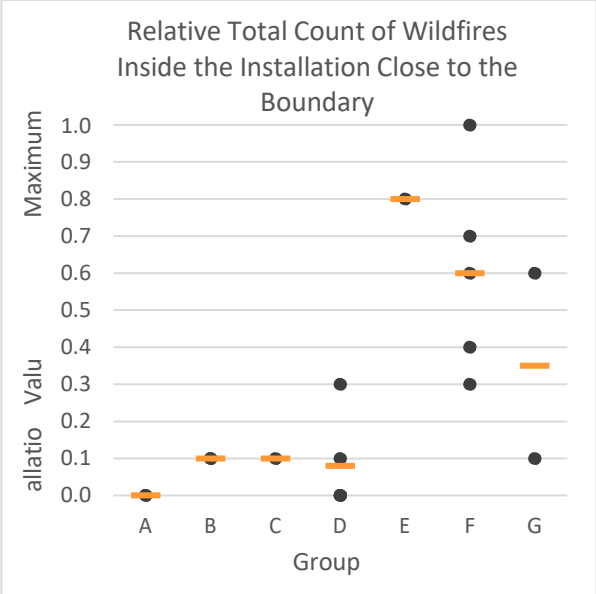


Figure 16. Clusters of the relative count of on-installation detected wildfires whose perimeters, while entirely contained within the installation boundary, extended within ate least 0.5 mi of the installation boundary. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

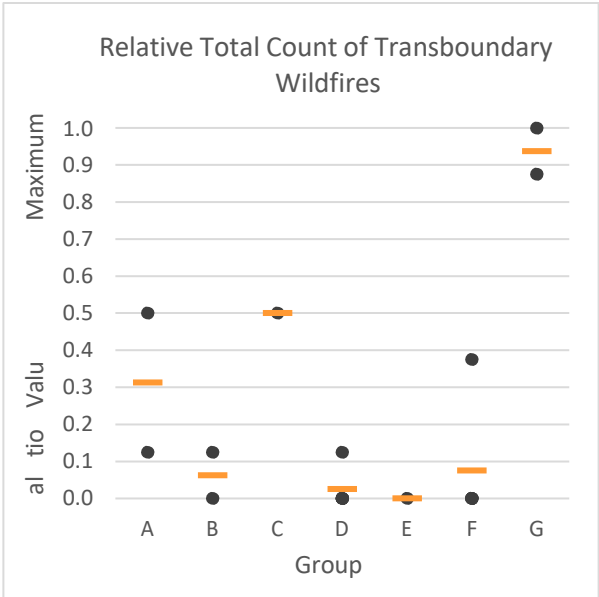


Figure 17. Clusters of the relative total count of detected wildfires that extend across an installation's boundary. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

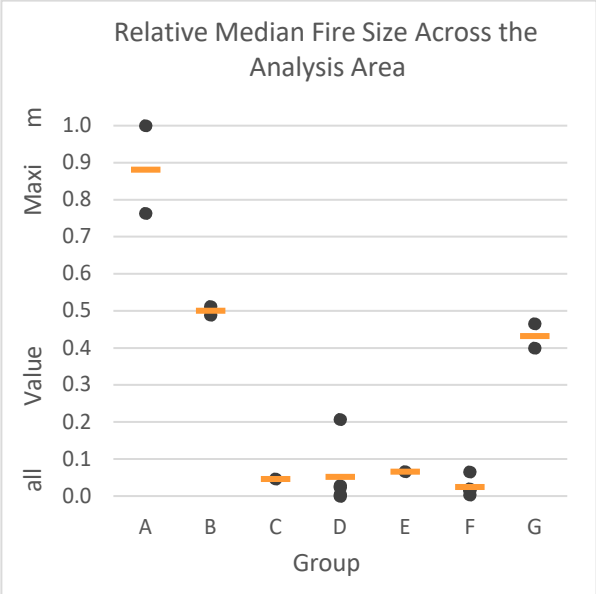


Figure 18. Clusters of the relative median fire size of detected wildfires occurring anywhere in the analysis area (on-installation and/or within the surrounding 5-mile buffer). Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

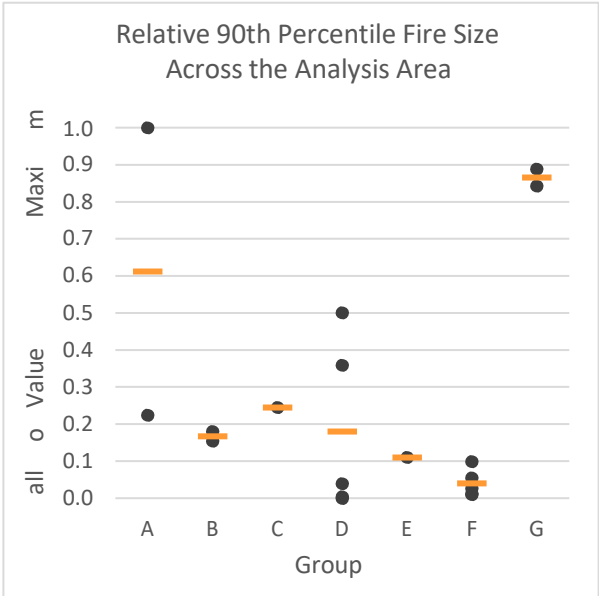


Figure 19. Clusters of he relative 90th percentile of detected wildfires occurring anywhere in the analysis area. This metric was not found to be a significant differentiator among clusters by the Kruskal-Wallis test. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

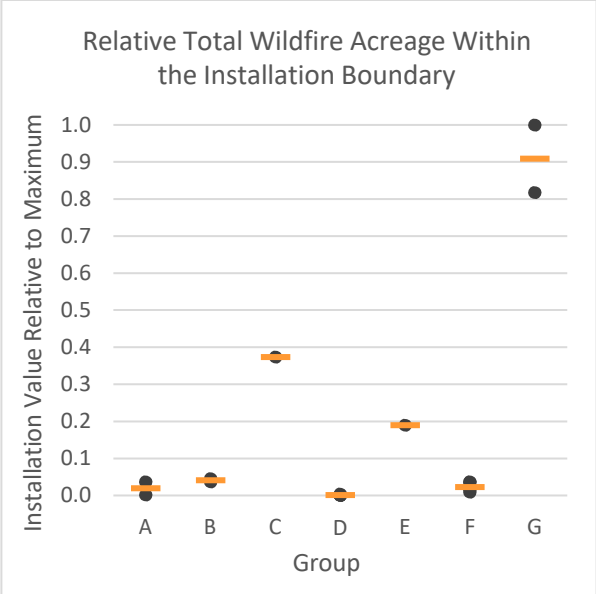


Figure 20. Clusters of the relative total acreage, across the entire study period, of detected wildfires, or portions of detected wildfires, occurring on-installation. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

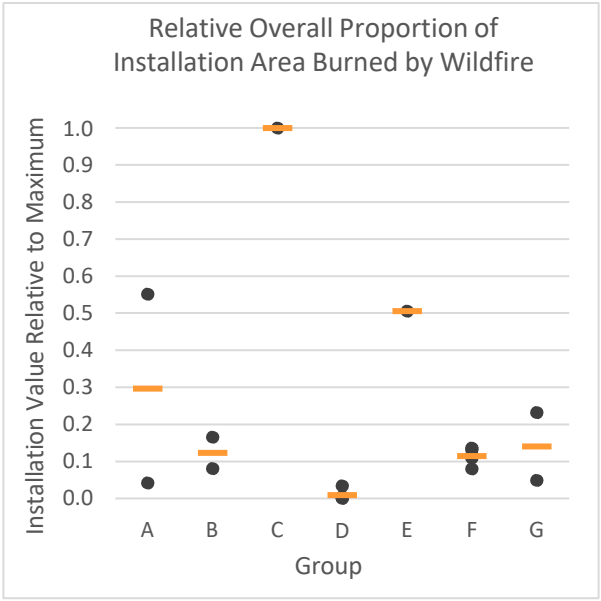


Figure 21. Clusters of the relative unique acreage, across the entire study period, of detected wildfires, or portions of wildfires, occurring on-installation, normalized by that installation's area. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

INITIAL CATEGORIZATION BY CLUSTER

Triaging the installations included considering each group's distribution across the metrics as shown in the figures above. These measures highlighted the likenesses and differences among them, and informed the final categorization of each group. The 90th PS was not a statically significant metric for differentiation among Air Force clusters, so this metric were not considered when assigning installations to fire hazard categories.

Group A tended to have moderate values for TCT and high values for MS. However, the MS metric results should be considered in light of the low to moderate TC and TCT, as well as the relatively low TA, which indicates most of the transboundary fire acreage is occurring off-installation. Ellsworth AFB in particular had very low TC results. There was greater variability between sites in PAB, and even though Mountain Home is approximately twice the size of Ellsworth AFB, its PAB was over 11 times that of Ellsworth AFB. All other metrics were consistently very low. Because of a limited number of elevated metrics, the overall initial wildland fire hazard categorization of Group A was moderate.

Similarly, metrics for Group B tended to be low to moderate and included values that were low to very low. The cluster had high PL, but the low TC results indicate that, though large fires occur, the overall probability of a fire is low. Nonetheless, the TCL was elevated over other groups, and is not subject to interpretation in light of other values. The MS was also elevated substantially relative to other groups. The multiple metrics with at least somewhat elevated values warranted a categorization for the group as moderate.

Group C consisted of just one installation with multiple elevated metrics (MC, TCT, and TA) as well as a high value for TC and the highest PAB of any installation (excluding the outlier installations). This group experienced numerous fires that together burned much of the installation over the study period. Those fires summed to a moderate total acreage with low individual fire sizes. Additionally, even for having

relatively low numbers of large fires, the transboundary count was moderate. Based on these considerations, Group C was categorized as facing a high wildland fire hazard.

Mean values for Group D were uniformly very low to low across all metrics, though there were individual installations within the group that scored moderate values for TC, TCC, and MC. Overall, though, this group exhibited muted fire potential. Thus, the overall wildland fire hazard categorization of Group D was low.

Group E, like Group C, also consisted of just one installation. This group had the highest TC, and MC, as well as a very high value for the TCL. Numerous other metrics were solidly moderate. Notable for this group is the high value for TCC, indicating that although fires have not historically crossed the installation boundary, that potential certainly exists given the large number of fires, their size, and their proximity to the boundary. Additionally, although the PAB was moderate relative to the maximum, this group's mean was the second highest among all groups. Although other metrics, such as the MS, were low to moderate, the multiple highly elevated metrics indicated a high wildfire hazard for Group E.

Group F included moderate values for the TC and MC, and moderate to high values for the TCC. Several other metrics ranged from low to moderate. The numerous on-installation fires experienced by Group F were offset by the small relative fire sizes and, unlike Group C, the TA and PAB remained low. Based on these observations, Group F was categorized as facing a moderate wildfire hazard.

Measures for Group G were elevated for almost every metric. This included maximum observed values, excluding outlier installations, for TCC, TCT, and TA. Although the MC was moderate, it was still the second highest among groups. The TCC was moderate, but when considered in the context of the very high mean for TCT, it indicates a strong tendency among the group for potential problems with transboundary fires. Although the PAB is fairly low, this reflects the very large size of these installations, one of which is nearly one million acres and the other nearly three million acres, not a lack of wildfire. Indeed, the total acreage burned for this group was the highest of any group (data not shown), and the MS was moderate. Based on the multiple high and very high metrics, Group G deserved a high categorization.

CATEGORIZATION REVISIONS

Within each initial group, installations were determined by the algorithm to be more similar to each other than to other installations. However, as shown in Figure 12 –Figure 21, some groups had high within-group variability for some metrics. Because of this within group variability, each installation was reviewed against its group's initial categorization, and adjusted if that classification was not justified by these data and expert opinion.

Upon review, only one installation changed categorization from that of their original group. Ellsworth AFB was originally placed into Group A, which was categorized as moderate fire hazard. However, the very high MS was based on a sample of relatively few wildfires in the analysis area, and, as previously discussed, is therefore suspect. Unlike Mountain Home AFB (the other installation in the Group A), Ellsworth AFB did not have other elevated values that would justify a moderate categorization. It was, therefore, re-categorized as low.

OUTLIER INSTALLATIONS

Five installations with outlier values for one or more metric were removed from the cluster analysis and evaluated independently. These installations are discussed below, in alphabetical order.

The highest TC, MC, and TCC were all found at Avon Park, and were all statistical outliers, resulting in classification of Avon Park as an outlier, while also demonstrating the high wildfire hazard potential there. Avon Park also had the highest TCL and very high TA and PAB. These results clearly warrant a wildfire hazard categorization of high.

The Barry M Goldwater AFR had values for the 90th PS metric high enough to be classified as a statistical outlier. The TA and TCL were also both greater than any non-outlier installation, and the TC was one of the highest of any non-outlier installation. Other metrics were primarily moderate with only two metrics being low. Notably, 89% of the fires and 98% of the acreage occurred in just one year, an unusually high precipitation year that produced a historic flush of vegetation in parts of the desert southwest where vegetation is normally too sparse to carry fire. This is a well-known outlier year for fire activity in the southwest. Removing this one year of data drastically reduced the values of almost all metrics. Thus, we categorized BMG AFR as moderate.

Dare County Bombing Range also had a range of low, moderate, and extreme metric values. The 90th PS and the PAB were both outliers from the overall Air Force dataset, and second only to Saylor Creek Bombing Range. The TA, MS, and PL were all moderate even when compared only to non-outlier installations. The remaining metrics were low when comparing to non-outlier installations. Based on these considerations, Dare County Bombing Range was categorized as moderate.

Eglin/Hurlburt AFB had a wide range of values with few moderate metrics. Values for the TC, MC, and TCC were all outliers. TA was higher than any non-outlier installation and TCL was second only to Avon Park, though the PL was relatively low due to the large number of fires overall. Other metrics were also low, but the very high numbers of fires and large total acreage warrant categorization as high.

Saylor Creek Bombing Range had the highest overall values for TCT, 90th PS, and PAB, it also had the second highest value for TA. Saylor Creek Bombing Range also had a high MC, TCL, and MS when compared to the non-outlier installations. The remaining metrics were moderate or low relative to the non-outlier installations. The high values for so many metrics clearly marked Saylor Creek Bombing Range as facing a high wildfire hazard.

CATEGORIZATION AND DISCUSSION

The wildfire hazard categorization of each installation, as determined by this analysis, is shown in Table 8. These categorizations reflect the aggregation of the 10 metrics characterizing aspects of wildfires and the adjustments made due to subject matter expert input. This analysis identified 7 Air Force installations as having a high wildland fire hazard, 10 as moderate, 6 as low, and 14 as negligible.

The installations categorized as high had high and/or outlier values for numerous metrics, whereas the moderate installations tended to have elevated values for fewer metrics, but low values for others. The installations categorized as low had few, if any, elevated metrics; none of the low installations had any metric with a relative value of more than 25% of the non-outlier maximum for that metric.

Fourteen installations had zero fires detected anywhere in the analysis area, and at an additional 3 installations, fires were only detected in the 5-mile buffer surrounding the installation. These installations were categorized as negligible.

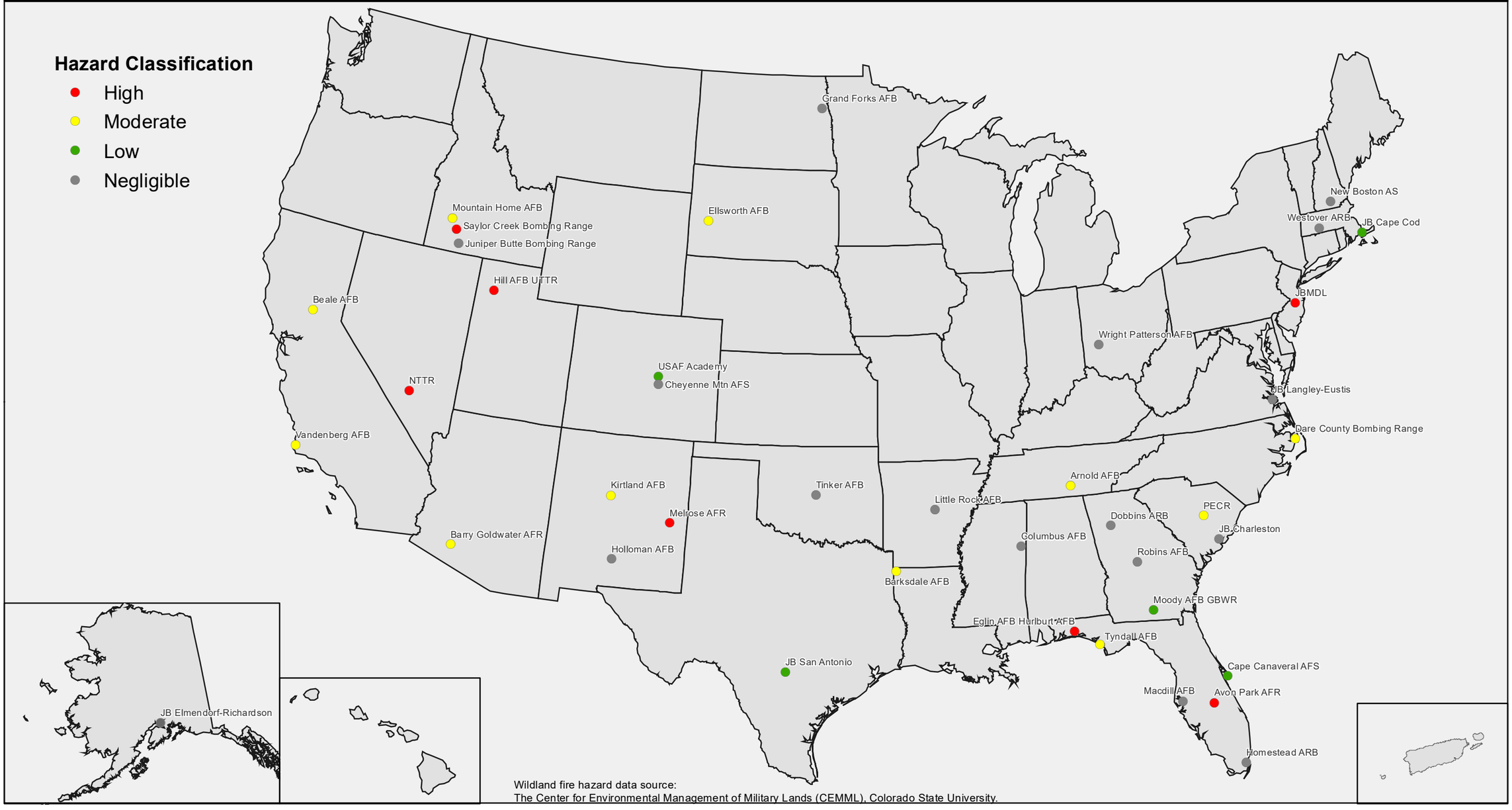
Table 8. Air Force installation wildfire hazard categorization. No fires were detected wholly or partially within any installation in the negligible category. Outlier installations are marked with an asterisk.

HIGH	MODERATE	LOW	NEGLIGIBLE
AVON PARK AFR*	ARNOLD AFB	CAPE CANAVERAL AFS	CHEYENNE MTN AFS
EGLIN AFB HURLBURT AFB*	BARKSDALE AFB	ELLSWORTH AFB	COLUMBUS AFB
HILL AFB UTTR	BARRY GOLDWATER AFR*	JB CAPE COD	DOBBINS ARB
JB MCGUIRE DIX LAKEHURST	BEALE AFB	JB SAN ANTONIO	GRAND FORKS AFB
MELROSE AFR	DARE COUNTY BOMBING RANGE*	MOODY AFB GRAND BAY	HOLLOMAN AFB
NTTR	KIRTLAND AFB	USAF ACADEMY	HOMESTEAD ARB
SAYLOR CREEK BOMBING RANGE*	MOUNTAIN HOME AFB		JB CHARLESTON
	PECR		JB ELMENDORF RICHARDSON
	TYNDALL AFB		JB LANGLEY FORT EUSTIS
	VANDENBERG AFB		JUNIPER BUTTE BOMBING RANGE
			LITTLE ROCK AFB
			MACDILL AFB
			NEW BOSTON AS
			ROBINS AFB
			TINKER AFB
			WESTOVER ARB
			WRIGHT PATTERSON AFB

Air Force

Wildfire Hazard Classification

Figure 22



Wildland fire hazard data source:
The Center for Environmental Management of Military Lands (CEMML), Colorado State University.

Army Results

FIRE DETECTIONS

Fifty-four Army installations were included in this analysis. An initial pass through the data revealed 13 installations with no detected fires occurring anywhere inside the installation or within the 5-mile buffer, and an additional 6 installations where fires were detected within the 5-mile buffer but not inside the installation boundary. We categorized these installations as having negligible wildfire hazard within the scope of this analysis and removed them from further comparative analyses.

The 13 installations with no wildfires detected anywhere (on-installation or within the buffer) over the entire study period are shown in Table 9. Also shown are the 6 installations whose detected fires only occurred wholly outside the installation boundary but within the 5-mile buffer, and the remaining 35 installations with at least one wildfire detected on-installation. While it is possible that some wildfires do occur on or near installations at which no fires were detected, again, this study's purpose is not a full accounting of all fires, but an analysis of comparable data across all installations that reasonably represents wildfire hazard.

Two installations were identified as outliers and are indicated with asterisks in Table 9. These were removed from the cluster analysis and evaluated independently per the methodology of this study.

Table 9. List of Army installations where fires were detected, were only detected wholly outside the installation boundary, or were not detected at all during the study period 2005 - 2014. Outliers are marked with an asterisk.

At Least One Fire Detected On Post	No Fires Detected On Post, at Least One Fire Detected Off Post in Analysis Area	No Fires Detected Anywhere in Analysis Area
Aberdeen Proving Ground (APG)	Fort Buchanan	Adelphi
Camp Mackall	Fort Detrick	Carlisle Barracks
Camp Parks	Fort Leavenworth	Detroit Arsenal
Dugway Proving Ground (DPG)	Fort Meade	Fort Belvoir
Fort A.P. Hill	Sharpe Army Depot	Fort Greeley
Fort Benning*	West Point	Fort Hamilton
Fort Bliss		Fort Lee
Fort Bragg		Fort Myer McNair
Fort Campbell		Natick
Fort Carson		Picatinny Arsenal
Fort Devens		Presidio of Monterey
Fort Drum		Rock Island Arsenal
Fort Gordon		USAG Miami
Fort Hood		
Fort Huachuca		
Fort Hunter Liggett		
Fort Irwin		
Fort Jackson		
Fort Knox		
Fort Leonard Wood		
Fort McCoy		
Fort Polk		
Fort Riley		
Fort Rucker		
Fort Sill		
Fort Stewart		
Fort Wainwright*		
JB Lewis-McChord (JBLM)		
Pinon Canyon Maneuver Site (PCMS)		
Redstone Arsenal		
USAG Hawaii Pohakuloa Training Area (PTA)		
USAG Hawaii Schofield Barracks West and East Ranges (SBMR)		
White Sands Missile Range		
Yakima Training Center		
Yuma Proving Ground		

FIRE HAZARD METRICS

The figures below show the rescaled values for each metric listed in Table 2. These are the scaled values excluding Fort Benning and Fort Wainwright which were identified as outlier installations.

The greatest TC was found at YTC, Fort Bliss, and Fort Bragg. The next 12 installations all have TC metrics of 42 to 56% of YTC. There is a notable drop in the TC between the upper 15 installations and the lower 18. All the installations above this break in the data experience a moderate to large numbers of wildfires every year. The bottom 10 installations all have a TC of less than 10% that of YTC.

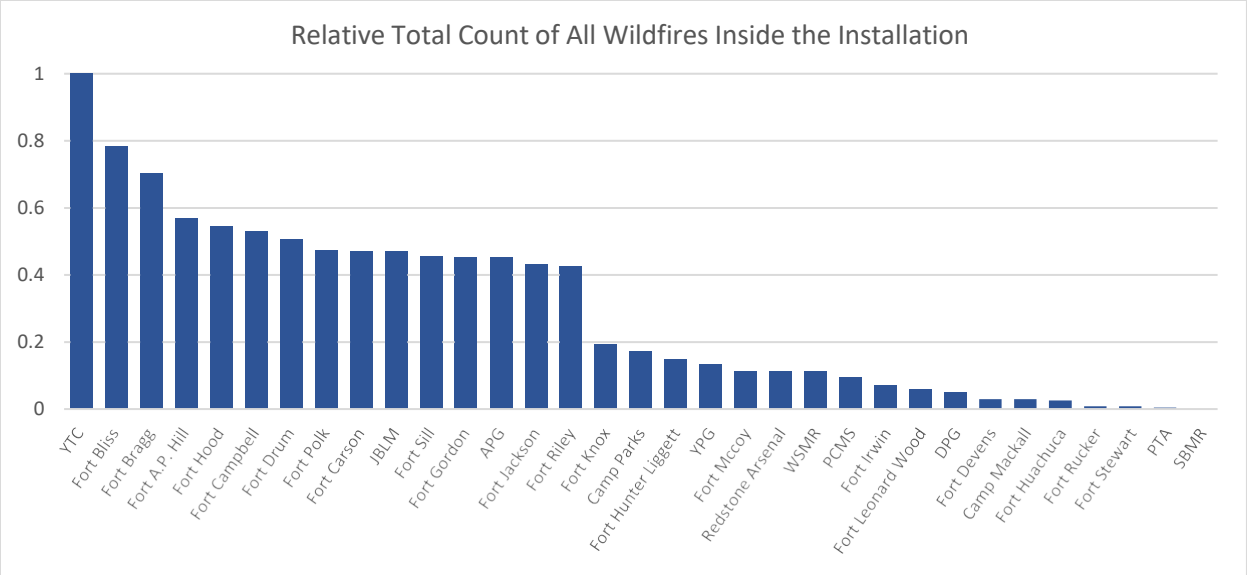


Figure 23. The relative total count, across the entire study period, of detected wildfires whose perimeters are entirely contained within the installation boundary 2005 – 2014. Data have been rescaled relative to the maximum detected count from YTC after removing the outlier installations from the calculation.

The highest median fire count was at Fort Bragg (Figure 24). The next 11 installations had between 49% and 76% of Fort Bragg's median count. Here there is a small but notable drop, after which another 7 installations had between 22% and 39% of Fort Bragg's median count. There were 7 installations whose median count of detected fires within the analysis area was 0, indicating that more often than not, those installations and their surrounds would not experience a wildfire.

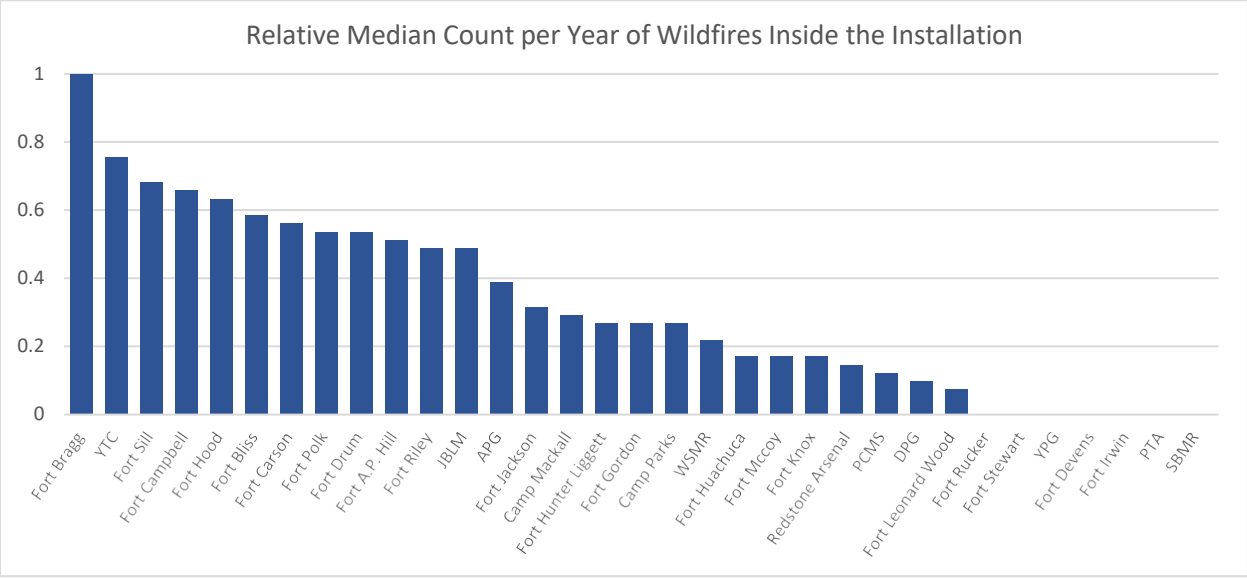


Figure 24. The relative median count per year of detected wildfires within the analysis area 2005 – 2014. Data have been rescaled relative to the maximum detected median count from Fort Bragg after removing the outlier installations from the calculation.

The highest TCL was at Fort Sill, Fort Bragg, Fort Polk, and Fort Hood (Figure 25). There are several distinct separations in the data. The first is between Fort Hood and YTC, a second between Fort Bliss and Fort Riley, and a third between PCMS and Fort Gordon.

Correlation may be expected between the large fire counts and installation size because this metric is a count of large fires whose perimeter is entirely contained within an installation's boundary. All else being equal, large fires are more likely to be transboundary fires, rather than entirely contained within the installation, at small installations than at larger installations. Although many of installations with the smallest large fire counts were, indeed, some of the smaller installations, Dugway Proving Ground, Fort Irwin, and Fort Stewart all had some of the lowest large fire counts yet are some of the largest installations. There was only moderate correlation between installation fire size and detected large fire counts wholly within the installation boundary. Thus, we concluded that on-installation large fire counts are more than a proxy for installation size.

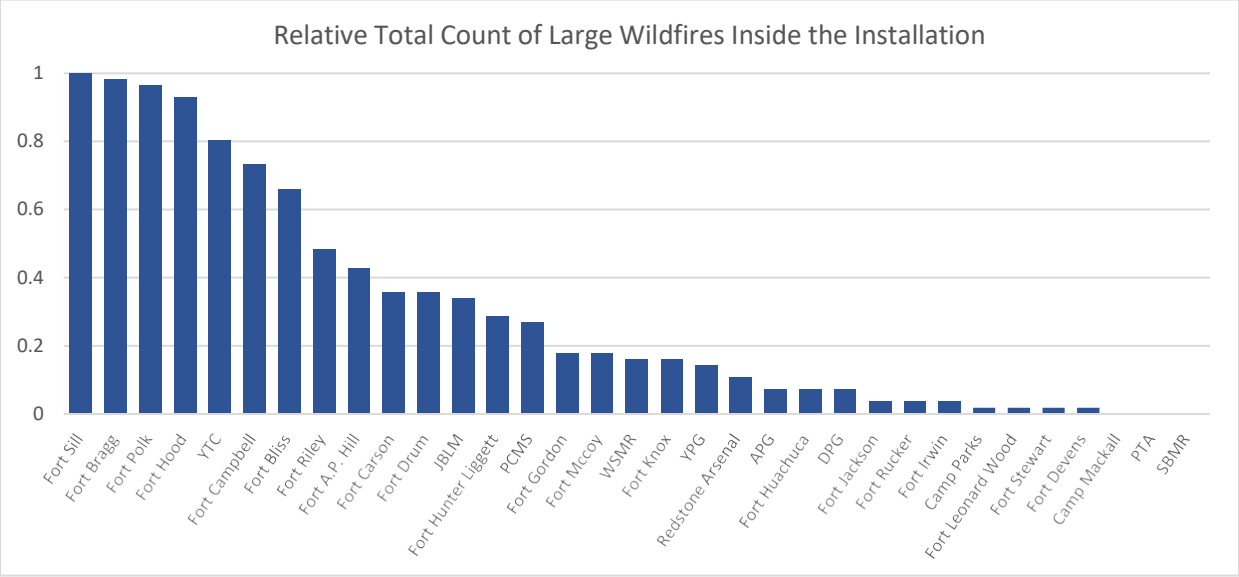


Figure 25. The relative total large fire (> 300 acres) count, across the entire study period, whose perimeters are entirely contained within the installation boundary 2005 – 2014. Data have been rescaled relative to the maximum detected count from Fort Sill after removing the outlier installations from the calculation.

Fort Rucker had the largest PL (Figure 26). Although a high large fire proportion in conjunction with a small total count of wildfires does indicate the potential for significant fire growth, it can also be skewed by the small sample size of the total fire count. Fort Rucker, with the largest relative proportion, was also one of the lowest installations in the TC metric, with only two fires detected over the 10-year study period used for Army installations. Both detected fires were greater than 300 acres. Although potentially interesting, the results from only 2 fires should not be used to infer that future fires at Fort Rucker will also grow to over 300 acres. Generally, greater meaningfulness can be attributed to large fire proportions (high or low) that are derived from larger total counts of on-installation wildfires. These would be installations with a high TC.

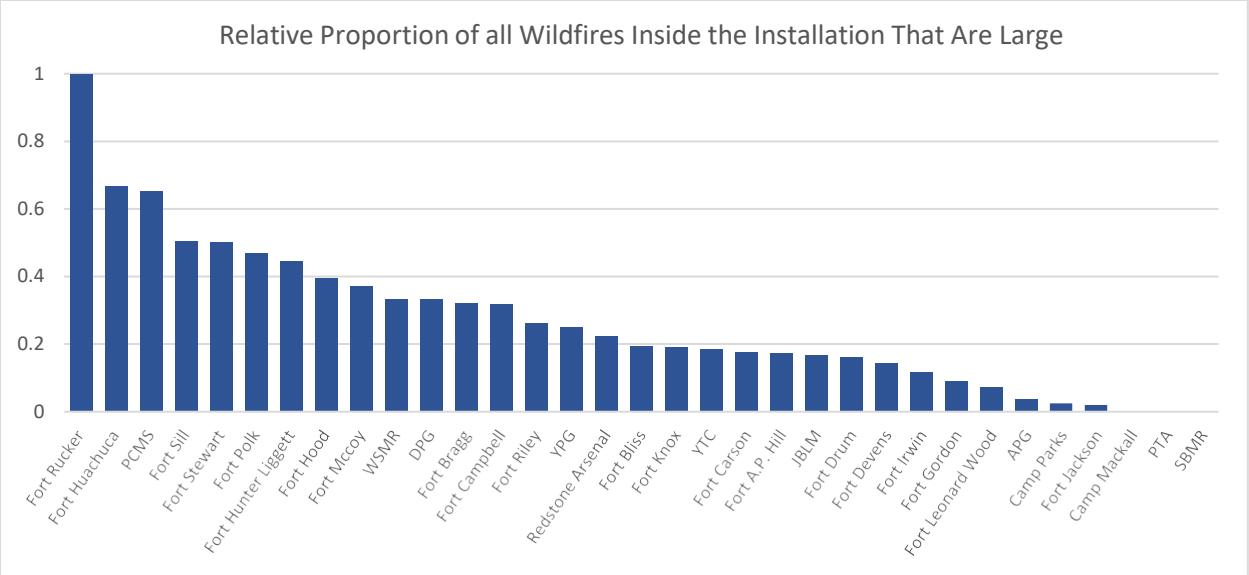


Figure 26. The relative proportion of detected wildfires whose perimeters are entirely contained within the installation boundary that were at least 300 acres 2005 – 2014. Data have been rescaled relative to the maximum proportion from Fort Rucker after removing the outlier installations from the calculation

The highest TCC was at Fort A.P. Hill (Figure 27). There were an additional 6 other installations with a TCC of at least 50% that of A.P. Hill. There was a break in the data between Fort Sill and Fort Carson, with a drop of 13% and another between Fort Carson and Fort Campbell of 11%. Eight installations had a TCC of zero. This metric does not include fires that actually cross the boundary, but installations with high values show the potential for future transboundary fires.

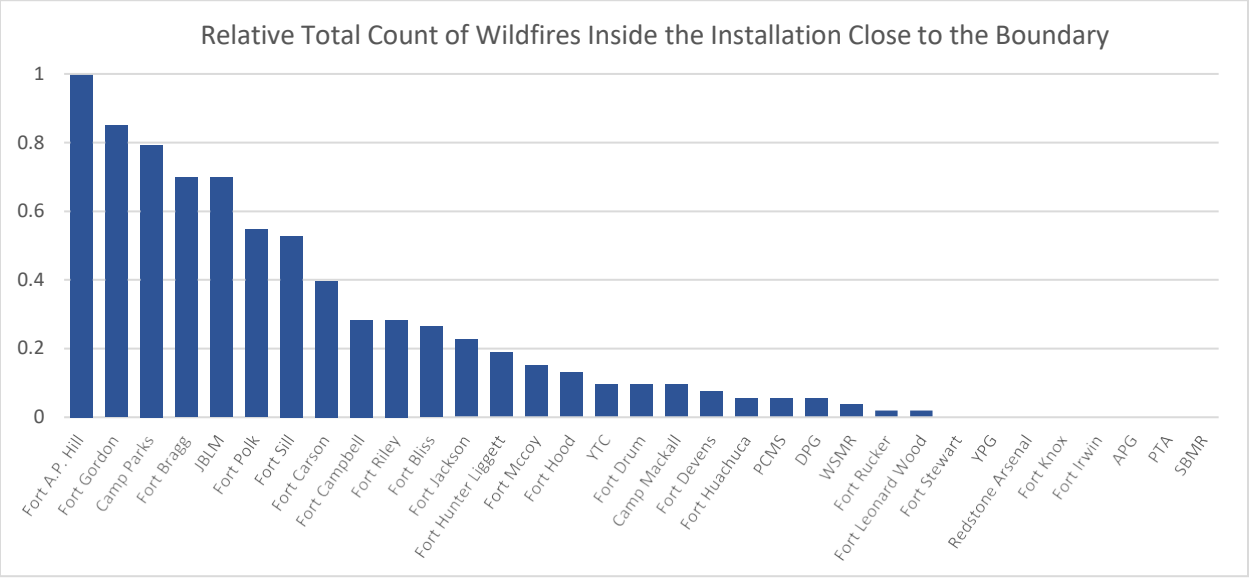


Figure 27. The relative total count of on-installation detected wildfires whose perimeters, while entirely contained within the installation boundary, extended within 0.5 mi of the installation boundary 2005 – 2014. These fires did not cross the installation boundary. Data have been rescaled relative to the maximum detected count from Fort A.P. Hill after removing the outlier installations from the calculation.

Fort Bliss, Pinyon Canyon Maneuver Site, and Dugway Proving Ground had equally high maximum detected transboundary wildfire counts (Figure 28). Fort Hunter Liggett also had a high transboundary count. No transboundary fires were detected at 14 installations. All else being equal, smaller installations

would be expected to have higher transboundary wildfire counts, as the likelihood of being close enough to the boundary to cross it increases as installation area decreases. However, there is little correlation between installation area and transboundary fire counts, implying that other factors are driving this metric, and making it more meaningful to this analysis.

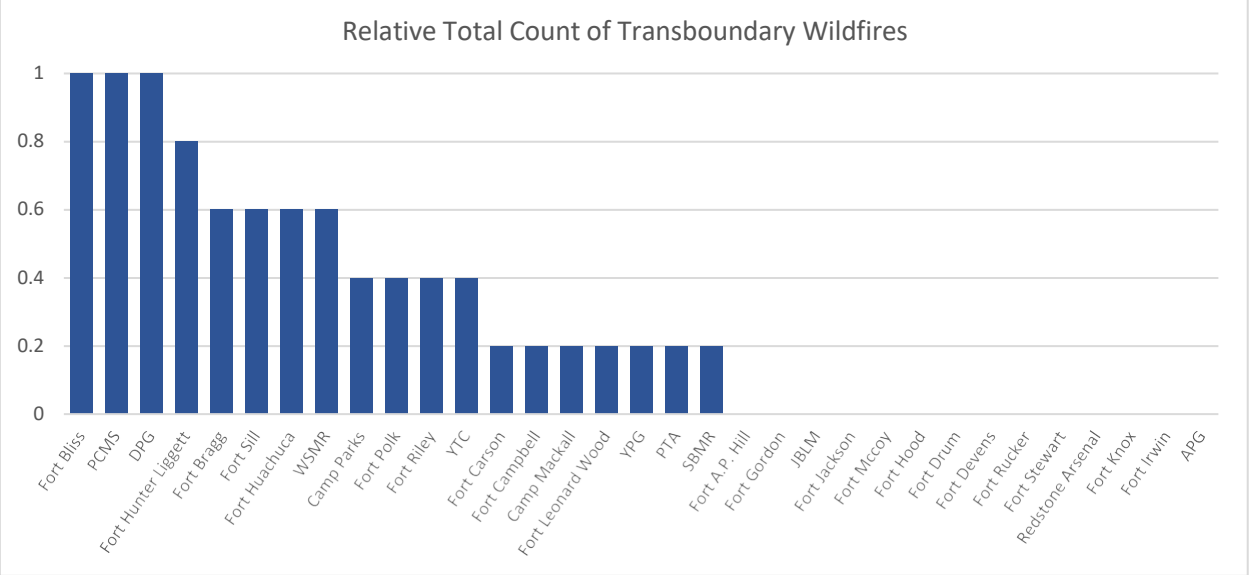


Figure 28. The relative total count of detected wildfires that extend across an installation's boundary 2005 – 2014. Data have been rescaled relative to the maximum detected count from Fort Bliss/PCMS/DPG after removing the outlier installations from the calculation.

The largest MS was at USAG Hawaii Pohakuloa Training Area (PTA) (Figure 8). However, there were only 5 fires detected in the PTA analysis area. The large median size does capture the potential for large fires at PTA, but with such a small sample, the true likelihood of fires there to be larger than fires at other installations is probably overestimated. Of the 10 installations with the greatest median fire sizes, 4 had fewer than 10 fires detected in the analysis area over the study period. Similar to the large fire proportion, the median fire size metric is more robust when calculated from a larger number of detected fires in the analysis area.

Disregarding installations with small sample sizes, the largest median fire sizes were at Fort Stewart, PCMS, and Fort Huachuca.

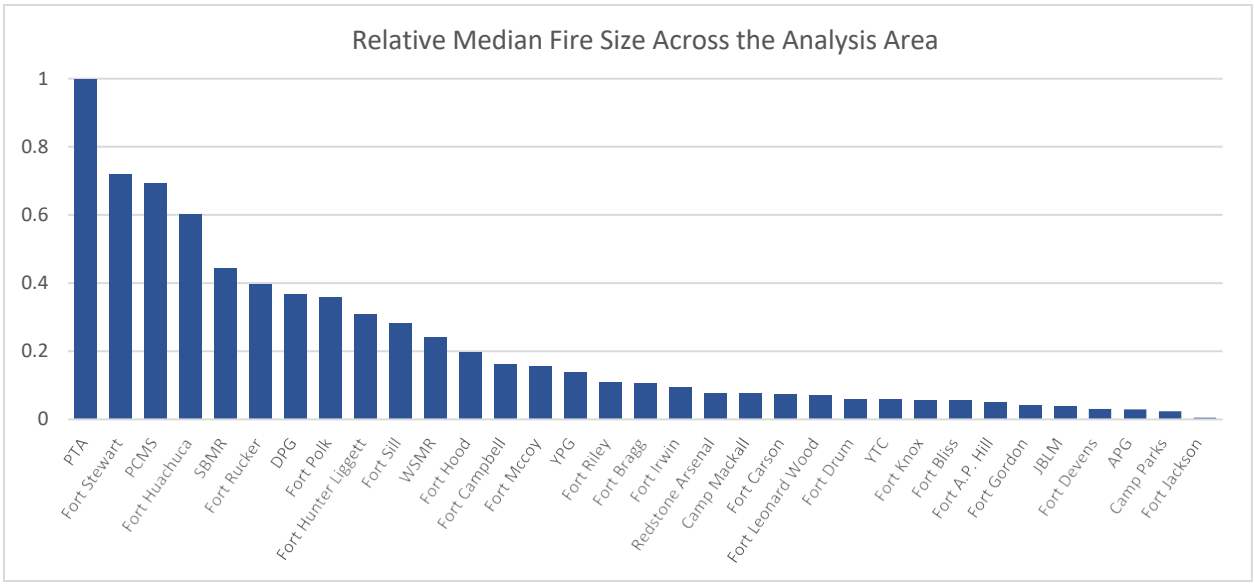


Figure 29. The relative median fire size of detected wildfires occurring anywhere in the analysis area 2005 - 2014. Data have been rescaled relative to the maximum detected median fire size from PTA after removing the outlier installations from the calculation.

The largest 90th percentile wildfire size was at DPG, which was nearly four times larger than the next installation, Fort Hunter Liggett (Figure 30). Despite this much larger result, DPG was not a statistical outlier for this metric. Like the median fire size metric, the 90th percentile wildfire size is more robust when calculated from a larger number of detected fires in the analysis area. Here, only two of the 10 installations with the largest 90th percentile wildfire sizes had fewer than 10 detected wildfires within the analysis area.

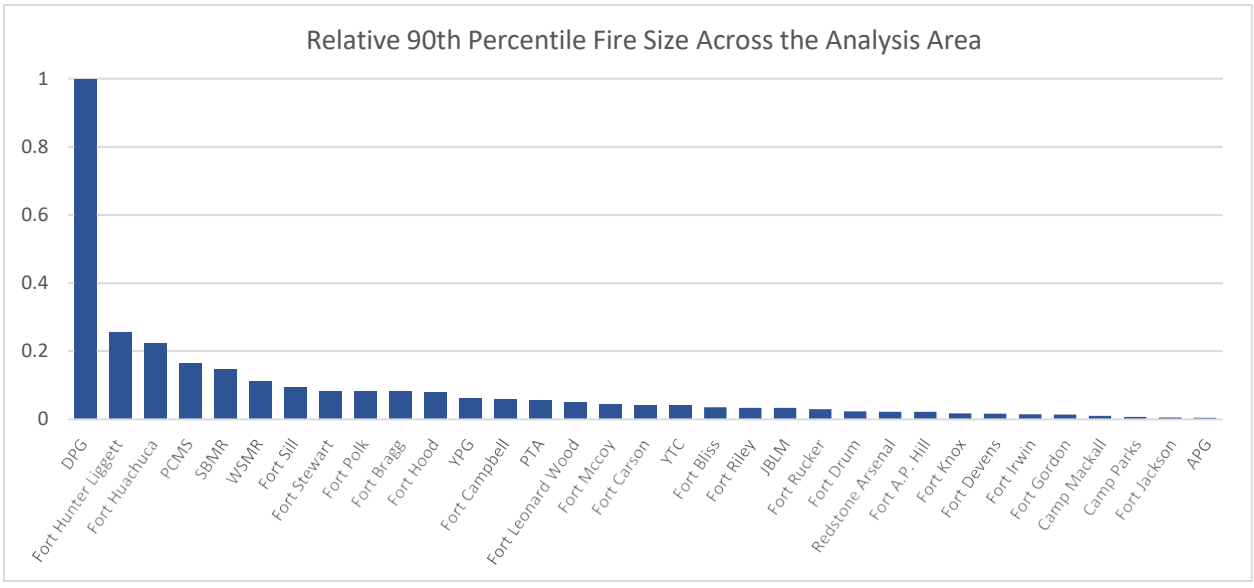


Figure 30. The relative 90th percentile fire size of detected wildfires occurring anywhere in the analysis area 2005 – 2014. Data have been rescaled relative to the maximum detected count from DPG after removing the outlier installations from the calculation.

The largest TA was at Fort Bragg, followed closely by PCMS and YTC (Figure 31). The distribution showed a distinct separation between the total acreages of the upper 12 and lower 21 installations. Although larger installations do have a greater potential capacity for total wildfire acreage than smaller installations,

the relationship between installation size and total acreage is weak, indicating other factors are driving this metric, and substantiating its usefulness as an indicator of wildfire hazard.

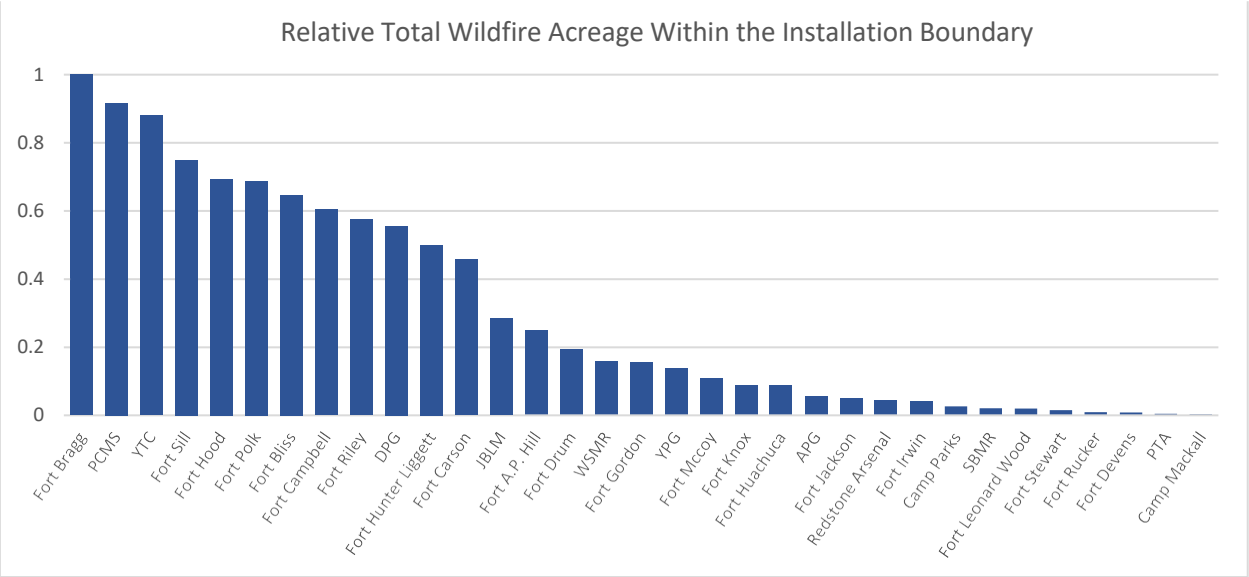


Figure 31. The relative total acreage of detected wildfires, or portions of detected wildfires, occurring on-installation 2005 – 2014. Data have been rescaled relative to the maximum detected count from Fort Bragg after removing the outlier installations from the calculation.

The installation with the largest proportion burned by detected wildfire was Camp Parks (Figure 32). Although Camp Parks is also the smallest installation, there was no relationship between installation size and proportion burned across the entire set of installations. Fort Sill, PCMS, and Fort Riley all showed high proportions of the installation impacted by wildfire with a drop of 13% to the next installation, Fort Polk. There is also a smaller break in the data of 9% between Fort A.P. Hill and Fort Hood.

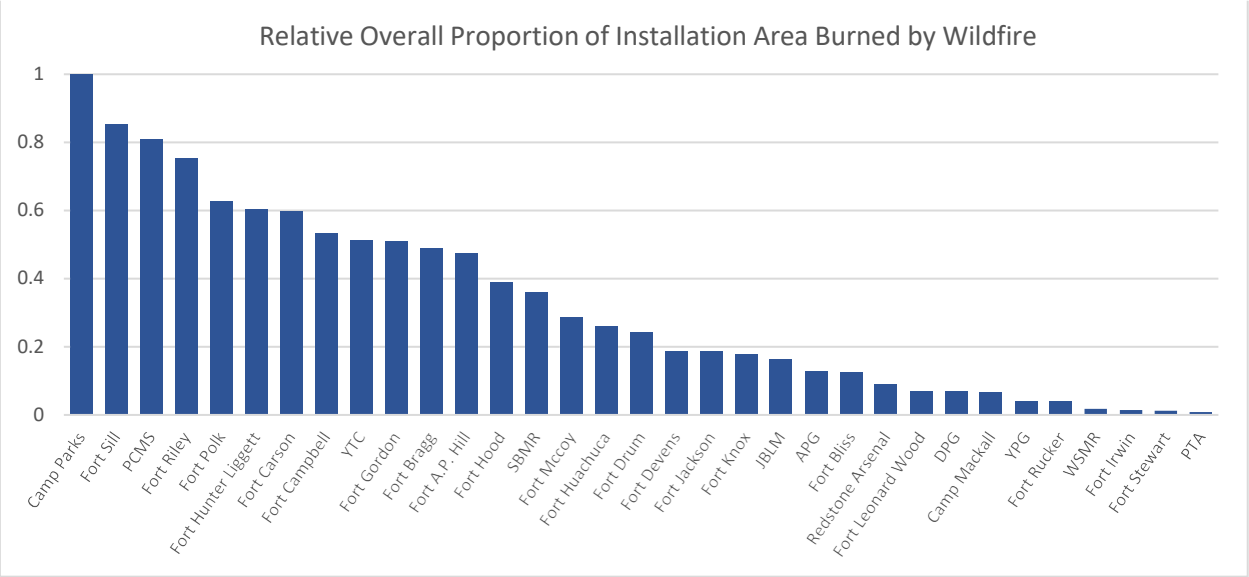


Figure 32. The relative unique acreage burned by wildfires, or portions of wildfires, occurring on-installation, normalized by that installation's area 2005 – 2014. Data have been rescaled relative to the maximum proportion from Camp Parks after removing the outlier installations from the calculation.

Installation Clusters

The above metrics characterize individual aspects of fire hazard for each installation, but making overall conclusions utilizing 10 separate characteristics across numerous installations is difficult. The results in Table 10 utilize the output from the K-means clustering after Fort Benning and Fort Wainwright were excluded due to their outlier values for one or more metrics. Each group contains installations that are more alike to each other than they are to installations in other groups. In addition to facilitating prioritization among installations, the groupings also identify installations that share common hazard characteristics.

Table 10. Army installation groups formed by K-means clustering, after excluding the outlier installations which have high, outlier values for many metrics. Here, the outlier installations are identified in their own group.

Group ID	Installations
A	Fort Huachuca
	Fort Stewart
	Fort Rucker
	USAG Hawaii Pohakuloa Training Area
B	Dugway Proving Ground
	Fort Hunter Liggett
	Pinyon Canyon Maneuver Site
C	Aberdeen Proving Ground
	Camp Mackall
	Fort Devens
	Fort Drum
	Fort Irwin
	Fort Jackson
	Fort Knox
	Fort Leonard Wood
	Fort McCoy
	Redstone Arsenal
	USAG Hawaii Schofield Barracks
	White Sands Missile Range
	Yuma Proving Ground
D	Camp Parks
	Fort A.P. Hill
	Fort Carson
	Fort Gordon
	JB Lewis-McChord
E	Fort Bliss
	Fort Bragg
	Fort Campbell
	Fort Hood
	Fort Polk
	Fort Riley
	Fort Sill
	Yakima Training Center
Outliers	Fort Benning
	Fort Wainwright

The means of each group for each metric are shown in Table 11. The highest group mean was 0.933, Group B's TCT. Group B also had the highest group mean for 90th PS. The lowest group mean was 0.011, Group A's TC. Group A had the lowest mean for several other metrics as well. Like any comparison of means, the within-group variability should be considered when evaluating the significance of the difference among them. Full results of pairwise tests for significance (Dunn's Test) are in Appendix A.

For this analysis to be valid, the within-group variability must be considered when evaluating the significance of the differences among them. The Kruskal-Wallis post-hoc test found that all variables provided statistically significant differentiation among clusters. Full results of pairwise tests for significance (Dunn's Test) are in Appendix A – Kruskal-Wallis and Dunn's Tests.

Table 11.Army group means for each wildfire hazard metric.

	A	B	C	D	E
Relative Total Count of All Wildfires Inside the Installation	0.011	0.097	0.172	0.426	0.614
Relative Median Count per Year of Wildfires Inside the Installation	0.043	0.163	0.178	0.420	0.668
Relative Total Count of Large Wildfires Inside the Installation	0.031	0.208	0.099	0.264	0.819
Relative Proportion of all Wildfires Inside the Installation That Are Large	0.542	0.477	0.147	0.126	0.331
Relative Total Count of Wildfires Inside the Installation Close to the Boundary	0.019	0.101	0.054	0.747	0.354
Relative Total Count of Transboundary Wildfires	0.200	0.933	0.108	0.120	0.450
Relative Median Fire Size Across the Analysis Area	0.680	0.456	0.114	0.046	0.166
Relative 90th Percentile Fire Size Across the Analysis Area	0.098	0.473	0.041	0.023	0.064
Relative Total Wildfire Acreage Within the Installation Boundary	0.029	0.658	0.072	0.234	0.730
Relative Overall Proportion of Installation Area Burned by Wildfire	0.080	0.493	0.144	0.549	0.535

Although K-means clusters are often described using the group mean, the range of values within a group for each metric is also informative. The mean and distribution of each group's values for each metric are shown in Figure 33 - Figure 42. Categorized wildland fire hazard was assigned after evaluating these means and distributions for each group among the metrics.

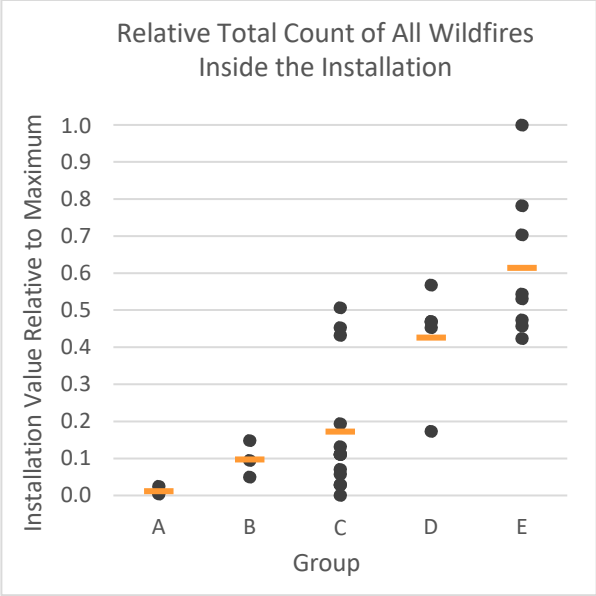


Figure 33. Clusters of the relative total count of detected wildfires whose perimeters are entirely contained within the installation boundary. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

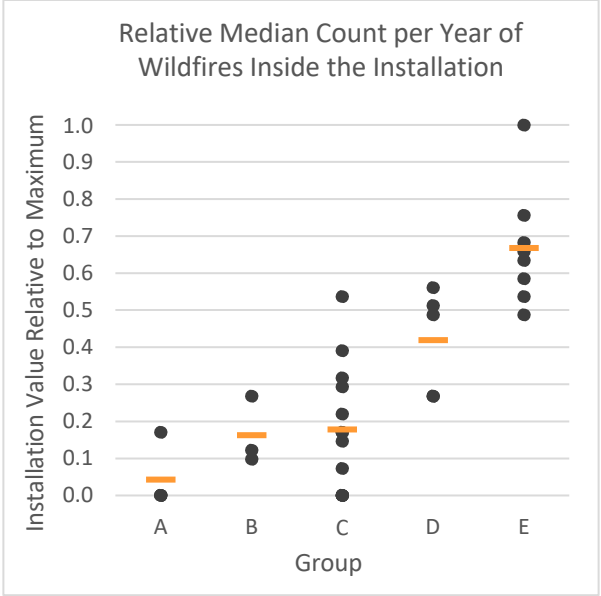


Figure 34. Clusters of the relative median count per year of detected wildfires within the analysis area. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

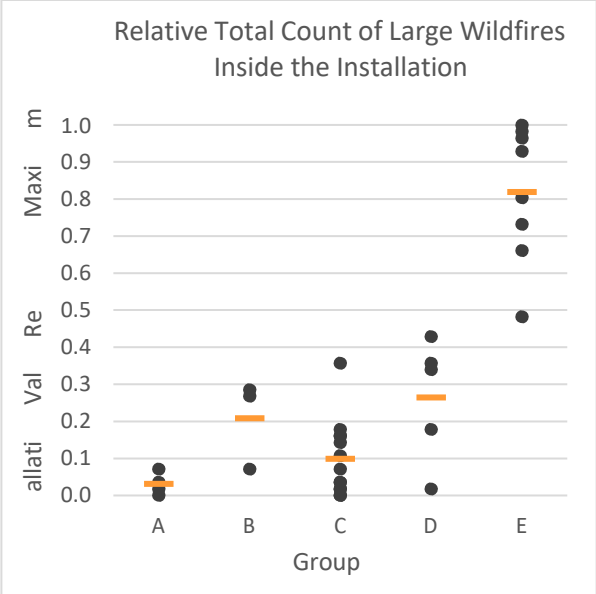


Figure 35. Clusters of the relative total large fire (>300 acres) count whose perimeters are entirely contained within the installation boundary. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

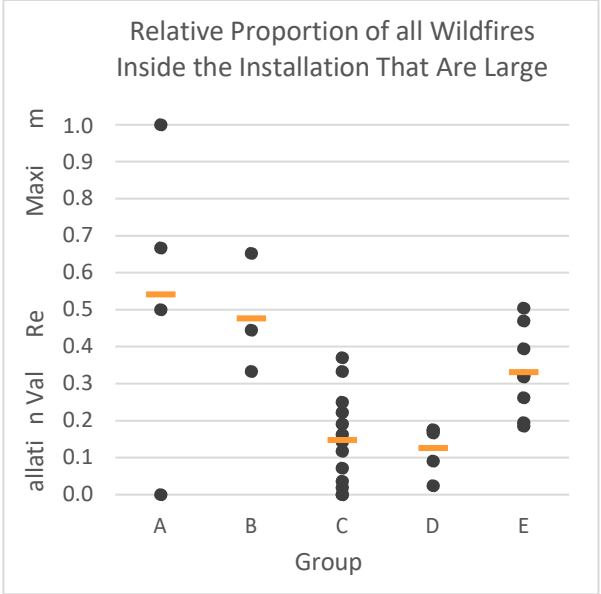


Figure 36. Clusters of the relative proportion of detected wildfires whose perimeters are entirely contained within the installation boundary that were at least 300 acres ("large"). Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

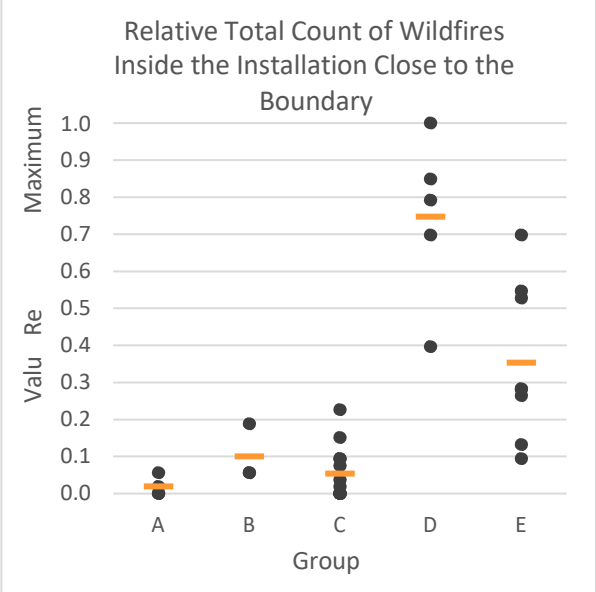


Figure 37. Clusters of the relative count of on-installation detected wildfires whose perimeters, while entirely contained within the installation boundary, extended within ate least 0.5 mi of the installation boundary. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

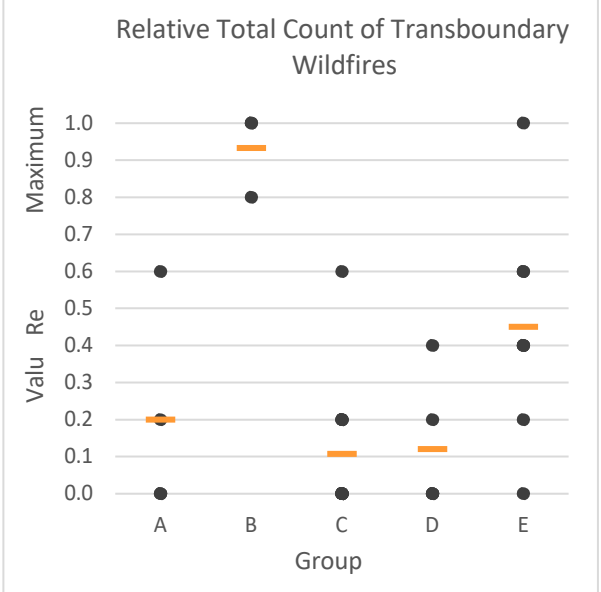


Figure 38. Clusters of the relative total count of detected wildfires that extend across an installation's boundary. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

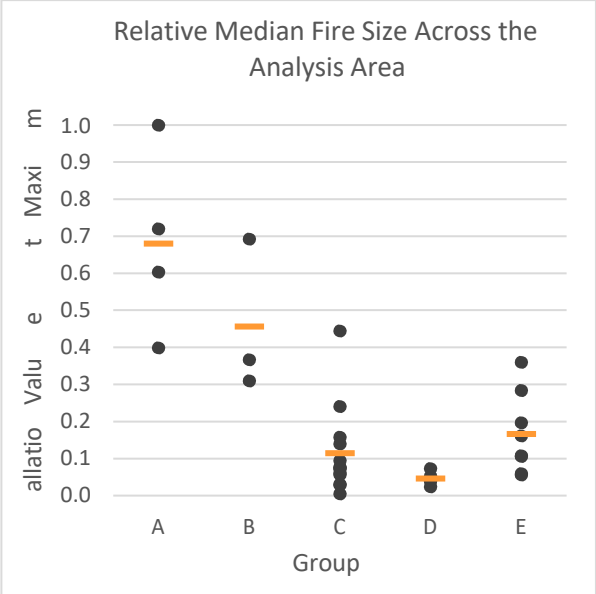


Figure 39. Clusters of the relative median fire size of detected wildfires occurring anywhere in the analysis area (on-installation and/or within the surrounding 5-mile buffer). Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

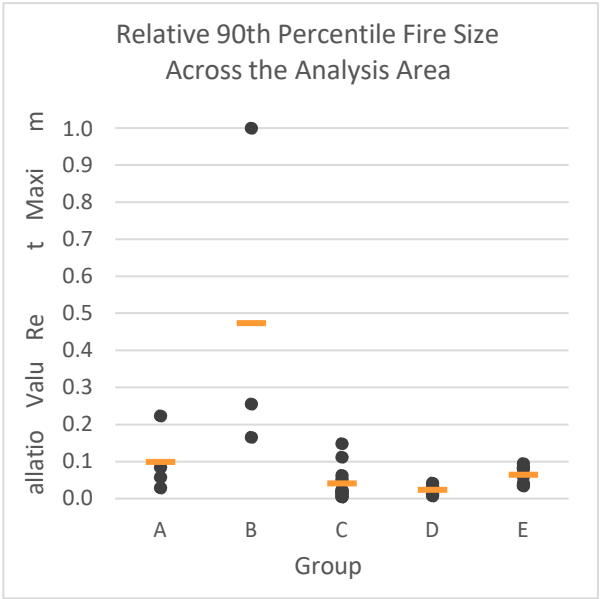


Figure 40. Clusters of the relative 90th percentile of detected wildfires occurring anywhere in the analysis area. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

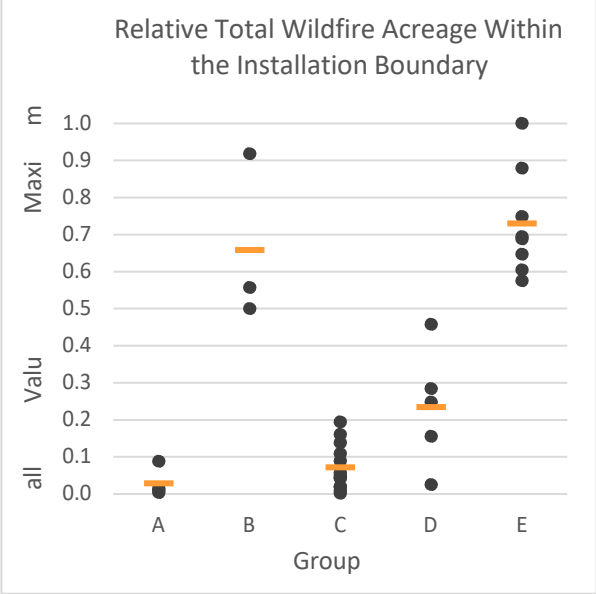


Figure 41. Clusters of the relative total acreage, across the entire study period, of detected wildfires, or portions of detected wildfires, occurring on-installation. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

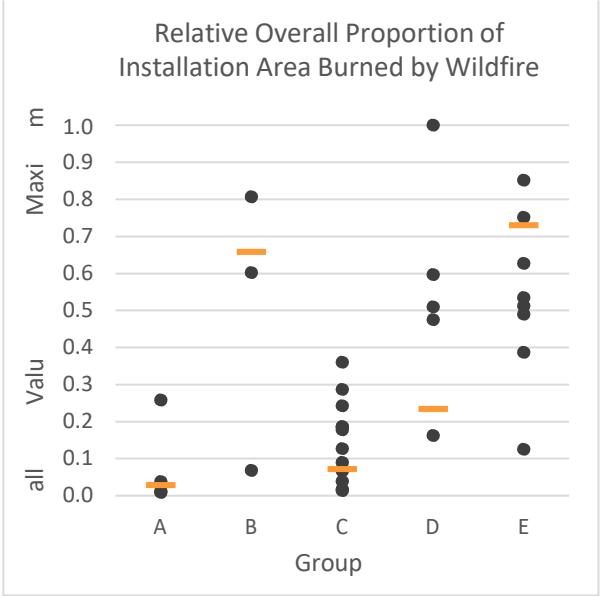


Figure 42. Clusters of the relative unique acreage, across the entire study period, of detected wildfires, or portions of wildfires, occurring on-installation, normalized by that installation's area. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

INITIAL CATEGORIZATION BY CLUSTER

Triaging the installations included considering each group's distribution across the metrics as shown in the figures above. These measures highlighted the likenesses and differences among them and informed the final categorization of each group.

Group A tended to have low on-installation wildland fire counts (TC, MC, TCL, TCC). Although the PL results included the entire possible range (0 – 1.0), the counts of total and large fires are so small that the proportion is less meaningful than at installations with larger sample sizes of both. The TCT was also low, with only one elevated, moderate installation in the Group (Fort Huachuca). The MS was moderate to large, but again, this is potentially an artifact of a small number of fires and this presumption is further supported by the results of the 90th PS, TA, and PAB. Given the predominance of results at the low end of the spectrum, the overall wildland fire hazard categorization of Group A was determined to be low.

Group B told a different story. Many wildfire count metrics were low to moderate (TC, MC, TCL, TCC), but the TCT mean was by far the highest of any group, a result contributed to by high values for all three installations in this group. The PL was moderate, but was the second highest among all groups and more reliable a metric than Group A due to the larger number of fires detected in Group B. All size measures were moderate to high (MS, 90th PS, TA, PAB). Because of the many metrics with high values, the overall wildland fire hazard categorization of Group B was high.

Group C's results were uniformly low to moderate across all metrics. There were very few metrics with individual installation results that were considerably higher than the group mean. Thus, the overall wildland fire hazard categorization of Group C was low.

There was high variability among metrics in Group D. The TC and MC were moderate, with individual installations ranging from low to moderate, though the mean was the second highest among all groups. The TCL and TCT also ranged from low to moderate among installations, and both had a low group mean. The PL was low. However, the TCC was much higher than other groups, with almost all installations contributing to that result, indicating that although fires have not historically crossed the installation boundary (as indicated by the low TCT), that potential is elevated at these installations. Individual fire sizes for this group were quite low (MS and 90th percentile fire size). Due in part to the low TC and MC, the TA was low, with only one installation in the moderate range. The PAB ranged across the spectrum from low to high, but the mean was low. Taken together, these factors indicated a moderate wildfire hazard for Group D.

Group E had the highest group mean for TC, MC, TCL, TA, and PAB. It also had moderate means for TCC, TCT, and PL. Because the TC for these installations was so high, the PL for individual installations in this group ranged from low to moderate. The TCC and TCT were the most variable metrics in this group, with individual installation values in both metrics spanning the spectrum. Although the individual fire sizes were low (90th PS) or low to moderate (MS), the high fire occurrence numbers resulted in a high TA, with most of the highest individual installation values in this group. The PAB ranged from low to high, with a high group mean. The abundance of metrics with high and moderate values warranted categorizing the wildland fire hazard for Group E as high.

CATEGORIZATION REVISIONS

Within each initial cluster, the installations were determined by the algorithm to be more similar to each other than to other installations. However, as shown in Figure 33 - Figure 42, some groups had high within-group variability for some of the metrics. Because of this within group variability, each installation was reviewed against its group's initial categorization, and adjusted if that classification was not justified by these data and expert opinion.

Upon review, only three installations changed categorization from that of their original group. White Sands Missile Range was originally placed in Group C with Aberdeen Proving Ground et al. and categorized as low. However, its transboundary fire count was notably higher than that of the other installations in the Group C, and warranted a moderate categorization.

Fort Huachuca was initially grouped with Fort Rucker, Fort Stewart, and USAG Hawaii Pohakuloa Training Area in Group A, and categorized as low. Given Fort Huachuca had the highest relative values in the group for many metrics, and often with a distinct gap between its elevated value and the rest of the group. In particular, the PWL, TCT, and MS were particularly high, relative to the other installations in Group A. As a result, we chose to re-categorize Fort Huachuca from low to moderate.

OUTLIER INSTALLATIONS

Two installations were removed from the analysis due to being identified as statistical outliers for one or more metrics. These were Fort Benning and Fort Wainwright.

Fort Wainwright was marked as an outlier due to a MS that was more than double the next highest installation, a 90th PS that was more than four times the next highest installation, and a TA that was more than three times the next highest installation. It also had the highest MC, PL. These results clearly mark it as an installation with high wildfire hazard.

Fort Benning was determined an outlier due to a TC that was more than twice that of the next highest installation. It also had the greatest MC and TCC. In addition, the TCL at Fort Benning was 67%, the PA was 48%, and the TA was 44% that of the highest non-outlier installation for each metric. These also clearly designate Fort Benning as an installation with high wildfire hazard.

CATEGORIZATION AND DISCUSSION

The wildfire hazard categorization of each installation, as determined by this analysis, is shown in Table 12. These categorizations reflect the aggregation of the 10 metrics characterizing aspects of wildland fire and the adjustments made due to subject matter expert input. This analysis identified 13 Army installations as having a high wildland fire hazard, 8 as moderate, 14 as low, and 19 as negligible.

The installations categorized as high had high and/or outlier values for numerous metrics, whereas the moderate installations tended to have elevated values for fewer metrics, but low values for others. The installations categorized as low had few, if any, elevated metrics; none of the low installations had any metric with a relative value of more than 25% of the non-outlier maximum for that metric.

Thirteen installations had zero fires detected anywhere in the analysis area, and an additional 6 installations only had detected fires in the 5-mile buffer surrounding the installation but not within the installation boundary. These installations were categorized as negligible.

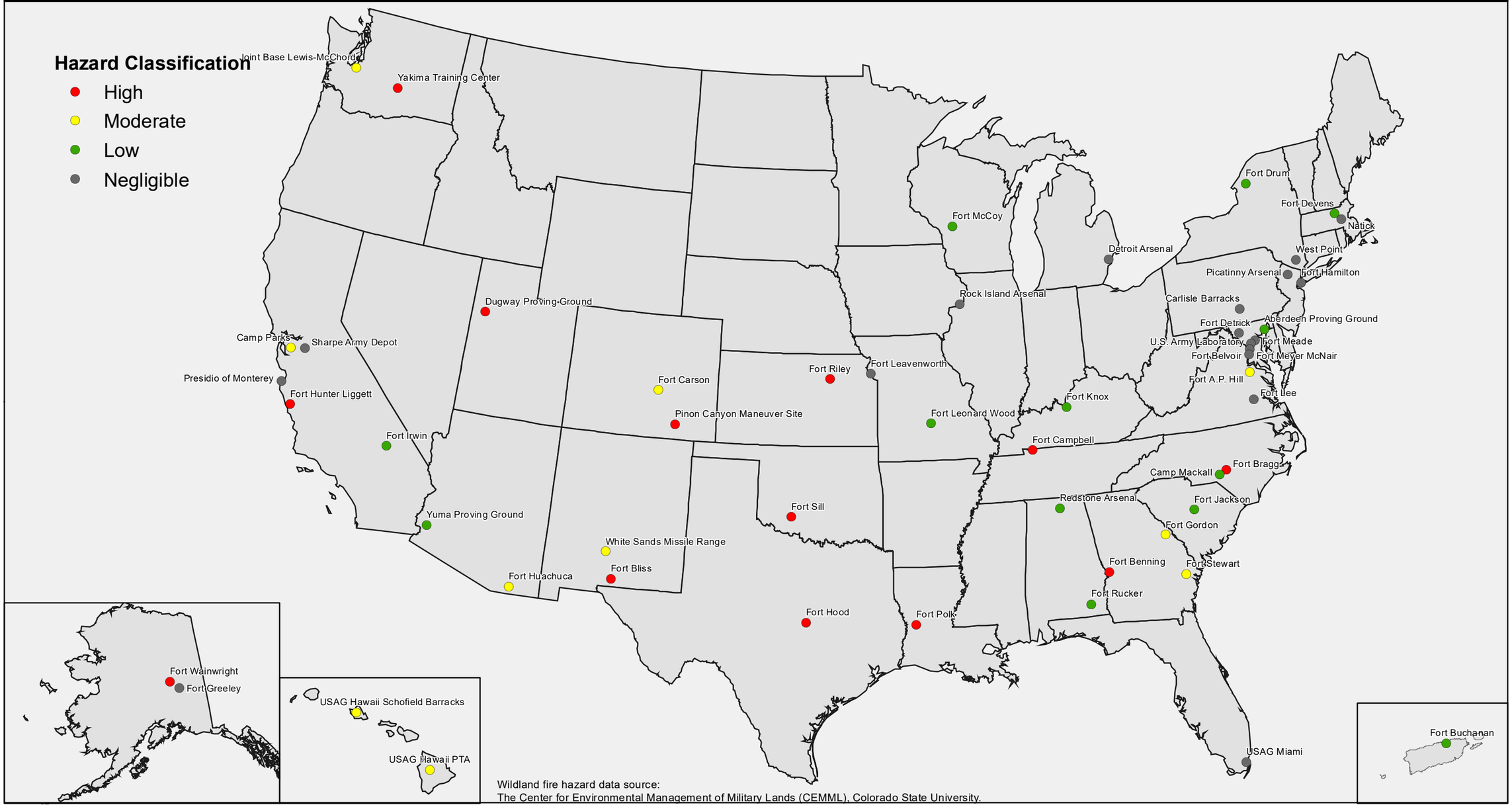
Table 12. Army installation wildfire hazard categorization. No fires were detected wholly or partially within any installation in the negligible category. Outlier installations are marked with an asterisk.

HIGH	MODERATE	LOW	NEGLIGIBLE
Dugway Proving Ground	Camp Parks	Aberdeen Proving Ground	Adelphi
Fort Benning*	Fort AP Hill	Camp Mackall	Carlisle Barracks
Fort Bliss	Fort Carson	Fort Devens	Detroit Arsenal
Fort Bragg	Fort Gordon	Fort Drum	Fort Belvoir
Fort Campbell	Fort Huachuca	Fort Irwin	Fort Greeley
Fort Hood	Joint Base Lewis-McChord	Fort Jackson	Fort Hamilton
Fort Hunter Liggett	USAG Hawaii PTA	Fort Knox	Fort Lee
Fort Polk	White Sands Missile Range	Fort Leonard Wood	Fort Meyer McNair
Fort Riley		Fort McCoy	Natick
Fort Sill		Fort Rucker	Picatinny Arsenal
Fort Wainwright*		Fort Stewart	Presidio of Monterey
Pinon Canyon MA		Redstone Arsenal	Rock Island Arsenal
Yakima Training Center		USAG Hawaii Schofield Barracks	USAG Miami
		Yuma Proving Ground	Fort Buchannan
			Fort Detrick
			Fort Leavenworth
			Fort Meade
			Sharpe Army Depot
			West Point

Army

Wildfire Hazard Classification

Figure 43



Wildland fire hazard data source:
The Center for Environmental Management of Military Lands (CEMML), Colorado State University.

Navy Results

FIRE DETECTIONS

Thirty-seven Navy installations were included in this analysis. An initial pass through the data revealed 5 installations with no detected fires occurring anywhere inside the installation or within the 5-mile buffer, and an additional 12 installations with fires occurring within the 5-mile buffer, but wholly outside the installation boundary. These 17 installations were categorized as having negligible fire hazard and removed from further comparative analyses.

The 5 installations with no wildfires detected anywhere (on-installation or within the buffer) over the entire study period are shown in Table 13. Also shown are the 12 installations whose detected fires occurred within the 5-mile buffer but wholly outside the installation boundary, and the remaining 20 installations with at least one wildfire detected on the installation.

NAWS China Lake was the only installation identified as an outlier, and is indicated with an asterisk in Table 13. It was removed from the cluster analysis and evaluated independently.

Table 13. List of Navy installations where fires were detected, were only detected wholly outside the installation boundary, or were not detected at all during the study period 2004 - 2014. Outliers are marked with an asterisk.

At Least One Fire Detected On Post	No Fires Detected On Post, at Least One Fire Detected Off Post in Analysis Area	No Fires Detected Anywhere in Analysis Area
DIXIE TARGET RANGE	PEARL HARBOR	NAS OCEANA
NALF ORANGE	NAVSUPPDET MONT DIXON FAC	NSB KINGS BAY
NAS CORPUS CHRISTI	NCTAMS PACIFIC	NWS SEAL BEACH
NAS FALLON	NIOC SUGAR GROVE	NWS YORKTOWN
NAS KINGSVILLE	NAVSUPPDET MONT CENT BCH	OLF WHITEHOUSE
NAS MERIDIAN	NOLF CHOCTAW	
NAS PENSACOLA	NAS JACKSONVILLE	
NAVSUPPDET MONT MAGNA UTAH	NAS WHITING FIELD	
NAWS CHINA LAKE*	NAVSUPPDET MONTEREY	
NCBC GULFPORT	CAMP MORENA	
NSA CRANE	NB SAN DIEGO	
NWS CHARLESTON	NOLF BREWTON	
NWS EARLE		
NWS SEAL BEACH DET FALLBROOK		
NWSTF BOARDMAN		
PINECASTLE RANGE		
POINT MUGU		
SAN CLEMENTE		
SAN NICOLAS ISLAND		
SANTA CRUZ ISLAND		

FIRE HAZARD METRICS

The figures below show the rescaled values for each metric listed in Table 2. These are the scaled values excluding NAWS China Lake, an outlier which skewed the metrics and obscured differences among the other installations.

The TC was greatest at Sam Clemente, with NAS Kingsville and Point Mugu also having high counts relative to other Navy installations (Figure 43). After those three installations, there was a fairly consistent decrease from one installation to the next, ending with three installations at which no detected fires occurred entirely on-installation (Dixie Target Range, NCBC Gulfport, and Santa Cruz Island).

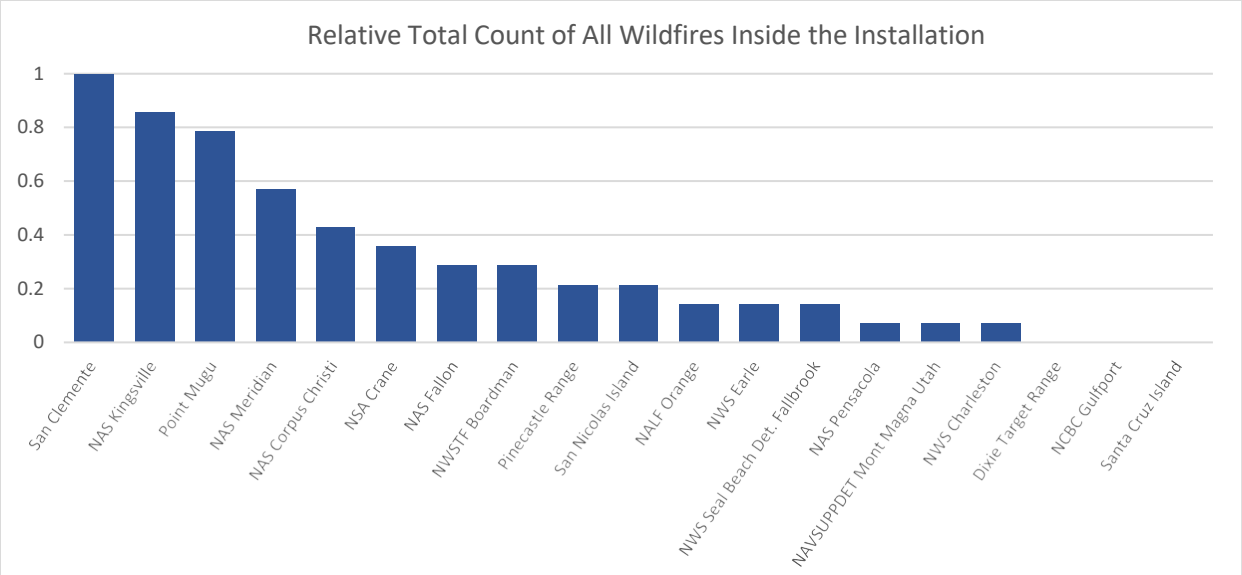


Figure 44. The relative total count, across the entire study period, of detected wildfires whose perimeters are entirely contained within the installation boundary 2004 – 2014. Data have been rescaled relative to the maximum detected count from San Clemente after removing the outlier installations from the calculation.

The highest MC of detected wildfires per year within the analysis area was NAS Meridian (Figure 44). Like the total count of on-installation fires, the median count per year decreased gradually, without distinct breaks between groups of installations. There were 6 installations whose median count of detected fires within the analysis area was 0, indicating that in a typical year, those installations and their immediate surrounds did not experience a wildfire.

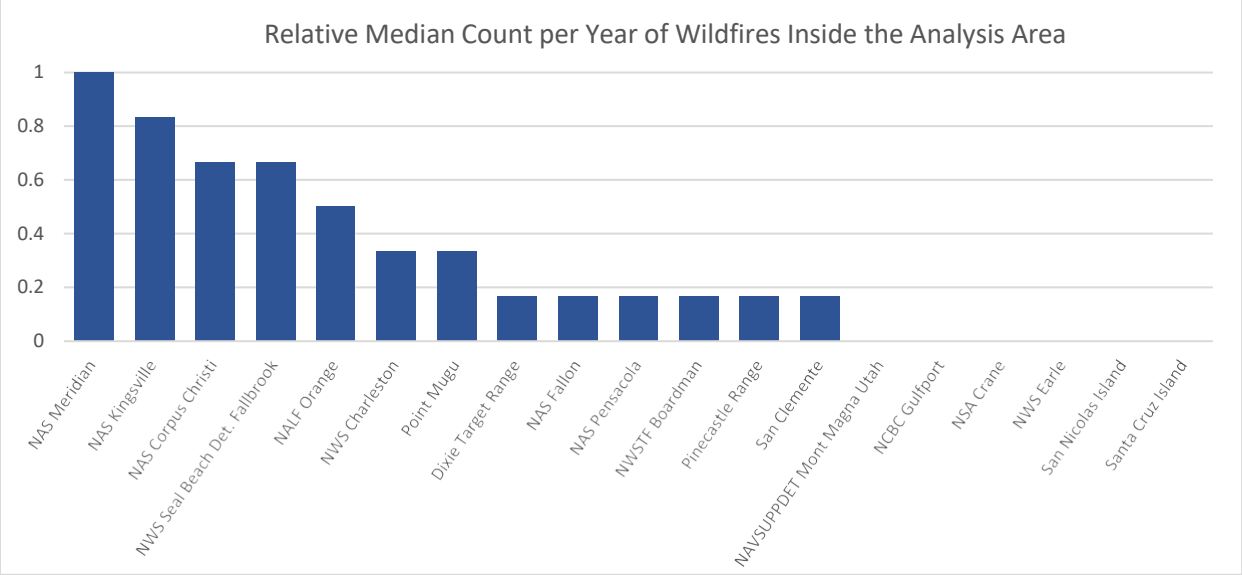


Figure 45. The relative median count per year of detected wildfires within the analysis area 2004 – 2014. Data have been rescaled relative to the maximum detected median count from NAS Meridian after removing the outlier installations from the calculation.

San Clemente, NWSTF Boardman, Pinecastle Range, and NWS Early had equally high TCL values (Figure 45). The remaining 15 installations had no wholly on-installation large fires detected. The binary results are due to very few large wildfires being detected within Navy installations. Correlation may be expected between the large fire counts and installation size because this metric is a count of large fires whose

perimeter is entirely contained within an installation's boundary. All else being equal, large fires are more likely to be transboundary fires, rather than entirely contained within the installation, at small installations than at larger installations. However, there was no relationship between installation size and the count of large fires detected wholly within the installation boundary. Thus, we concluded that on-installation large fire counts are more than a proxy for installation size. Six times as many large wildfires as the top installations shown in Figure 45 were detected at NAWS China Lake, the outlier installation.

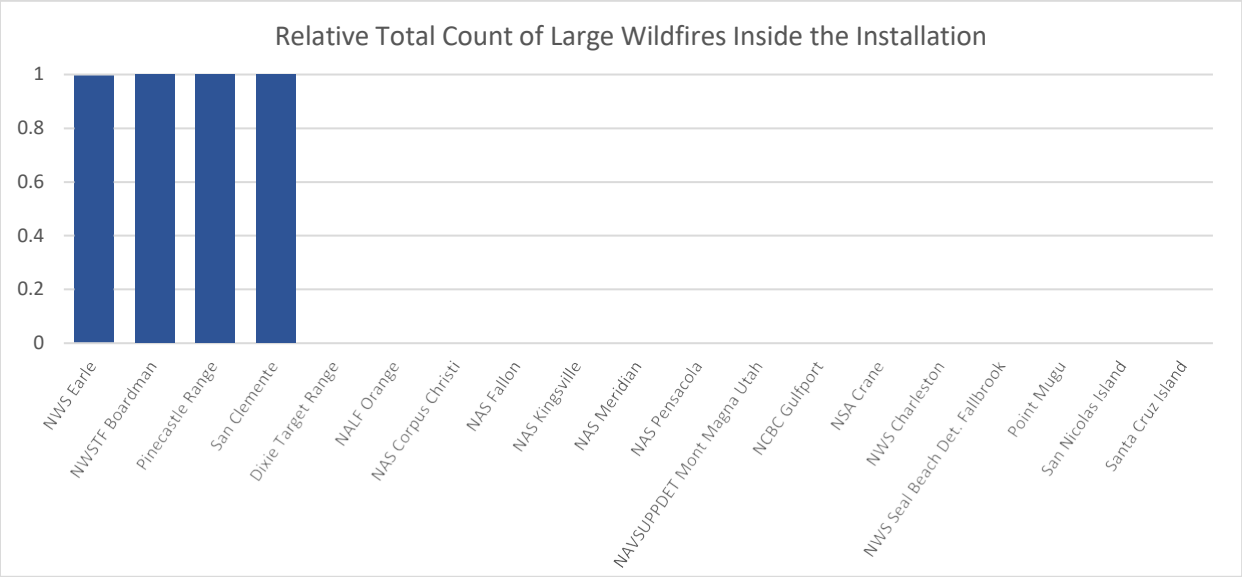


Figure 46. The relative total large fire (> 300 acres) count, across the entire study period, whose perimeters are entirely contained within the installation boundary 2004 – 2014. Data have been rescaled relative to the maximum detected count from NWS Earle after removing the outlier installations from the calculation.

NWS Earle also had the highest PL of all installations (Figure 46). Although a high PL in conjunction with a small TC does indicate the potential for significant fire growth, it can also be skewed by the small sample size of the TC. NWS Earle had a low TC and thus, although potentially interesting, the results should not be used to infer it has the greatest future potential for fires to grow to over 300 acres. Generally, greater meaningfulness can be attributed to large fire proportions (high or low) that are derived from larger total counts of on-installation wildfires, such as San Clemente, though the TC for all Navy installations, even outliers, was quite low.

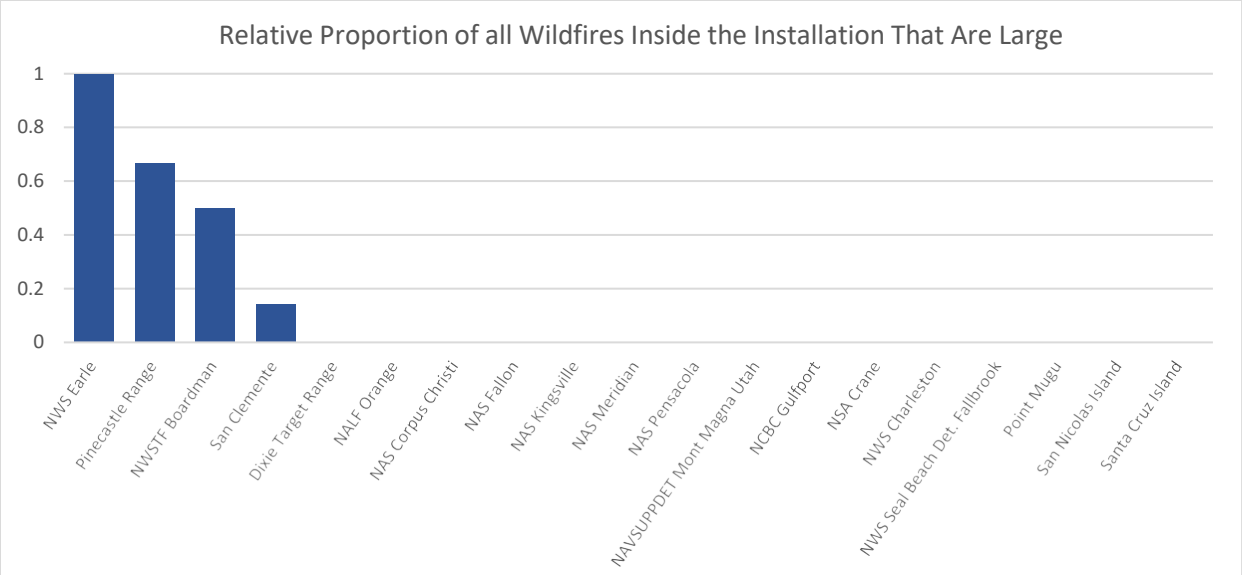


Figure 47. The relative proportion of detected wildfires whose perimeters are entirely contained within the installation boundary that were at least 300 acres 2004 – 2014. Data have been rescaled relative to the maximum proportion from NWS Earle after removing the outlier installations from the calculation.

The highest TCC was at NAS Kingsville (Figure 47). In addition to NAS Kingsville, three other installations had high or moderate TCCs, nine installations had a relatively low TCC, and at six installations no fires were detected within 0.5 miles of the boundary.

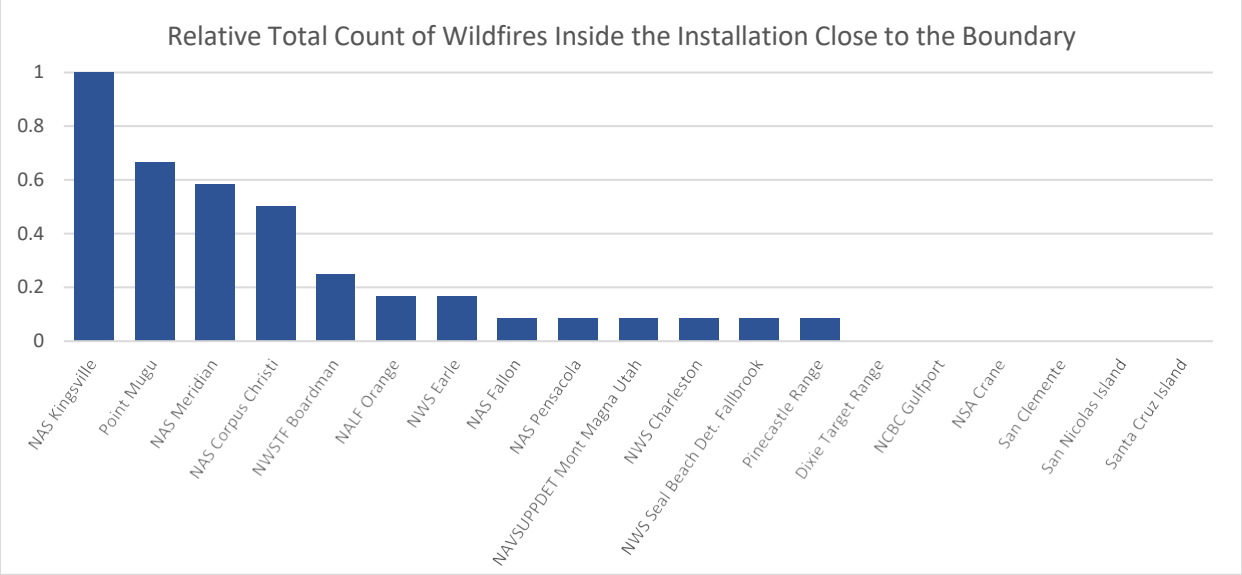


Figure 48. The relative total count of on-installation detected wildfires whose perimeters, while entirely contained within the installation boundary, extended within 0.5 mi of the installation boundary 2004 – 2014. These fires did not cross the installation boundary. Data have been rescaled relative to the maximum detected count from NAS Kingsville after removing the outlier installations from the calculation.

Dixie Target Range and NWS Seal Beach Det Fallbrook (NWS SBDF) had equally high TCT (Figure 48). Transboundary fires were also detected at Point Mugu, NAS Corpus Christi, NWSTS Boardman, NCBC Gulfport, and Santa Cruz Island. All else being equal, smaller installations would be expected to have higher TCT, as the likelihood of being close enough to the boundary to cross increases as installation area

decreases. However, there was no correlation between naval installation area and TCT, implying that other factors were driving this metric, making it more meaningful to this analysis.

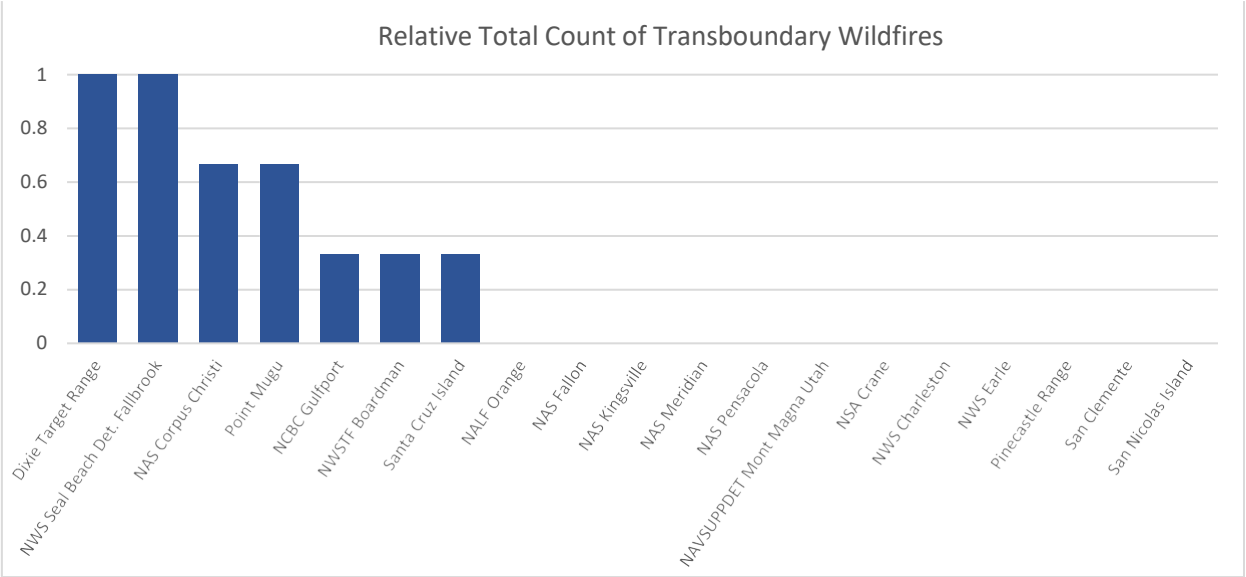


Figure 49. The relative total count of detected wildfires that extend across an installation's boundary 2004 – 2014. Data have been rescaled relative to the maximum detected count from Dixie Target Range after removing the outlier installations from the calculation.

After removing outliers, the largest MS was at Santa Cruz Island (Figure 49). NWSTF Boardman also had a high MS. The number of fires detected at Santa Cruz Island in particular was very low, meaning that although the large median size does capture the potential for large fires there, the likelihood for a typical fire there is probably overestimated. The MS metric is more useful for installations with a larger number of detected fires in the analysis area.

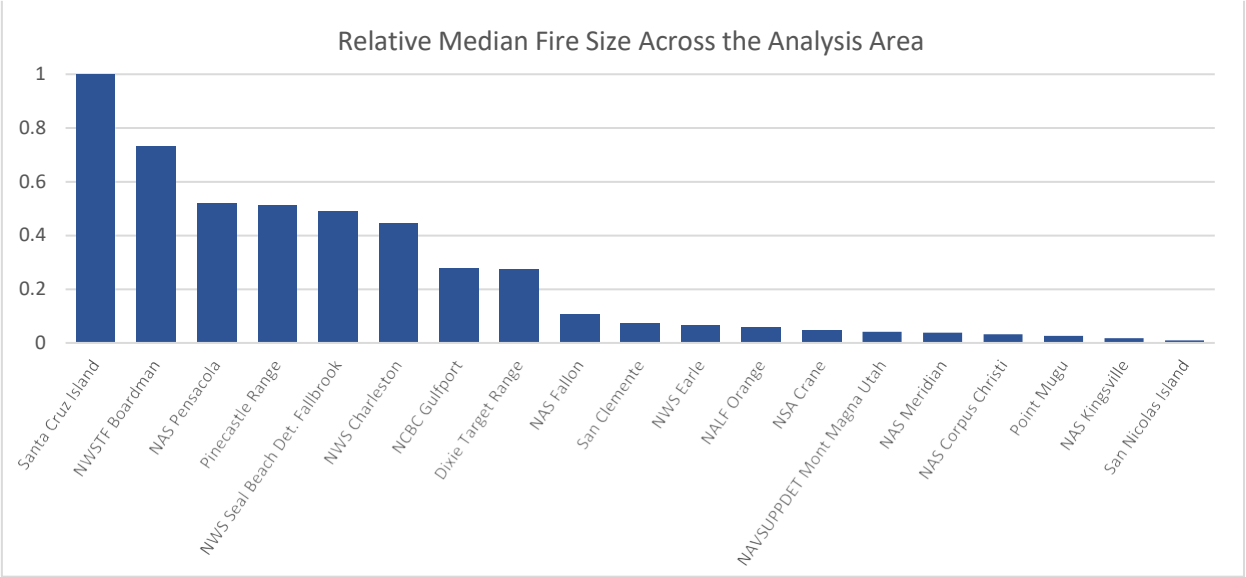


Figure 50. The relative median fire size of detected wildfires occurring anywhere in the analysis area 2004 – 2014. Data have been rescaled relative to the maximum detected median fire size from Santa Cruz Island after removing the outlier installations from the calculation.

The largest 90th PS was at NWSTF Boardman, with relatively large 90th PS's also detected at Pinecastle Range and Santa Cruz Island (Figure 50). These 90th percentile sizes were more than double the next largest 90th PS at NWS SBDF. However, like the MS metric, the 90th PS is more robust when calculated from a larger number of detected fires in the analysis area, and should be considered in light of the number of fires detected in the analysis area. In this light, the results for Santa Cruz Island should not be relied on due to the small number of fires detected in the analysis area.

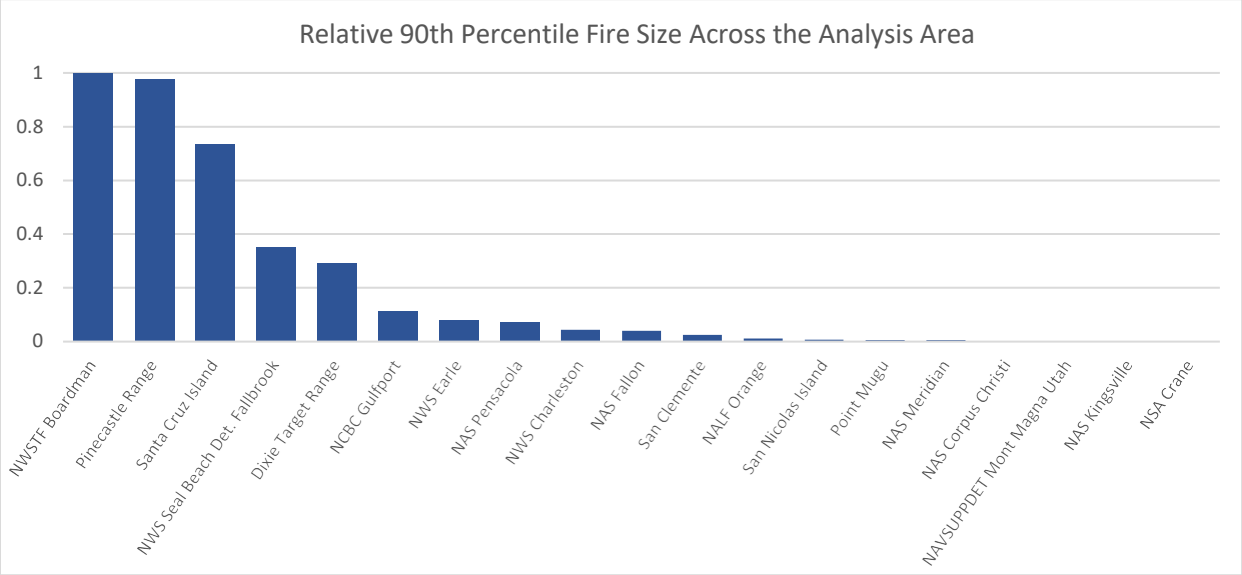


Figure 51. The relative 90th percentile fire size of detected wildfires occurring anywhere in the analysis area 2004 – 2014. Data have been rescaled relative to the maximum detected count from NWSTF Boardman after removing the outlier installations from the calculation.

The largest TA was at NWSTF Boardman, dwarfing the other installations' total detected on-installation wildfire acreage (Figure 51). Although larger installations do have a greater potential capacity for total wildfire acreage than smaller installations, there was no relationship between installation size and total acreage, even when excluding NWSTF Boardman, indicating other factors are driving this metric, and substantiating its usefulness as an indicator of wildfire hazard.

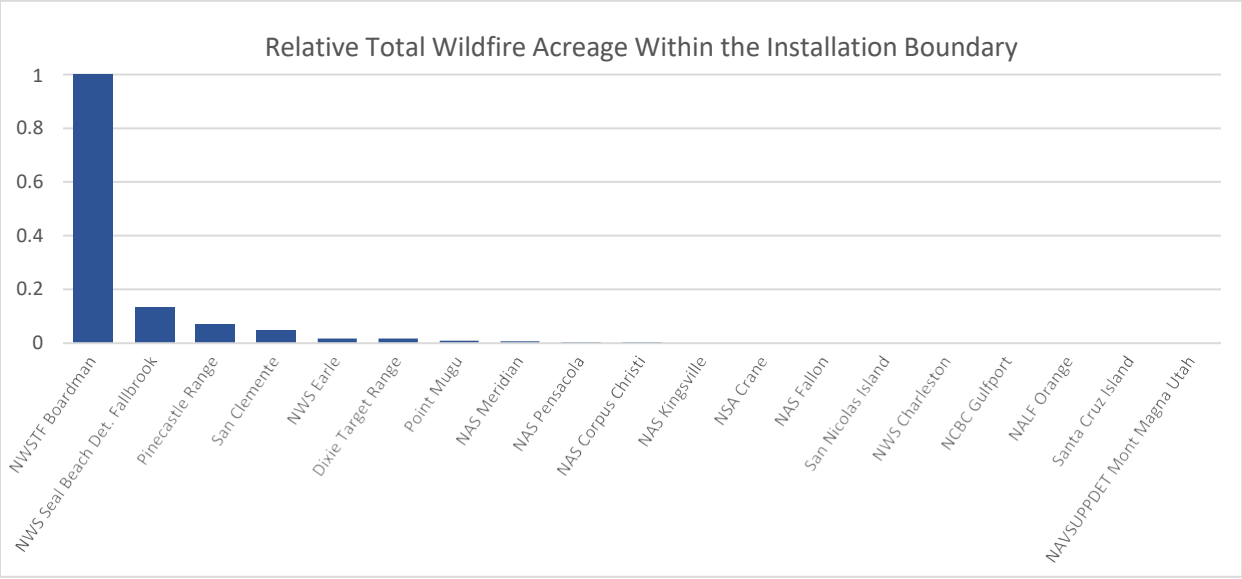


Figure 52. The relative total acreage of detected wildfires, or portions of detected wildfires, occurring on-installation 2004 – 2014. Data have been rescaled relative to the maximum detected count from NWSTF Boardman after removing the outlier installations from the calculation.

The installation with the largest PAB was Santa Cruz Island (Figure 52). Although Santa Cruz Island is also the smallest installation, there was no relationship between installation size and proportion burned across the set of Naval installations. In addition to Santa Cruz Island, high proportions of NWSTF Boardman, NWS SBDF, and Pinecastle Range have been impacted by wildfire. The remaining 15 installations had very small relative proportions. As with other fire size metrics, the sample size is relevant and the small sample size at Santa Cruz Island calls into question that particular result. The remaining installations with a high PAB all had far greater numbers of fires within (TC) and crossing the boundary (TCT).

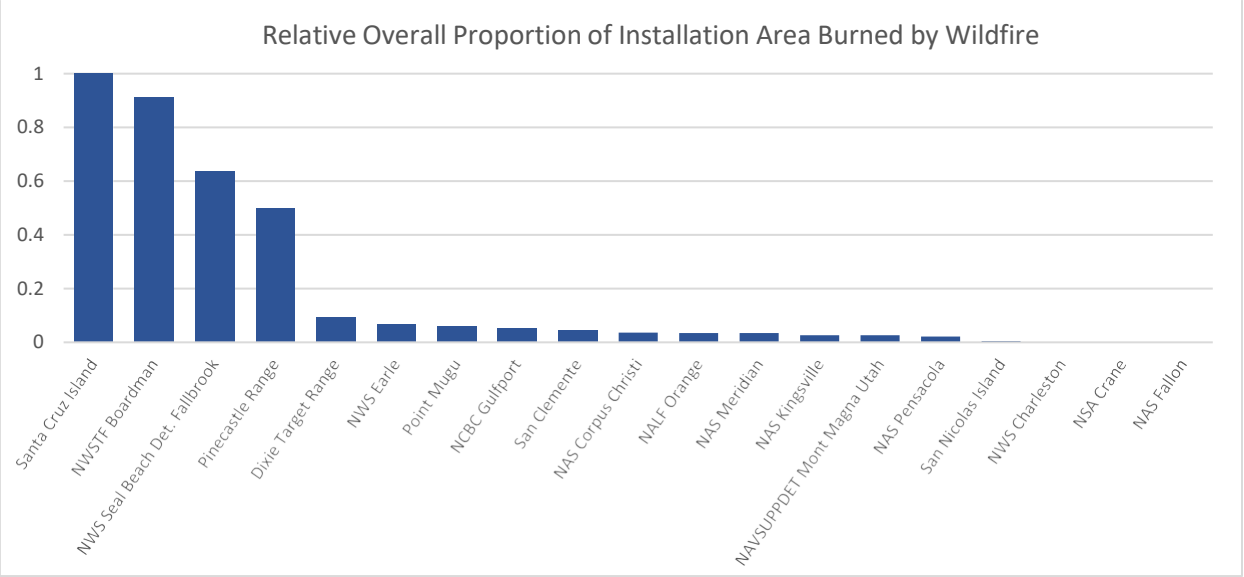


Figure 53. The relative unique acreage burned by wildfires, or portions of wildfires, occurring on-installation, normalized by that installation's area 2004 - 2014. Data have been rescaled relative to the maximum proportion from Santa Cruz Island after removing the outlier installations from the calculation.

INSTALLATION CLUSTERS

The above metrics characterize individual aspects of fire hazard for each installation, but making overall conclusions utilizing 10 separate characteristics across numerous installations is difficult. The results in Table 14 utilize the output from the K-means clustering after NAWS China Lake was excluded due to its outlier values for several metrics. Each group contains installations that are more alike to each other than they are to installations in other groups. In addition to facilitating prioritization among installations, the groupings also identify installations that share common hazard characteristics.

The means of each group for each metric are shown in Table 15. The highest group mean was 1.000 for TCL for Groups D and E. Group D also had one of the other highest means among all groups, for 90th PS. Low group means also reflect a shared trait. There were multiple group means of 0.000, particularly for the metrics related to large fires (TCL and PL), and many near zero values, indicating installations where the fires exhibiting that metric rarely detected.

For this analysis to be valid, the within-group variability must be considered when evaluating the significance of the differences among them. The Kruskal-Wallis post-hoc test found that all variables, except the relative 90th percentile fire size across the analysis area, provided statistically significant

differentiation among clusters. Full results of pairwise tests for significance (Dunn's Test) are in Appendix A – Kruskal-Wallis and Dunn's Tests.

Table 14. Navy installation groups formed by K-means clustering, after excluding NAWS China Lake, which is identified as an outlier.

Group ID	Installations
A	DIXIE TARGET RANGE
	NWS SEAL BEACH DET FALLBROOK
	SANTA CRUZ ISLAND
B	NCBC GULFPORT
	NAS PENSACOLA
	NAVSUPPDET MONT MAGNA UTAH
	NWS CHARLESTON
	NALF ORANGE
	SAN NICOLAS ISLAND
	NAS FALLON
	NSA CRANE
C	NAS CORPUS CHRISTI
	NAS MERIDIAN
	POINT MUGU
	NAS KINGSVILLE
D	PINECASTLE RANGE
	NWSTF BOARDMAN
E	NWS EARLE
	SAN CLEMENTE
OUTLIERS	NAWS CHINA LAKE

Table 15. Navy group means for each metric.

	A	B	C	D	E
Relative Total Count of All Wildfires Inside the Installation	0.048	0.152	0.661	0.250	0.571
Relative Median Count per Year of Wildfires Inside the Analysis Area	0.278	0.146	0.708	0.167	0.083
Relative Total Count of Large Wildfires Inside the Installation	0.000	0.000	0.000	1.000	1.000
Relative Proportion of all Wildfires Inside the Installation That Are Large	0.000	0.000	0.000	0.583	0.571
Relative Total Count of Wildfires Inside the Installation Close to the Boundary	0.028	0.063	0.688	0.167	0.083
Relative Total Count of Transboundary Wildfires	0.778	0.042	0.333	0.167	0.000
Relative Median Fire Size Across the Analysis Area	0.588	0.188	0.029	0.623	0.068
Relative 90th Percentile Fire Size Across the Analysis Area	0.461	0.036	0.005	0.989	0.052
Relative Total Wildfire Acreage Within the Installation Boundary	0.050	0.002	0.005	0.534	0.032
Relative Overall Proportion of Installation Area Burned by Wildfire	0.576	0.018	0.039	0.705	0.056

Although K-means clusters are often described using the group mean, the range of values within a group for each metric is also informative. The mean and distribution of each group's values for each metric is shown in Figure 53 – Figure 62. Categorized wildland fire hazard was assigned after evaluating the means and distributions for each group among the metrics.

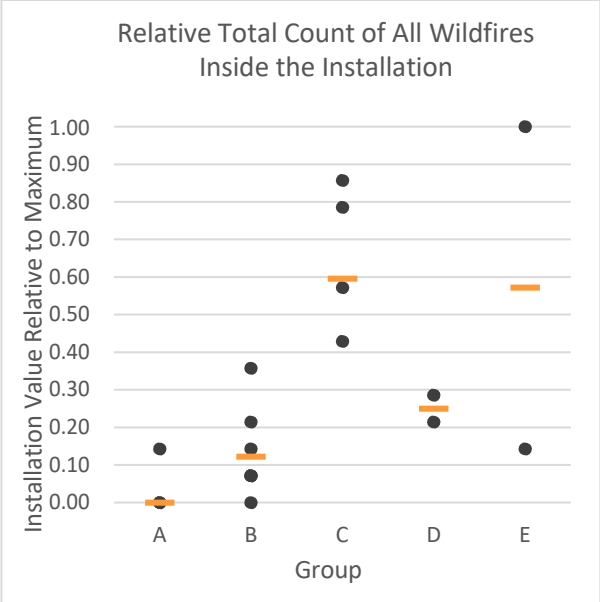


Figure 54. Clusters of the relative total count of detected wildfires whose perimeters are entirely contained within the installation boundary. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

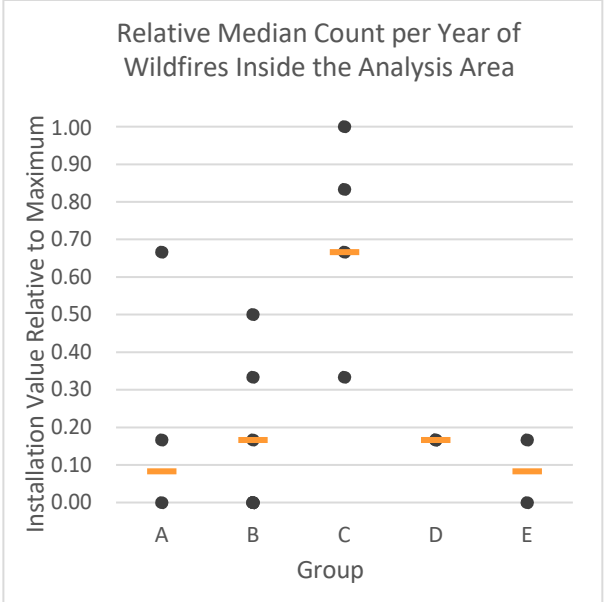


Figure 55. Clusters of the relative median count per year of detected wildfires within the analysis area. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

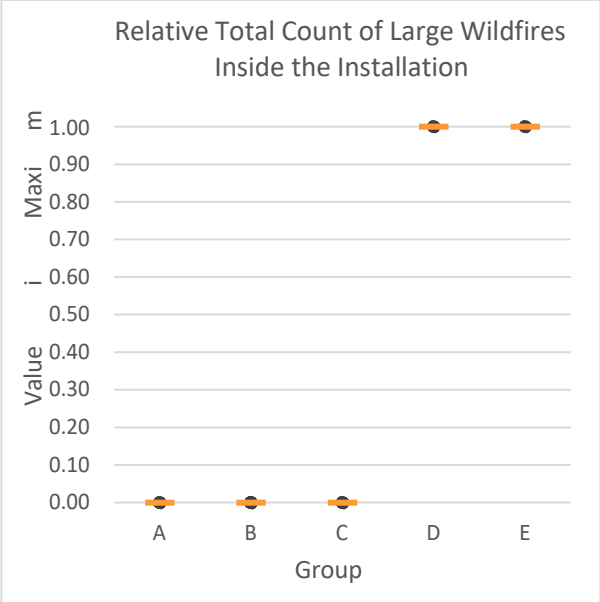


Figure 56. Clusters of the relative total large fire (>300 acres) count whose perimeters are entirely contained within the installation boundary. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

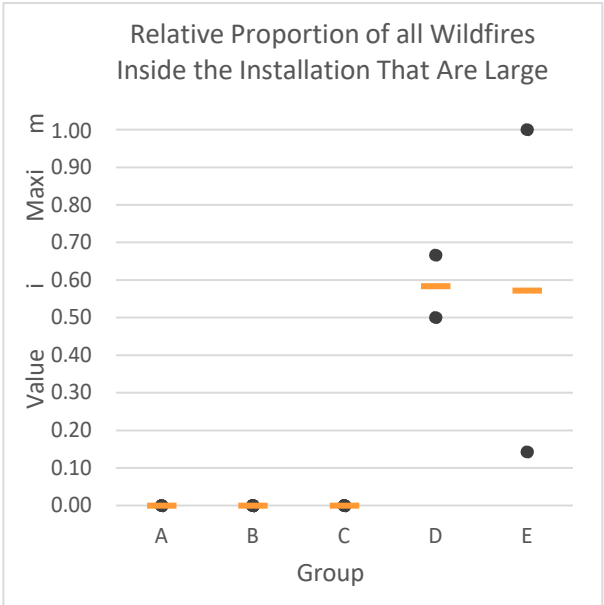


Figure 57. Clusters of the relative proportion of detected wildfires whose perimeters are entirely contained within the installation boundary that were at least 300 acres ("large"). Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

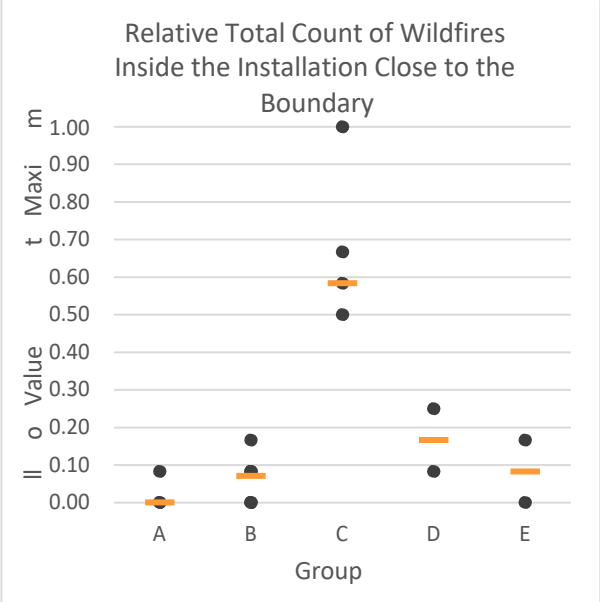


Figure 58. Clusters of the relative count of on-installation detected wildfires whose perimeters, while entirely contained within the installation boundary, extended within ate least 0.5 mi of the installation boundary. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

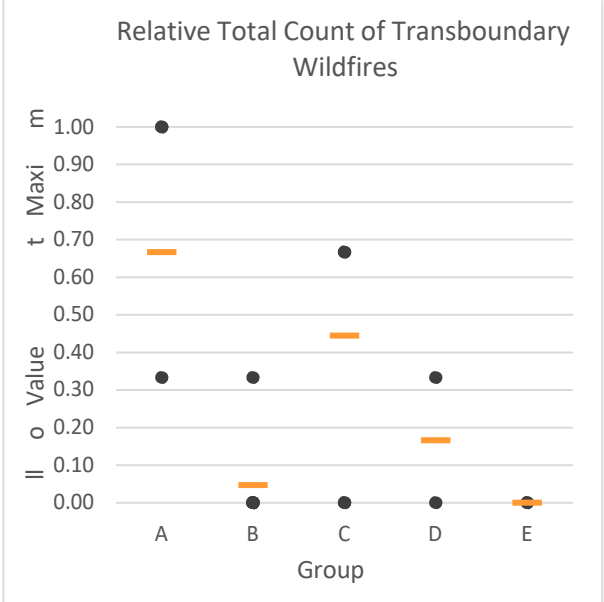


Figure 59. Clusters of the relative total count of detected wildfires that extend across an installation's boundary. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

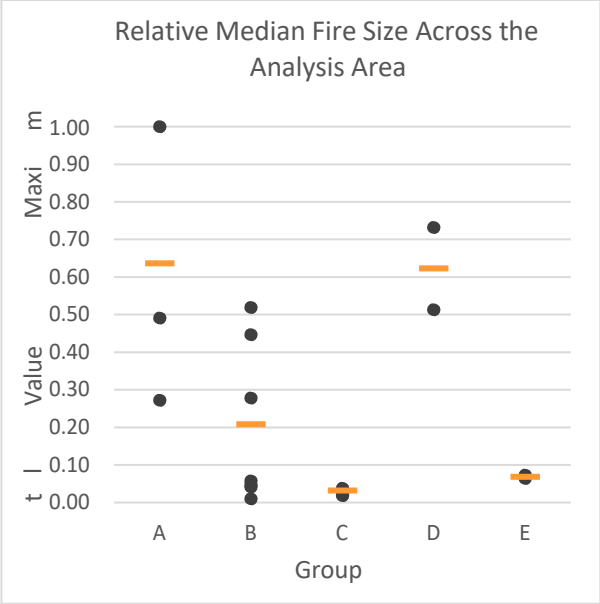


Figure 60. Clusters of the relative median fire size of detected wildfires occurring anywhere in the analysis area (on-installation and/or within the surrounding 5-mile buffer). Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

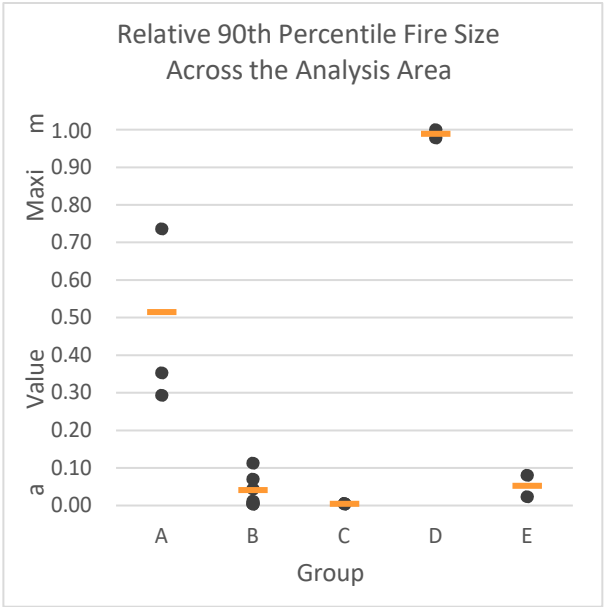


Figure 61. Clusters of the relative 90th percentile of detected wildfires occurring anywhere in the analysis area. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

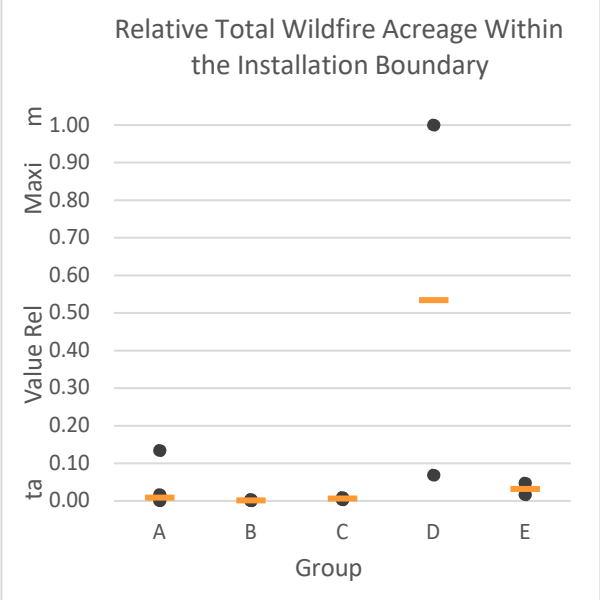


Figure 62. Clusters of the relative total acreage, across the entire study period, of detected wildfires, or portions of detected wildfires, occurring on-installation. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

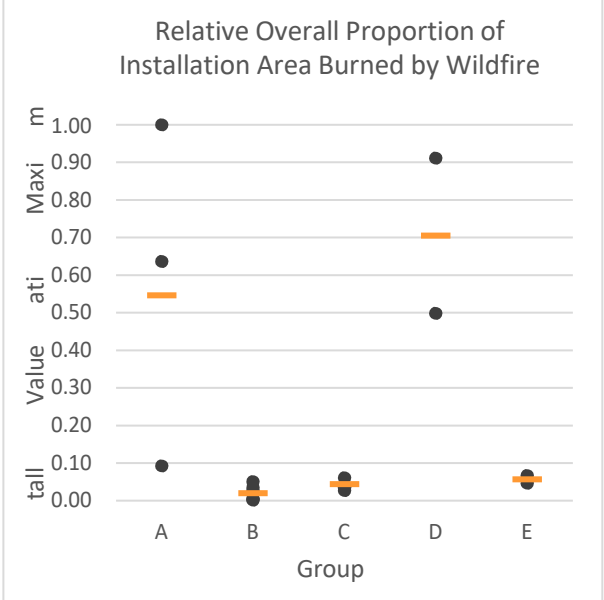


Figure 63. Clusters of the relative unique acreage, across the entire study period, of detected wildfires, or portions of wildfires, occurring on-installation, normalized by that installation's area. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

INITIAL CATEGORIZATION BY CLUSTER

Triaging the installations included considering each group's distribution across the metrics as shown in the figures above. These measures highlighted the likenesses and differences among them and informed the final categorization of each group. The 90th PS was not a statically significant metric for differentiation among Air Force clusters, so the values of this metric were not considered when assigning installations to fire hazard categories.

Group A had relatively low TC and no TCL, but also had the highest values for TCT and MS. These results indicated a group of installations with few fires, but the fires that occurred were large. Given the low TC, which only counts fires wholly within the installation boundary, and the high MS, which counts fires throughout the analysis area, these installations are appeared to be experiencing larger fires outside the installation boundary. Combined with the high TCT, this indicates installations that are threatened by fires burning onto the installation from elsewhere. With a low TC, limited MC, the complete lack of on-installation large fires, but indications of potential for off-installation fires to burn onto the installations, Group A was categorized as moderate wildfire hazard.

Group B told a different story. Metrics were low to very low with a few individual installations as exceptions. Metrics that showed any elevated values at all were related to fires in the analysis area, rather than within the installation boundary. Based on the consistently low values for nearly all metrics at all installations, Group B was categorized as facing a low wildfire hazard.

Group C had elevated values across all installations for all metrics related to the count of fires. There were high values for TC, MC, and TCC for all installations in this group. The high TCC indicates potential for transboundary fires. Mitigating the high numbers of fires was the relatively small fire size metrics, including the lowest MS mean of all groups. In all fire size measures, Group C was uniformly low. Balancing fire counts and fire sizes, Group C warranted a moderate wildfire hazard categorization.

Group D had multiple metrics of both fire count and size that were elevated, though it was the fire size that stood out. The TC and MC were both on the low end of the scale, but higher or equivalent to other groups. The mean TCL and PL were all the highest of any group. Combined with the moderate level of fire occurrence, the propensity for larger fires is of concern. Group D was categorized as high wildfire hazard.

Group E had the highest TCL as well as individual installations with outstandingly high metrics for TC and PL, though the remaining installation was relatively low, resulting in very high deviation in these metrics. The other metrics for this group were uniformly low. Though the high TCL is cause for concern, and the individual high results for TC and PL add to that somewhat, uniformity of low results throughout the remainder of the metrics lead to categorization of Group E as moderate overall wildfire hazard.

CATEGORIZATION REVISIONS

Within each initial group, installations were determined by the algorithm to be more similar to each other than to other installations. However, as shown in Figure 53 through Figure 62, some groups had high within-group variability for some metrics. Because of this within group variability, each installation was reviewed against its group's initial categorization, and adjusted if that classification was not justified by these data and expert opinion.

Upon review, only one installation changed categorization from that of its original group. NWS Earle was originally placed in Group E with San Clemente and categorized as moderate as some of its metrics were high, and others were low. One of NWS Earle's very high metrics was the PL. However, the TC was relatively low. Thus, as discussed above, this metric had less meaningfulness than if it were derived from higher total counts of on-installation wildfires. Reconsidering NWS Earle with that in mind, it had only one

elevated metric, which was equally high at four other installations. Thus, NWS Earle was re-categorized as facing a low wildfire hazard.

OUTLIER INSTALLATIONS

NAWS China Lake was the only Navy outlier installation. It had the highest values of any Navy installation for TC, TCL, 90th PS, and TA. It also had the second highest MS and third highest PL. The remaining metrics were uniformly moderate, with the only exception being TCC and TCT which were both low. Because of the number and extremity of the elevated metrics, NAWS China Lake was categorized as facing a high wildfire hazard.

CATEGORIZATION AND DISCUSSION

The wildfire hazard categorization of each installation, as determined by this analysis, is shown in Table 16. These categorizations reflect the aggregation of the 10 metrics characterizing aspects of wildland fire and the adjustments made due to subject matter expert input. This analysis identified 3 Navy installations as having a high wildfire hazard, 8 as moderate, 9 as low, and 17 as facing a negligible wildfire hazard.

The installations categorized as high had high and/or outlier values for numerous metrics, whereas the moderate installations tended to have elevated values for fewer metrics, but low values for others. The installations categorized as low had few, if any, elevated metrics. None of the low installations had any metric with a relative value of more than 55% of the non-outlier maximum for that metric, while every installation in the moderate and high categories had at least one metric in excess of 55% of the non-outlier maximum.

Five installations had zero fires detected anywhere in the analysis area, and an additional 6 installations only had detected fires in the 5-mile buffer surrounding the installation but not within the installation boundary. These installations were categorized as negligible.

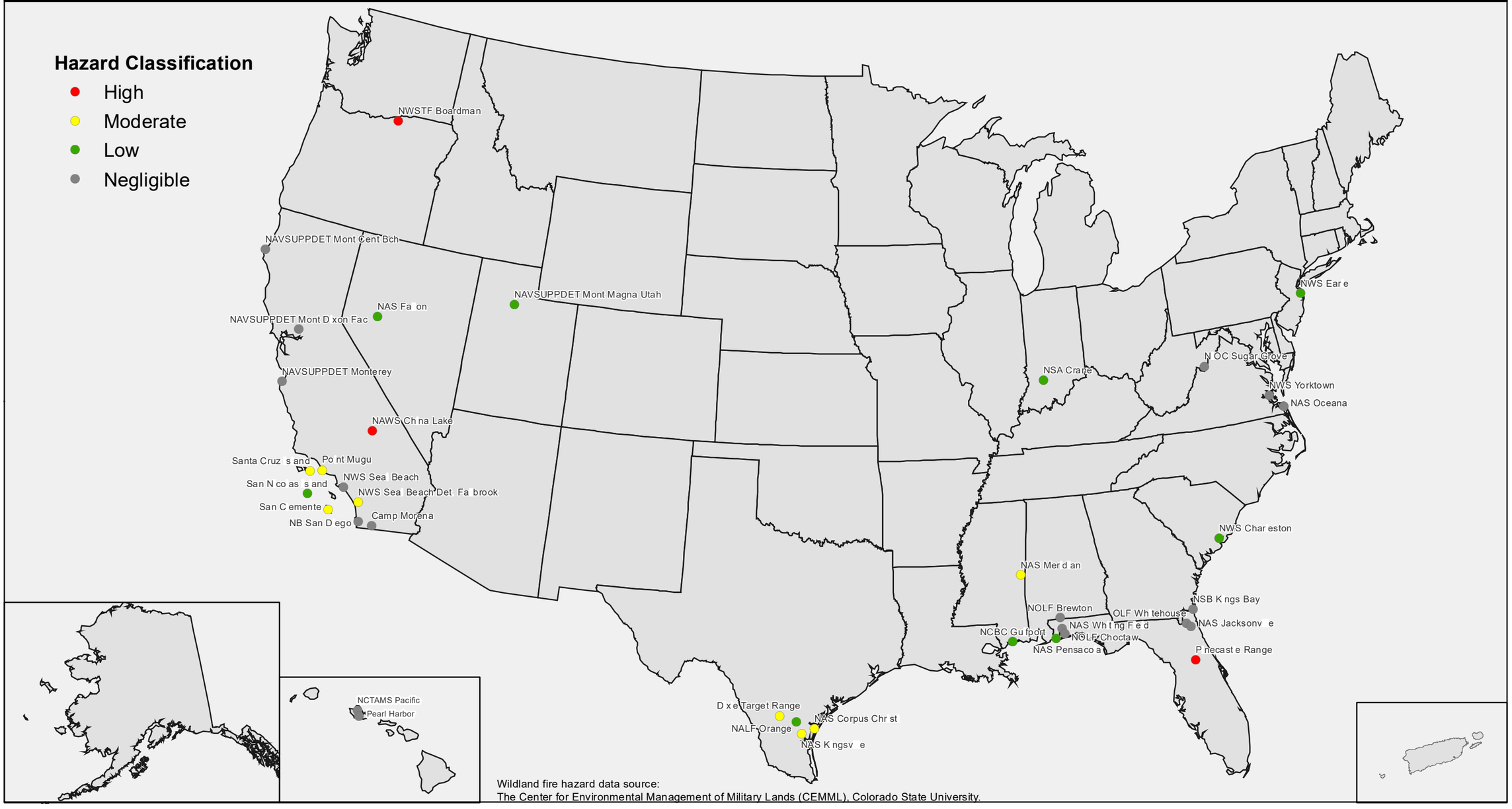
Table 16. Navy installation wildfire hazard categorization. No fires were detected wholly or partially within any installation in the negligible category. Outlier installations are marked with an asterisk.

HIGH	MODERATE	LOW	NEGLIGIBLE
NAWS China Lake*	DIXIE TARGET RANGE	NALF ORANGE	CAMP MORENA
NWSTF BOARDMAN	NAS CORPUS CHRISTI	NAS FALLON	NAS JACKSONVILLE
PINECASTLE RANGE	NAS KINGSVILLE	NAS PENSACOLA	NAS OCEANA
	NAS MERIDIAN	NAVSUPPDET MONT MAGNA UTAH	NAS WHITING FIELD
	NWS SEAL BEACH DET FALLBROOK	NCBC GULFPORT	NAVSUPPDET MONT CENT BCH
	POINT MUGU	NSA CRANE	NAVSUPPDET MONT DIXON FAC
	SAN CLEMENTE	NWS CHARLESTON	NAVSUPPDET MONTEREY
	SANTA CRUZ ISLAND	NWS EARLE	NB SAN DIEGO
		SAN NICOLAS ISLAND	NCTAMS PACIFIC
			NIOC SUGAR GROVE
			NOLF BREWTON
			NOLF CHOCTAW
			NSB KINGS BAY
			NWS SEAL BEACH
			NWS YORKTOWN
			OLF WHITEHOUSE
			PEARL HARBOR

Navy

Wildfire Hazard Classification

Figure 64



Wildland fire hazard data source:
The Center for Environmental Management of Military Lands (CEMML), Colorado State University.

Marine Corps Results

FIRE DETECTIONS

Fourteen Marine Corps installations were included in this analysis. An initial pass through the data revealed 3 installations with no detected fires occurring anywhere inside the installation or within the 5-mile buffer, and an additional 2 installations with fires occurring within the 5-mile buffer, but wholly outside the installation. These five installations were categorized as having negligible fire hazard and removed from further comparative analyses.

The three installations with no wildfires detected anywhere (on-installation or within the buffer) over the entire study period are shown in Table 17. Also shown are the two installations whose detected fires only occurred wholly outside the installation boundary, and the remaining nine installations with at least one wildfire detected on-installation.

Because the dataset of installations with at least one fire detected within the installation boundary was small (only 9 installations), K-means clustering was not used for the analysis of Marine Corps data. Additionally, no outliers were identified due to a lack of sufficient data points with which to statistically determine outlier status. Instead, the installations were considered and categorized individually.

Table 17. List of Marine Corps installations where fires were detected, were only detected wholly outside the installation boundary, or were not detected at all during the study period 2004 - 2014. Outliers are marked with an asterisk.

At Least One Fire Detected On Post	No Fires Detected On Post, at Least One Fire Detected Off Post in Analysis Area	No Fires Detected Anywhere in Analysis Area
CAMP PENDLETON	MCAS CHERRY POINT	MCAS BEAUFORT
CAMP LEJEUNE	BARRY GOLDWATER RANGE WEST	MCAGCC TWENTYNINE PALMS
MCB QUANTICO		MCRD PARRIS ISLAND
CHOC MT AIR GNRY RNG		
POINT OF MARSH TARGET AREA		
MCB HAWAII KANEOHE BAY		
MCAS MIRAMAR		
MCOLF ATLANTIC		
MWTC BRIDGEPORT		

FIRE HAZARD METRICS

The figures below show the rescaled values for each metric listed in Table 2.

The highest TC was at Camp Pendleton where almost twice as many fires were detected at the installation with the second highest TC, Camp Lejeune (Figure 64). The remaining installations had few detected fires inside the boundary relative to these two installations. The TC at 3 installations (MCAS Miramar, MCOLF Atlantic, and MWTC Bridgeport) was zero.

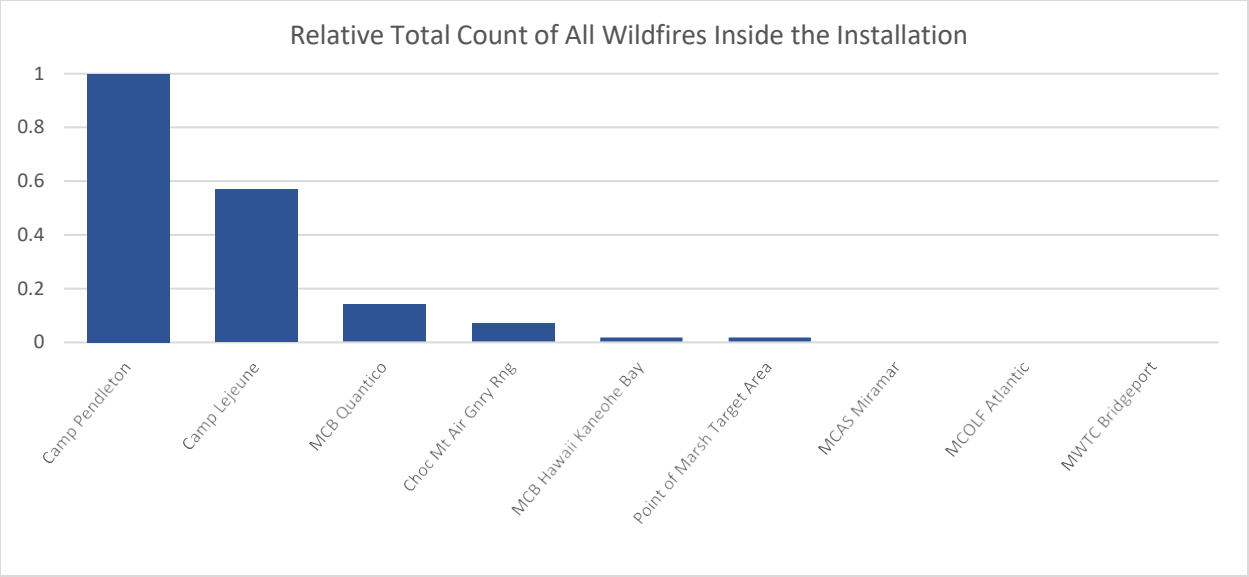


Figure 65. The relative total count, across the entire study period, of detected wildfires whose perimeters are entirely contained within the installation boundary 2004 – 2014. Data have been rescaled relative to the maximum detected count from Camp Pendleton.

The highest MC was also at Camp Pendleton, although Camp Lejeune differed by 7% (Figure 65). There were 3 installations with much lower median counts (Chocolate Mountain Air Gunnery Range, MCB Quantico, and MCAS Miramar), and 7 installations whose median count of detected fires with the analysis area was 0, indicating that more often than not, those installations and their 5-mile buffer areas did not experience a wildfire.

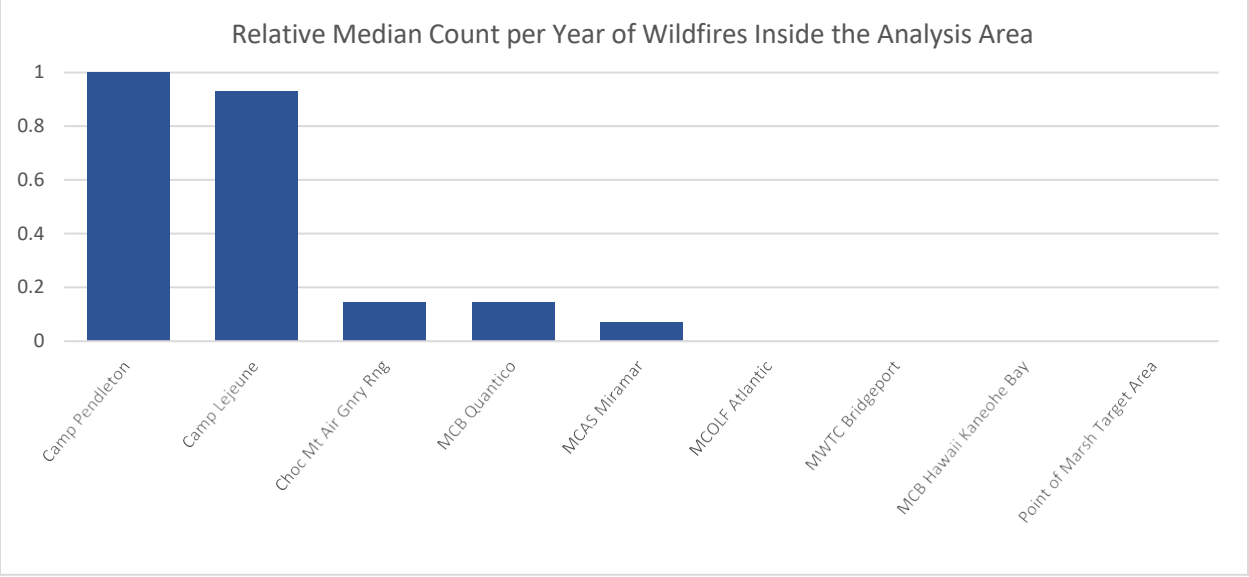


Figure 66. The relative median count per year of detected wildfires within the analysis area 2004 – 2014. Data have been rescaled relative to the maximum detected median count from Camp Pendleton.

The highest TCL was at Camp Pendleton (Figure 66), and Camp Lejeune followed with 59% as many. MCB Quantico and Point of Marsh Target Area also had at least one large fire detected over the study period, but no fires greater than 300 acres were detected wholly within the boundary of the remaining five

installations. However, all installations except Marine Corp Base Hawaii (MCBH) Kaneohe Bay did have at least one large wildfire detected either wholly or partially outside the installation boundary.

Correlation may be expected between the large fire counts and installation size because this metric is a count of large fires whose perimeter is entirely contained within an installation's boundary. All else being equal, large fires are more likely to be transboundary fires, rather than entirely contained within the installation, at small installations than at larger installations. However, because Chocolate Mountain Air Gunnery range (CMAGR), the largest Marine Corps installation, had zero detected large fires, it affected our analysis of a relationship between large fires on the installations relative to installation size. Removing CMAGR from consideration, there was a stronger relationship between on-installation large fire count and installation size than seen in other branches. With the small size of the data set, only eight installations without Chocolate Mountain, it is not possible to draw statistically reliable conclusions. As a result, this metric was viewed with caution during the analysis of installation wildfire hazard.

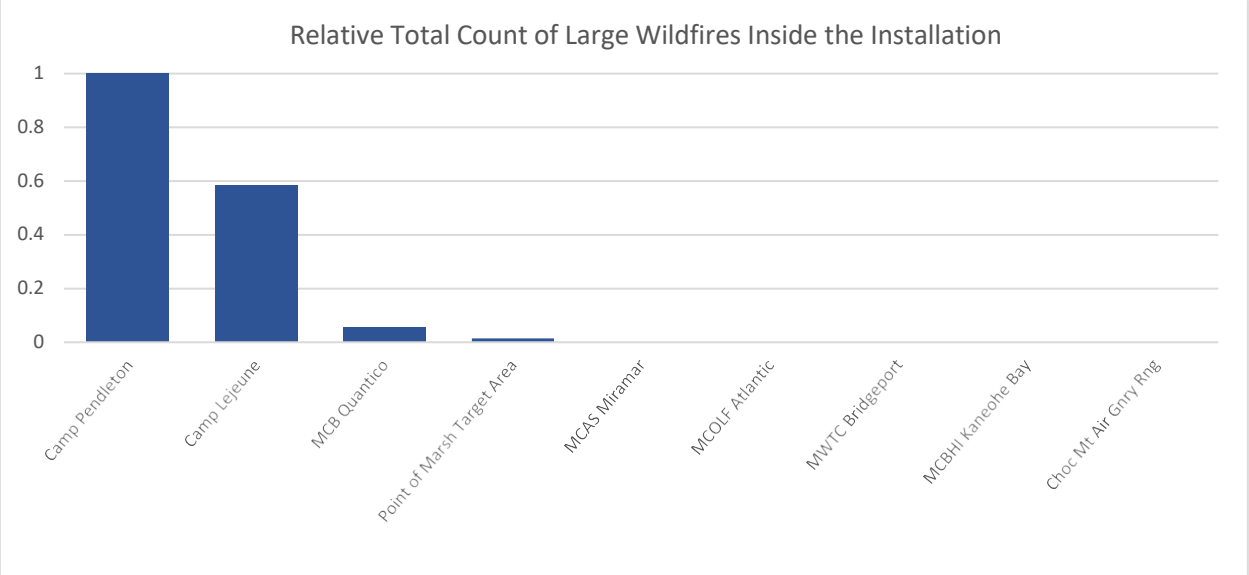


Figure 67. The relative total large fire (> 300 acres) count, across the entire study period, whose perimeters are entirely contained within the installation boundary 2004 – 2014. Data have been rescaled relative to the maximum detected count from Camp Pendleton.

Camp Lejeune and Camp Pendleton had similarly high PL (Figure 67). These installations both had a substantial total number of fires detected, providing a high degree of reliability to the PL metric. MCB Quantico also had a lower, but sufficient, total fire count to make the PL metric reasonably reliable. However, Point of Marsh Target Area (PMTA) had a high PL, yet a low TC. Although potentially interesting, the results from only a few fires should not be used to infer that future fires at PMTA have a high likelihood of growing to over 300 acres. Generally, greater meaningfulness can be attributed to large fire proportions (high or low) that are derived from larger total counts of on-installation wildfires.

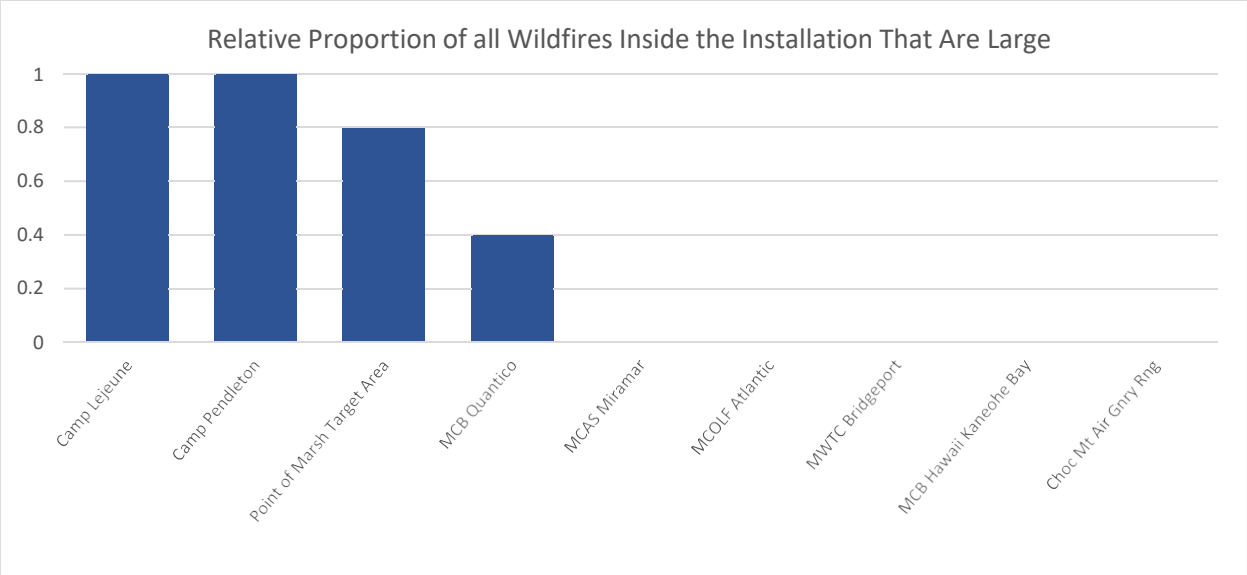


Figure 68. The relative proportion of detected wildfires whose perimeters are entirely contained within the installation boundary that were at least 300 acres 2004 – 2014. Data have been rescaled relative to the maximum proportion from Camp Lejeune.

The highest TCC by a wide margin was at Camp Lejeune (Figure 68). There were 4 other installations with detected fires close to the installation boundary: Camp Pendleton, MCBH, Point of Marsh Target Area, and MCB Quantico. No fires were detected within 0.5 miles of the boundary at the remaining four installations. However, all four of those installations had a transboundary fire detected (see below).

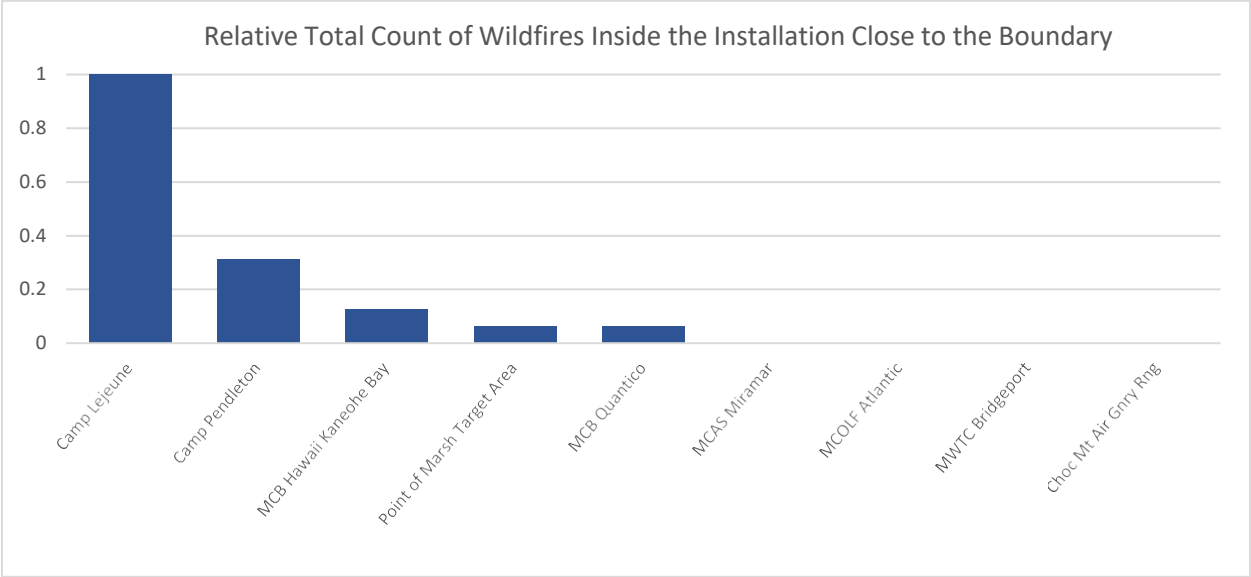


Figure 69. The relative total count of on-installation detected wildfires whose perimeters, while entirely contained within the installation boundary, extended within 0.5 mi of the installation boundary 2004 – 2014. These fires did not cross the installation boundary. Data have been rescaled relative to the maximum detected count from Camp Lejeune.

Camp Pendleton had the highest detected TCT (Figure 69). At least one transboundary wildfire was detected at four additional installations (MCAS Miramar, MCOLF Atlantic, MWTC Bridgeport, and Chocolate Mountain Air Gunnery Range). There were no detected transboundary fires at the four remaining installations. All else being equal, smaller installations would be expected to have higher TCT, as the likelihood of being close enough to the boundary to cross increases as installation area decreases.

However, there was no correlation between naval installation area and TCT, implying that other factors were driving this metric, making it more meaningful to this analysis.

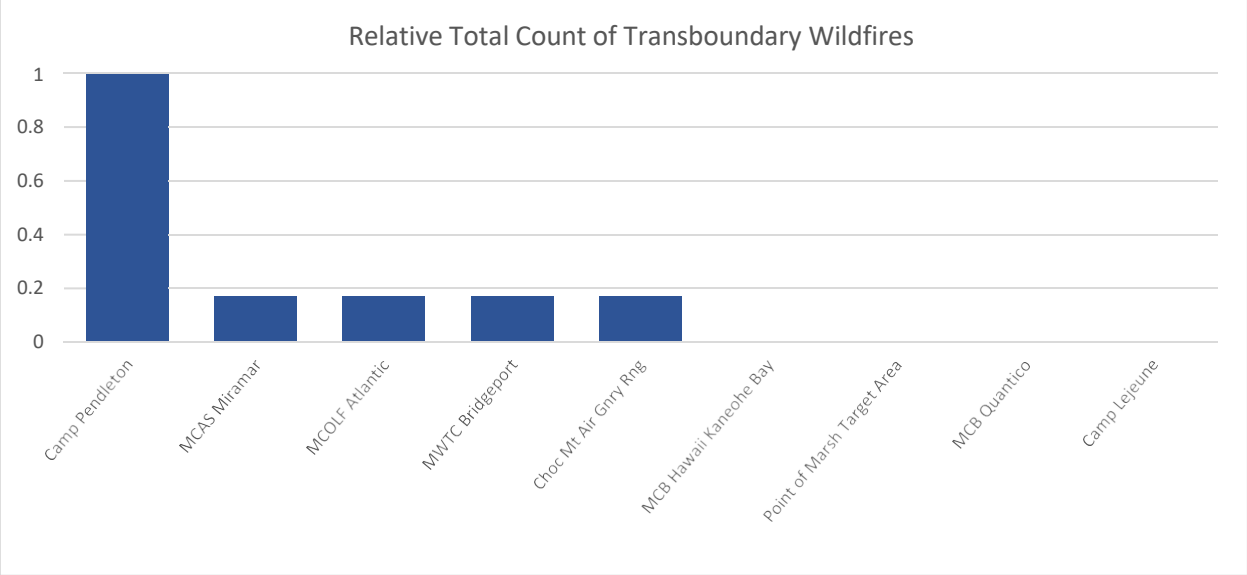


Figure 70. The relative total count, across the entire study period, of detected wildfires that extend across an installation's boundary 2004 - 2014. Data have been rescaled relative to the maximum detected transboundary fire count from Camp Pendleton.

The largest MS was at PMTA (Figure 70). However, there were few wildfires detected in the PMTA analysis area, calling into question the validity of this result. The large median size does capture the potential for large fires at PMTA, but with such a small sample, the likelihood of a large fire, relative to other Marine Corps installations, is probably overestimated. Similar to the PL, the MS metric is more robust when calculated from a larger number of detected fires in the analysis area.

Camp Lejeune and Camp Pendleton had the next largest MS and the next four installations were only somewhat lower. Chocolate Mountain Air Gunnery Range and MCBH were exposed to notably smaller fires than the other Marine Corps installations, only 4.5% and 3.1%, respectively, of the median size at Point of Marsh Target Area.

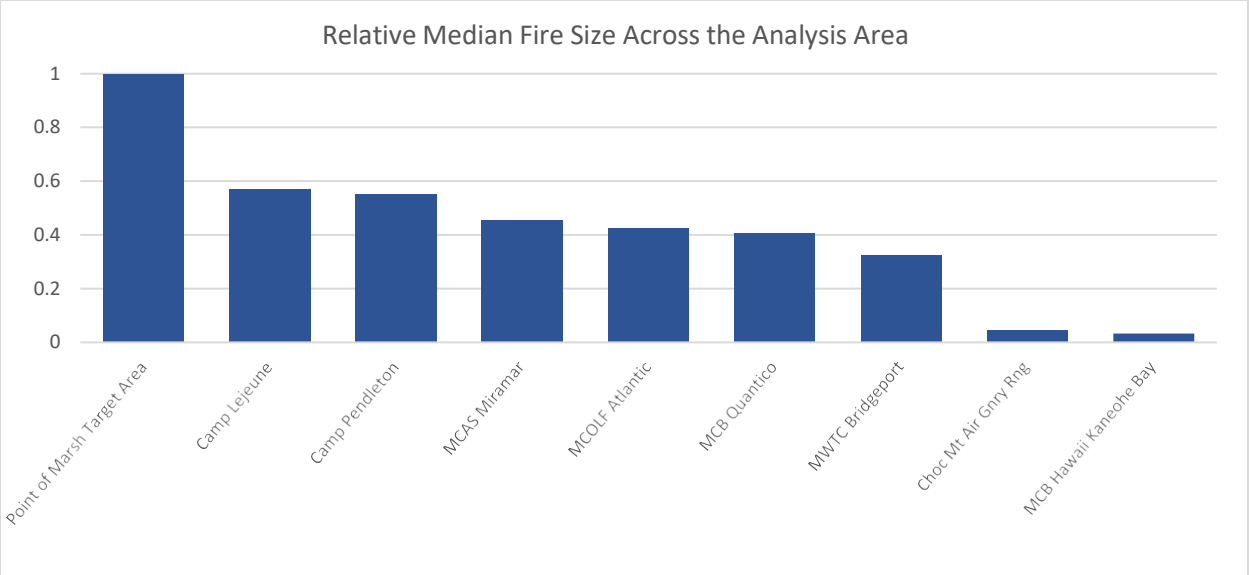


Figure 71. The relative median fire size of detected wildfires occurring anywhere in the analysis area 2004 – 2014. Data have been rescaled relative to the maximum detected median fire size from Point of Marsh Target Area.

The largest 90th PS by far was at MCAS Miramar at an order of magnitude larger than any other installation (Figure 71). Like the median fire size metric, the 90th percentile wildfire size is more robust when calculated from a larger number of detected fires in the analysis area. MCAS Miramar had very few detected wildfires within the boundary (TC) and only a handful in the analysis area.

In addition to MCAS Miramar, 4 other installations had few firea detected within the analysis area. Only at Camp Pendleton, Camp Lejeune MCB Quantico, and Chocolate Mountain were sufficient fires detected to support full consideration of this metric. As a result, this metric was not utilized in the categorization of Marine Corps installations.

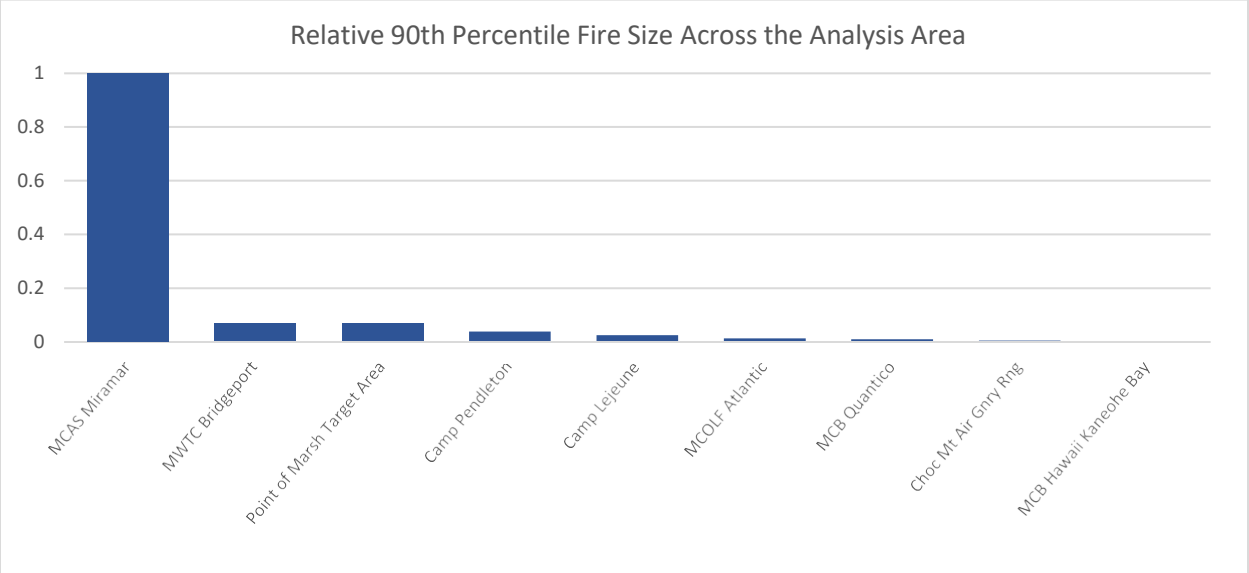


Figure 72. The relative 90th percentile fire size of detected wildfires occurring anywhere in the analysis area 2004 – 2014. Data have been rescaled relative to the 90th percentile wildfire size from MCAS Miramar.

The largest TA was at Camp Pendleton, which was more than three times that of any other installation (Figure 72). Camp Lejeune had the second largest TA, at 27% of the Camp Pendleton acreage, and in turn had ten times as much burned acreage as the next highest installation, MCB Quantico. The remaining installations had between 0.7% (PMTA) and 0.0004% (MCOLF Atlantic) of the Camp Pendleton total acreage. Although larger installations do have a greater potential capacity for total wildfire acreage than smaller installations, the relationship between installation size and total acreage was weak, indicating other factors were contributing to this metric, and substantiating its usefulness as an indicator of wildfire hazard.

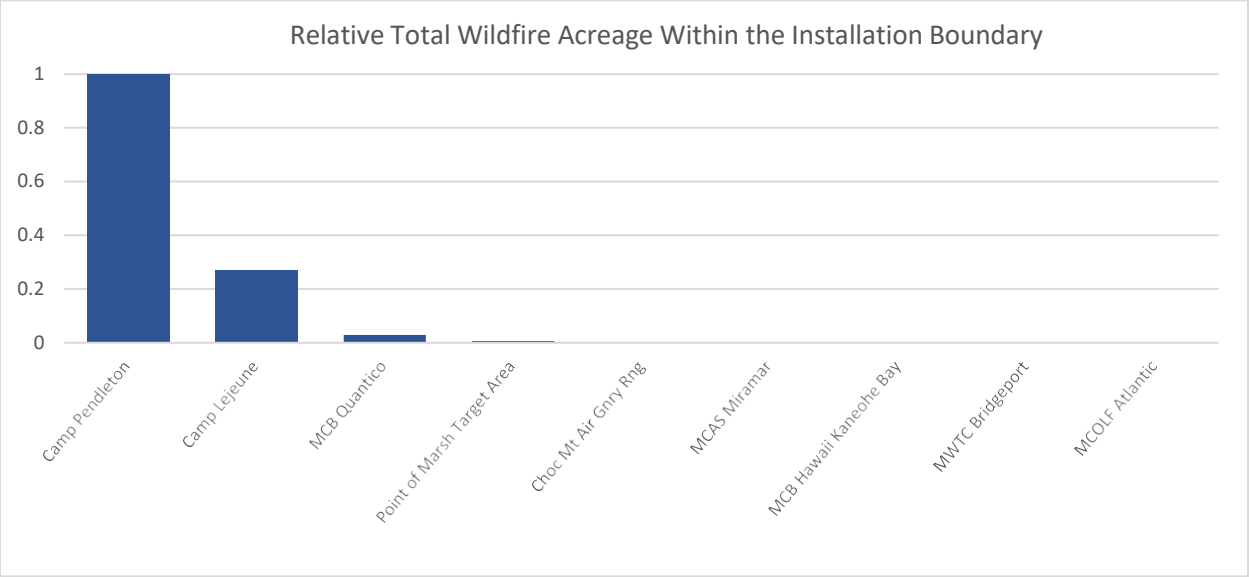


Figure 73. The relative total acreage of detected wildfires, or portions of detected wildfires, occurring on-installation 2004 – 2014. Data have been rescaled relative to the maximum detected count from Camp Pendleton.

The installation with the largest PAB was Camp Pendleton (Figure 73). MWTC Bridgeport, the smallest installation in the dataset had the second highest PAB. Camp Lejeune, although large, had a comparable result to MWTC Bridgeport. The remaining installations had significantly lower proportions than the three highest installations. There was no relationship between installation size and PAB.

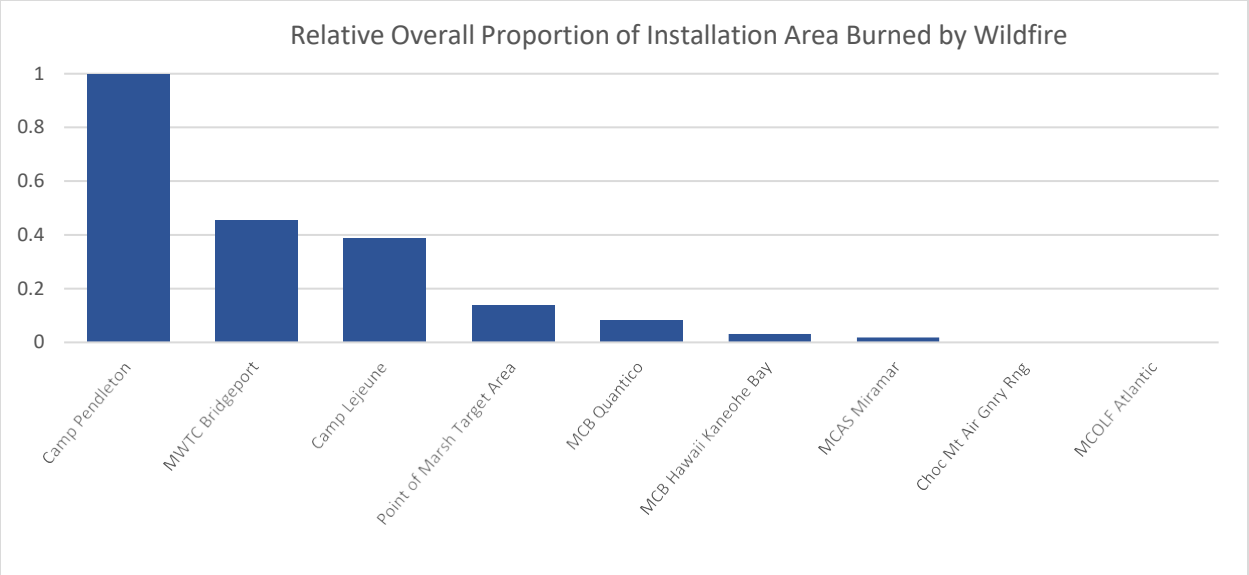


Figure 74. The relative unique acreage burned by wildfires, or portions of wildfires, occurring on-installation, normalized by that installation's area 2004 – 2014. Data have been rescaled relative to the maximum proportion from Camp Pendleton.

CATEGORIZATION AND DISCUSSION

The wildfire hazard categorization of each installation, as determined by this analysis, is shown in Table 18. These categorizations reflect the aggregation of the 10 metrics characterizing aspects of wildland fire and the adjustments made due to subject matter expert input. Because there were an insufficient number of installations to statistically determine whether there were correlations between installation size and some of the metrics, metrics that are potentially directly impacted by installation size were given lower weight in the considerations. Installations with a low total number of fires detected, particularly within the installation, were generally weighted at the low end of the wildfire hazard spectrum.

Within the Marine Corps, this analysis identified 2 installations as having a high wildfire hazard. Camp Pendleton and Camp Lejeune both had high on-installation fire counts (TC), many transboundary fires (TCT) and fires close to the installation boundary (TCC), and high total detected wildfire acreage within the installation boundaries (TA) relative to other installations considered in this assessment. For those few metrics that these two installations did not rank in the top 3 installations, they always ranked in the middle of the pack, never at the bottom. These results clearly indicate there is substantial fire potential at these installations relative to other Marine Corps installations, justifying placement in the high wildfire hazard category.

Four installations were categorized as facing a moderate wildfire hazard. A moderate categorization reflected an installation ranking in the middle for many metrics, or a mix of high and low value metrics. These installations had several on-installation fires, but much lower fire counts that the high category installations. These installations also had a rank metric value of zero in only a few metrics

The 3 installations categorized as facing a low wildfire hazard all had one detectable transboundary fire, but no other detected wildfires within the installation boundary. These installations had low relative values for most metrics and limited or no metrics with moderate or high values. The 90th percentile fire size across the analysis area of MCAS Miramar and MWTC Bridgeport was relatively high, which does indicate the potential for the regional weather and vegetation to promote significant fires, but the fire counts were so low that this is an unreliable statistic. Although the hazard faced by these installations is

low, they face a distinctly different wildfire hazard than the negligible-categorized installations, and low wildfire hazard should not be interpreted as none.

Two installations had zero fires detected anywhere in the analysis area, and an additional 3 installations only had detected fires in the 5-mile buffer surrounding the installation. These were all categorized as having negligible wildfire hazard.

Table 18. Marine Corps installation wildfire hazard categorization. No fires were detected wholly or partially within any installation in the negligible category. There were no outlier installations within the Marine Corps.

HIGH	MODERATE	LOW	NEGLIGIBLE
CAMP LEJEUNE	CHOC MT AIR GNRY RNG	MCAS MIRAMAR	BARRY GOLDWATER RANGE WEST
CAMP PENDLETON	MCB HAWAII KANEOHE BAY	MCOLF ATLANTIC	MCAGCC TWENTYNINE PALMS
	MCB QUANTICO	MWTC BRIDGEPORT	MCAS BEAUFORT
	POINT OF MARSH TARGET AREA		MCAS CHERRY POINT
			MCRD PARRIS ISLAND

Marine Corps

Wildfire Hazard Classification

Figure 75

Wildland fire hazard data source:
The Center for Environmental Management of Military Lands (CEMML), Colorado State University.

Cross-Branch Results

FIRE DETECTIONS

145 installations from the Air Force (40), Army (54), Navy (37), and Marine Corps (14) were included in the Cross-Branch analysis. An initial pass through the data revealed 35 installations with no detected fires occurring anywhere inside the installation or within the 5-mile buffer, and an additional 26 installations that only had detected fires occurring wholly outside the installation within the 2005 – 2014 period of record used for the cross-branch analysis. We categorized any these as negligible wildfire hazard within the scope of this analysis, and removed them from further comparative analyses.

The 35 installations with no wildfires detected anywhere (on-installation or within the 5-mile buffer) over the entire study period are shown in Table 19. Also shown are the 26 installations whose detected fires only occurred wholly outside the installation boundary, and the remaining 84 installations with at least one wildfire detected on-installation. While it is possible that some wildfires do occur at or near installations at which no fire was detected, again, this study's purpose is not a full accounting of all fires, but an analysis of comparable data across all installations that reasonably represents wildfire hazard.

Twelve installations were identified as outliers and are indicated with asterisks in Table 19. These were removed from the cluster analysis and evaluated independently per the methodology of this study, leaving 72 installations in the analysis pool. Note that the set of outliers for the Cross-Branch analysis is not merely a compilation of the outliers from each individual branch. Considered collectively, the statistical evaluation of outliers changes due to the different sample. Therefore, installations may have moved into or out of outlier status relative to the analyses of the individual military branches.

The analysis time period was constrained to 2005 – 2014 by Army data availability. This is one year shorter than the individual branch analyses for the Air Force, Navy, and Marine Corps (2004 – 2014) and therefore some installations changed categories in Table 19 as fires in 2004 are not included in this analysis.

Table 19. List of Cross-Branch installations where fires were detected, were only detected wholly outside the installation boundary, or were not detected at all during the study period 2005 - 2014. Outliers are marked with an asterisk.

At Least One Fire Detected On Post	No Fires Detected On Post, at Least One Fire Detected Off Post in Analysis Area	No Fires Detected Anywhere in Analysis Area
ABERDEEN PROVING GROUND	BARRY GOLDWATER RANGE WEST	ADELPHI
ARNOLD AFB	CAMP MORENA	CARLISLE BARRACKS
AVON PARK AFR*	FORT BUCHANAN	CHEYENNE MTN AFS
BARKSDALE AFB	FORT DETRICK	COLUMBUS AFB
BARRY GOLDWATER AFR*	FORT LEAVENWORTH	DETROIT ARSENAL
BEALE AFB	FORT MEADE	DOBBINS ARB
CAMP LEJEUNE	JB CHARLESTON	FORT BELVOIR
CAMP MACKALL	LITTLE ROCK AFB	FORT GREELY
CAMP PARKS	MCAS CHERRY POINT	FORT HAMILTON
CAMP PENDLETON	MCOLF ATLANTIC	FORT LEE
CAPE CANAVERAL AFS	MWTC BRIDGEPORT	FORT MYER MCNAIR
CHOC MT AIR GNRY RNG	NAS JACKSONVILLE	GRAND FORKS AFB
DARE COUNTY BOMBING RANGE*	NAS WHITING FIELD	HOLLOMAN AFB
DIXIE TARGET RANGE	NAVSUPPDET MONT CENT BCH	HOMESTEAD ARB
DUGWAY PROVING GROUND*	NAVSUPPDET MONT DIXON FAC	JB ELMENDORF RICHARDSON
EGLIN AFB HURLBURT AFB*	NAVSUPPDET MONTEREY	JB LANGLEY FORT EUSTIS
ELLSWORTH AFB	NB SAN DIEGO	JUNIPER BUTTE BOMBING RANGE
FORT AP HILL*	NCTAMS PACIFIC	MACDILL AFB
FORT BENNING*	NIOC SUGAR GROVE	MCAGCC TWENTYNINE PALMS
FORT BLISS	NOLF BREWTON	MCAS BEAUFORT
FORT BRAGG	NOLF CHOCTAW	MCRD PARRIS ISLAND
FORT CAMPBELL	PEARL HARBOR	NAS OCEANA
FORT CARSON	SANTA CRUZ ISLAND	NATICK
FORT DEVENS	SHARPE ARMY DEPOT	NEW BOSTON AS
FORT DRUM	TINKER AFB	NSB KINGS BAY
FORT GORDON	WEST POINT	NWS SEAL BEACH
FORT HOOD		NWS YORKTOWN
FORT HUACHUCA		OLF WHITEHOUSE
FORT HUNTER LIGGETT		PICATINNY ARSENAL
FORT IRWIN		PRESIDIO MONTEREY
FORT JACKSON		ROBINS AFB
FORT KNOX		ROCK ISLAND ARSENAL
FORT LEONARD WOOD		USAG MIAMI
FORT MCCOY		WESTOVER ARB
FORT POLK		WRIGHT PATTERSON AFB
FORT RILEY		
FORT RUCKER		
FORT SILL		
FORT STEWART		
FORT WAINWRIGHT*		
HILL AFB UTTR		
JB CAPE COD		
JB LEWIS MCCHORD		
JB MCGUIRE DIX LAKEHURST		
JB SAN ANTONIO		
KIRTLAND AFB		
MCAS MIRAMAR*		
MCB HAWAII KANEOHE BAY		
MCB QUANTICO		
MELROSE AFR		
MOODY AFB GRAND BAY		

At Least One Fire Detected On Post	No Fires Detected On Post, at Least One Fire Detected Off Post in Analysis Area	No Fires Detected Anywhere in Analysis Area
MOUNTAIN HOME AFB		
NALF ORANGE		
NAS CORPUS CHRISTI		
NAS FALLON		
NAS KINGSVILLE		
NAS MERIDIAN		
NAS PENSACOLA		
NAVSUPPDET MONT MAGNA UTAH		
NAWS CHINA LAKE		
NCBC GULFPORT		
NSA CRANE		
NTTR*		
NWS CHARLESTON		
NWS EARLE		
NWS SEAL BEACH DET FALLBROOK		
NWSTF BOARDMAN*		
PECR		
PINECASTLE RANGE		
PINON CANYON		
POINT MUGU		
POINT OF MARSH TARGET AREA		
REDSTONE ARSENAL		
SAN CLEMENTE		
SAN NICOLAS ISLAND		
SAYLOR CREEK BOMBING RANGE*		
TYNDALL AFB		
USAF ACADEMY		
USAG HAWAII PTA		
USAG HAWAII SCHOFIELD		
VANDENBERG AFB		
WHITE SANDS MISSILE RANGE		
YAKIMA TRAINING CENTER		
YUMA PROVING GROUND		

FIRE HAZARD METRICS

The figures below show the rescaled values for each metric listed in Table 2. These are the scaled values excluding the 12 outlier installations. Only the first 20 installations are shown. The full comparative graphs of all installations in the Cross-Branch analysis are available in Appendix A – Cross-Branch Graphs.

The greatest TC was at Yakima Training Center, closely followed by Camp Pendleton, Fort Bliss, and Fort Bragg (Figure 75). An additional 12 installations also had high total detected wildfire counts. There was a notable drop in the TC between the upper 16 installations and the middle 21 (12% drop). Of the lowest 35 installations, 6 had no wholly on-installation fires detected.

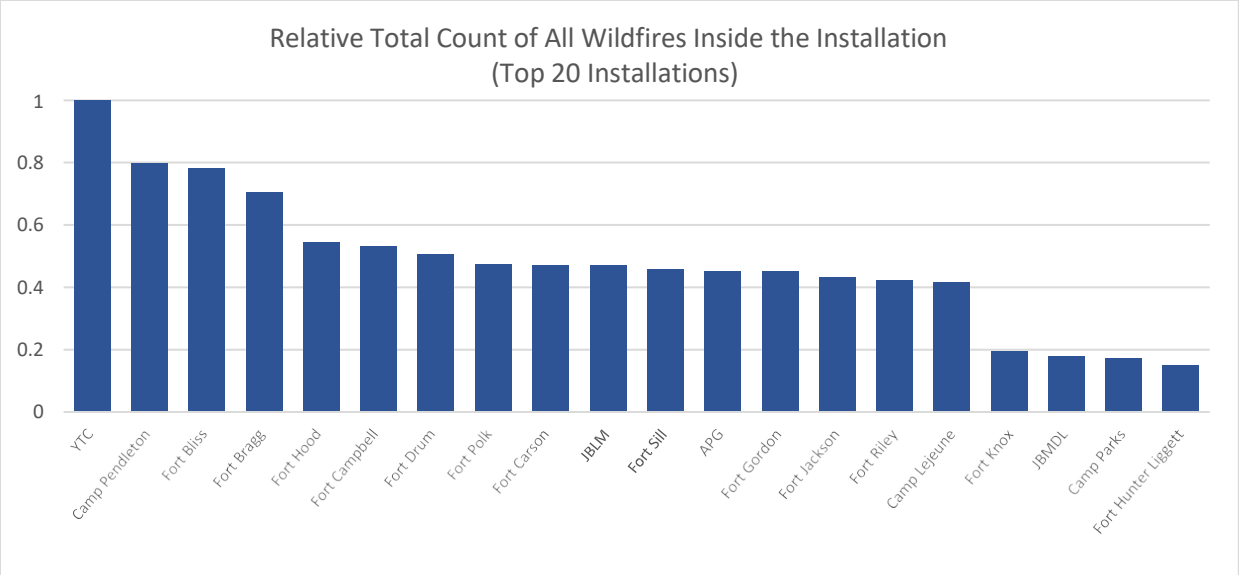


Figure 76. The relative total count, across the entire study period, of detected wildfires whose perimeters are entirely contained within the installation boundary 2005 – 2014. Data have been rescaled relative to the maximum detected count from YTC after removing the outlier installations from the calculation.

The highest MC was at Fort Bragg (Figure 76). The next 12 installations decreased gradually from 76% to 46% of Fort Bragg's median count. Between Camp Lejeune and Fort Jackson, values dropped rapidly by 14%, after which another 17 installations had 10% to 29% of Fort Bragg's MC. There were 19 installations whose MC was 0, indicating that in a "typical" year, those installations and their immediate surrounds did not experience a wildfire.

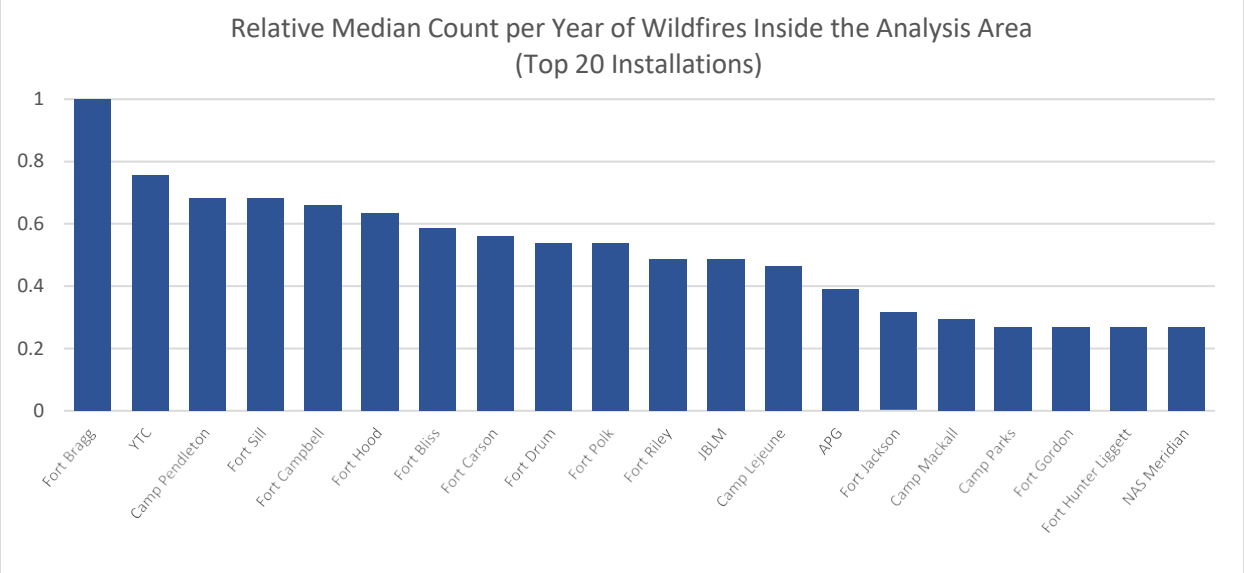


Figure 77. The relative median count per year of detected wildfires within the analysis area 2005 – 2014. Data have been rescaled relative to the maximum detected median count from Fort Bragg after removing the outlier installations from the calculation.

The highest TCL was found at Camp Pendleton, with Fort Sill, Fort Bragg, Fort Polk, and Fort Hood also having high values (Figure 77). There was a steep decline over the next 4 installations, decreasing from 70% to 42% of Camp Pendleton's count. Counts are relatively consistent from Fort Carson through PCMS, after which there was a drop of 6% to Hill AFB/UTTR. After this point, counts were again relatively

consistent at 14-15% of the value of Camp Pendleton rounding out the top 20 installations. There were 28 installations with no detected large fires wholly within the installation boundary.

Correlation may be expected between the large fire counts and installation size because this metric is a count of large fires whose perimeter is entirely contained within an installation's boundary. All else being equal, large fires are more likely to be transboundary fires, rather than entirely contained within the installation, at small installations than at larger installations. Although many installations with the smallest large fire counts were, indeed, some of the smaller installations, there was no statistically relevant relationship in the Cross-Branch data between detected large fire counts and installation size. Thus, we concluded that on-installation large fire counts were more than a proxy for installation size.

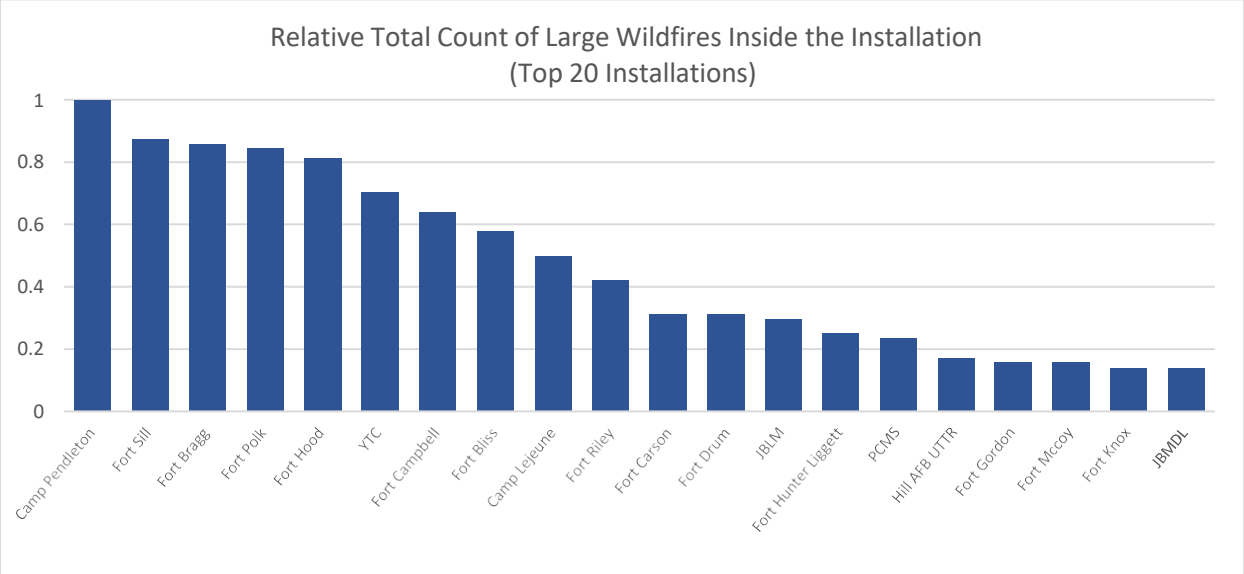


Figure 78. The relative total large fire (> 300 acres) count, across the entire study period, whose perimeters are entirely contained within the installation boundary 2005 – 2014. Data have been rescaled relative to the maximum detected large fire count from Fort Sill, after removing the outlier installations (which have high, outlier values for many metrics) from the calculation.

The PL was equally high at Vandenberg AFB and Fort Rucker (Figure 78). Although a high large fire proportion in conjunction with a small total count of wildfires does indicate the potential for significant fire growth, it can also be skewed by the small sample size of the total fire count. Vandenberg AFB and Fort Rucker, with the largest relative proportion, both had relatively very low TC (1.2% and 0.8% of the maximum count, respectively). But all of those few fires were greater than 300 acres. Although potentially interesting, the results from a limited number of fires should not be used to infer that future fires on Vandenberg AFB or Fort Rucker will also grow to over 300 acres. Generally, greater meaningfulness can be attributed to large fire proportions (high or low) that are derived from larger total counts of on-installation wildfires. Thus, of the top 20 results, those from PCMS, Hill AFB/UTTR, Fort Sill, Fort Polk, Fort Hunter-Liggett, Fort Hood, Fort McCoy, WSMR, Camp Pendleton, Fort Bragg, and Fort Campbell are all considered highly reliable.

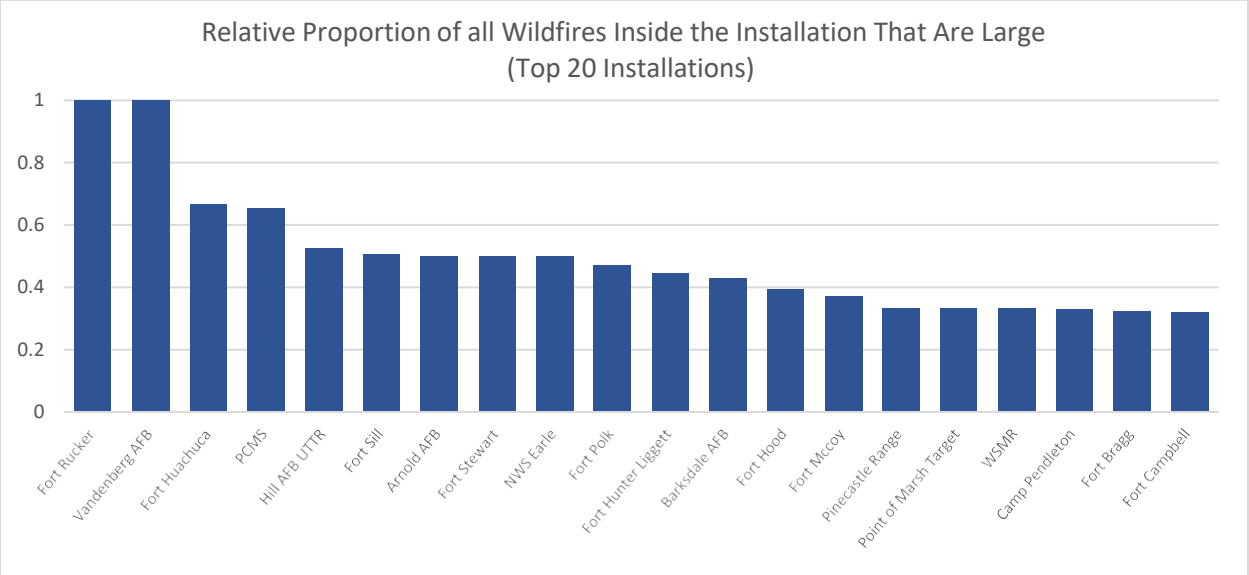


Figure 79. The relative proportion of detected wildfires whose perimeters are entirely contained within the installation boundary that were at least 300 acres 2005 – 2014. Data have been rescaled relative to the maximum proportion from Fort Rucker and Vandenberg AFB after removing the outlier installations from the calculation.

The highest TCC was at Fort Gordon followed closely by Camp Parks (Figure 79). Fort Bragg and JBLM also had high TCC values, both in excess of 80% of the value of Fort Gordon. The next four installations had relatively high TCC values, ranging from 43 to 64% that of Fort Gordon, but notably lower than the first 4 installations. Between Fort Carson and Fort Campbell, there was a drop of 13%. The next 7 installations were between 33% and 20% of Fort Gordon. There were 36 installations with lower close boundary counts, and 21 installations with no on-installation fires detected within 0.5 miles of the boundary.

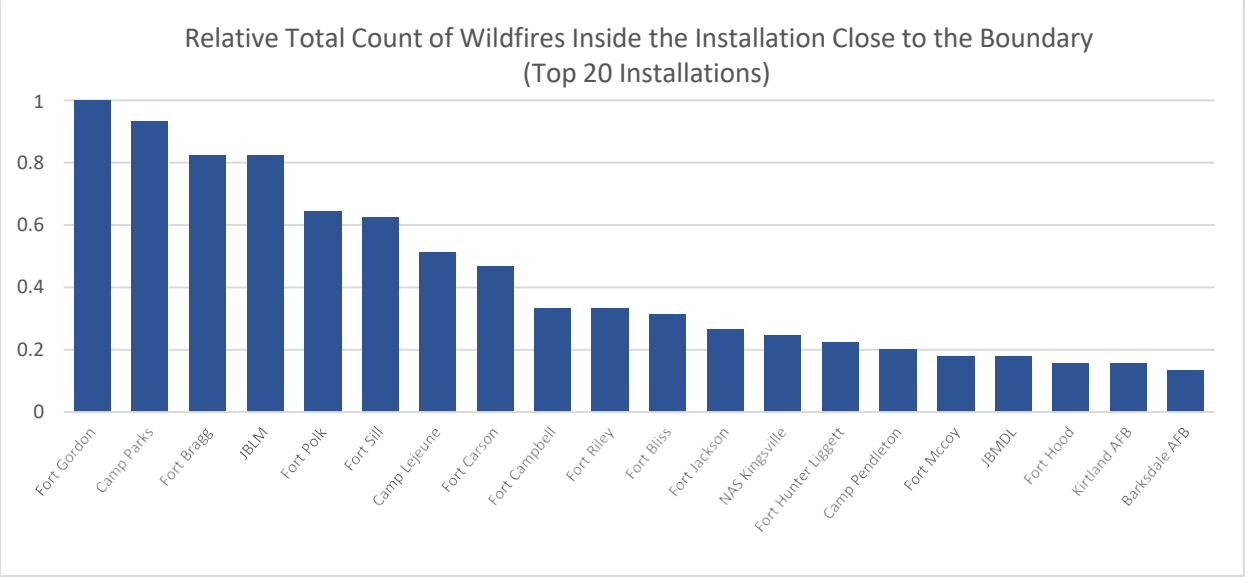


Figure 80. The relative total count of on-installation detected wildfires whose perimeters, while entirely contained within the installation boundary, extended within 0.5 mi of the installation boundary 2005 – 2014. These fires did not cross the installation boundary. Data have been rescaled relative to the maximum detected count from Fort Gordon after removing the outlier installations from the calculation.

Hill AFB/UTTR had the highest TCT value, with Fort Bliss, Camp Pendleton, and Pinyon Canyon Maneuver Site (PCMS) forming a second tier of installations with a high number of transboundary fires (Figure 80). PCMS through Dixie Target Range formed a group of 8 installations with a more moderate TCT. There were an additional 20 installations with a low TCT and 40 installations where no fires were detected that crossed the boundary.

All else being equal, smaller installations would be expected to have higher transboundary wildfire counts, as the likelihood of being close enough to the boundary to cross it increases as installation area decreases. However, there was little correlation between installation area and transboundary fire counts in this data, implying that other factors were driving this metric, and making it more meaningful to this analysis.

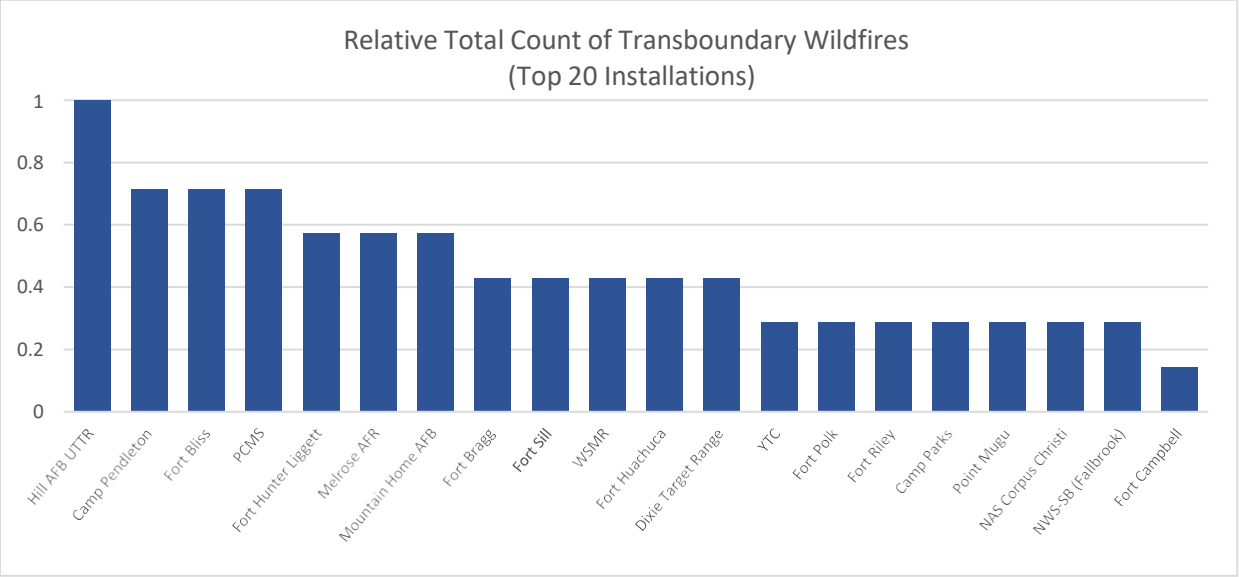


Figure 81. The relative total count of detected wildfires that extend across an installation's boundary 2005 - 2014. Data have been rescaled relative to the maximum detected count from Hill AFB/UTTR after removing the outlier installations from the calculation.

The largest MS was at Pinecastle Range (Figure 81). However, the relative count of fires within the Pinecastle analysis area was quite low. The large median size does capture the potential for large fires at Pinecastle Range, but with such a small sample, the true likelihood for a "typical" fire at Pinecastle Range to be the largest of typical fires at all installations is probably overestimated. Similar to the large fire proportion, the median fire size metric is more robust when calculated from a larger number of detected fires in the analysis area. Of the top 20 results, measures from PCMS, Hill AFB/UTTR, Fort Polk, Fort Hunter Liggett, Fort Sill, NAWS China Lake, WSMR, and Fort Hood can be considered reliable due to higher TC metrics.

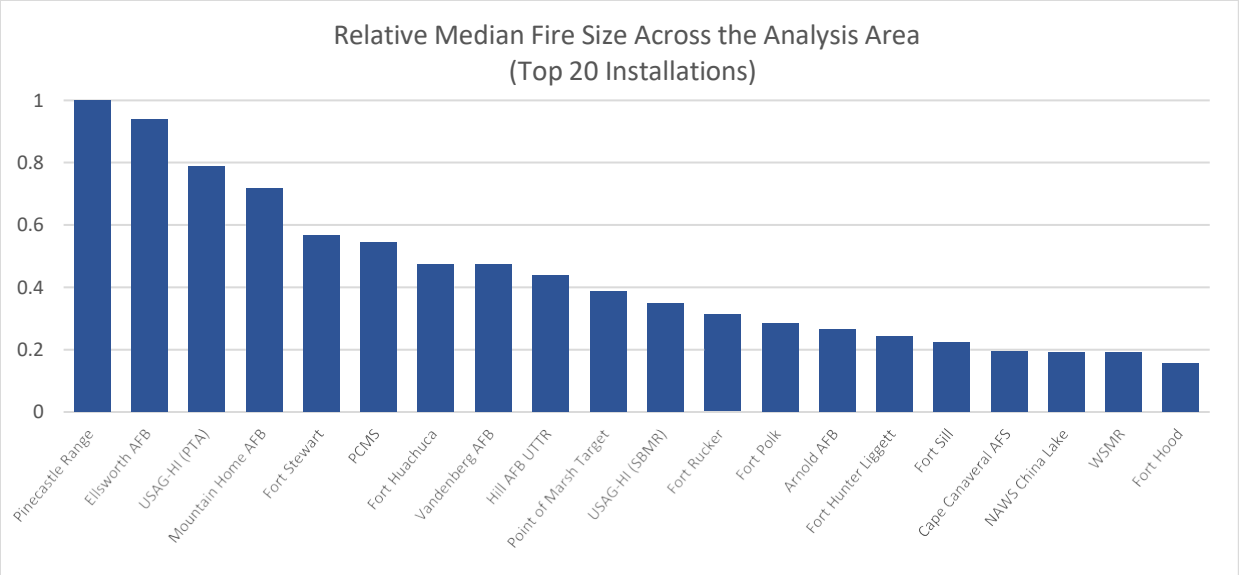


Figure 82. The relative median fire size of detected wildfires occurring anywhere in the analysis area 2005 – 2014. Data have been rescaled relative to the maximum detected median fire size from Pinecastle Range after removing the outlier installations from the calculation.

The largest 90th PS was at NAWS China Lake, closely followed by Pinecastle Range (Figure 82). Like the median fire size metric, the 90th percentile wildfire size is more robust when calculated from a larger number of detected fires in the analysis area. Here, half of the 6 installations with the largest 90th PS (NAWS China Lake, Hill AFB/UTTR, Fort Hunter Liggett) had moderate or high TC values. However, 11 of the top 20 installations had low enough wildfire counts (TC) to call into question the robustness of those results. The large number of installations with questionable 90th PS values resulted in reduced consideration for this metric in the placement of installations into wildfire hazard categories.

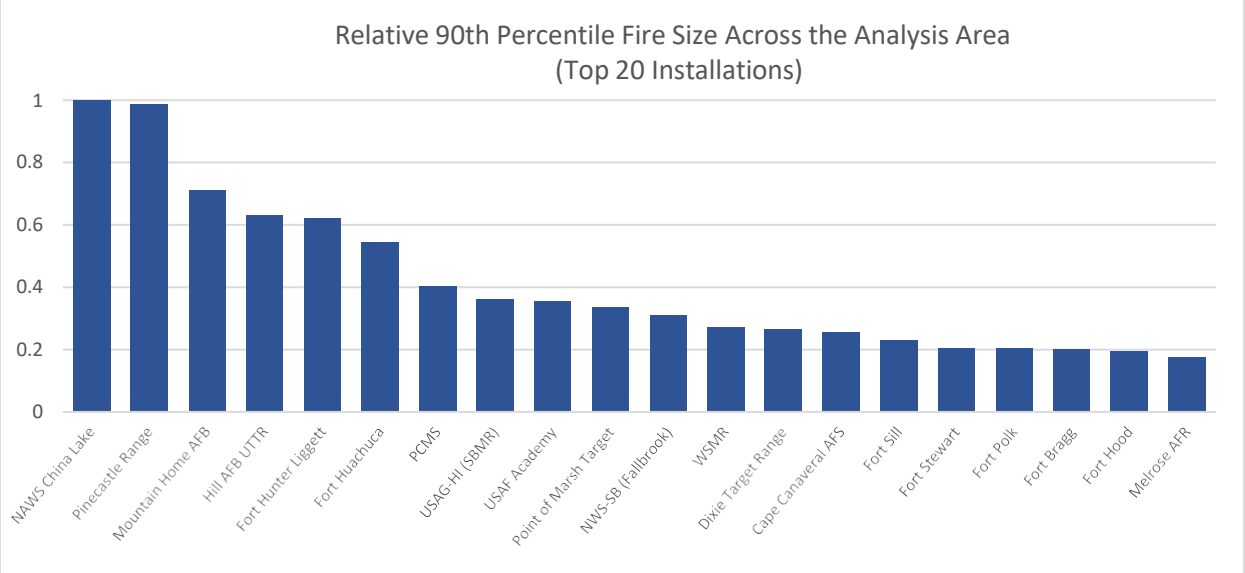


Figure 83. The relative 90th percentile fire size of detected wildfires occurring anywhere in the analysis area 2005 - 2014. Data have been rescaled relative to the maximum detected count from NWS China Lake after removing the outlier installations from the calculation.

The largest TA was at Camp Pendleton, with Fort Bragg, Pinyon Canyon Maneuver Site, and Yakima Training Center forming a second tier of high values (Figure 83). After a drop of 11% to Fort Sill, the distribution gradually declined from 63% of Camp Pendleton's value to 34% at NAWS China Lake, separating them from the top 4 installations. A drop of 10% to JBLM marked a shift to the last 58 installations with lower TA values. Although larger installations do have a greater potential capacity for total wildfire acreage than smaller installations, there was no relationship in the Cross-Branch dataset between installation size and total acreage, indicating other factors were driving this metric, and substantiating its usefulness as an indicator of wildfire hazard.

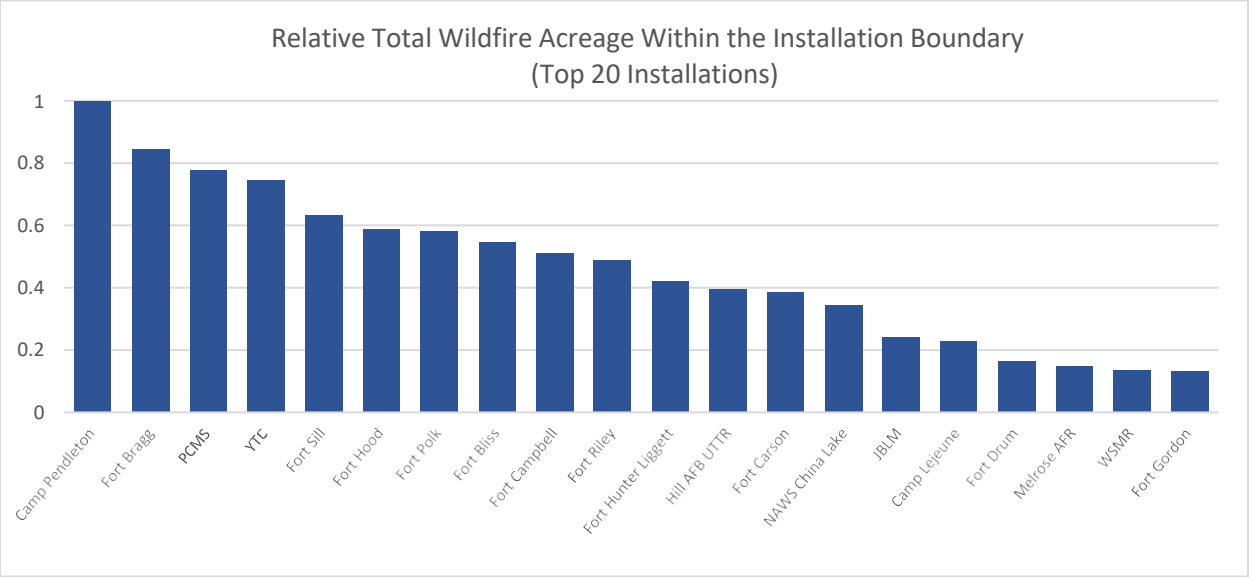


Figure 84. The relative total acreage of detected wildfires, or portions of detected wildfires, occurring on-installation 2005 – 2014. Data have been rescaled relative to the maximum detected count from Camp Pendleton after removing the outlier installations from the calculation.

NWS Seal Beach Det Fallbrook had the highest PAB (Figure 84). Camp Pendleton, Pinecastle Range, Camp Parks, Fort Sill, PCMS, and Fort Riley all had high values for this metric. There is a slight drop of 9% between those installations and the next 8 which and another slight drop of 7% to the remaining installations which continue to decrease into the low end of the TA spectrum. Although the installations with the greatest proportions burned are some of the smaller installations, there was no relationship between installation size and proportion burned across the entire Cross-Branch set of installations.

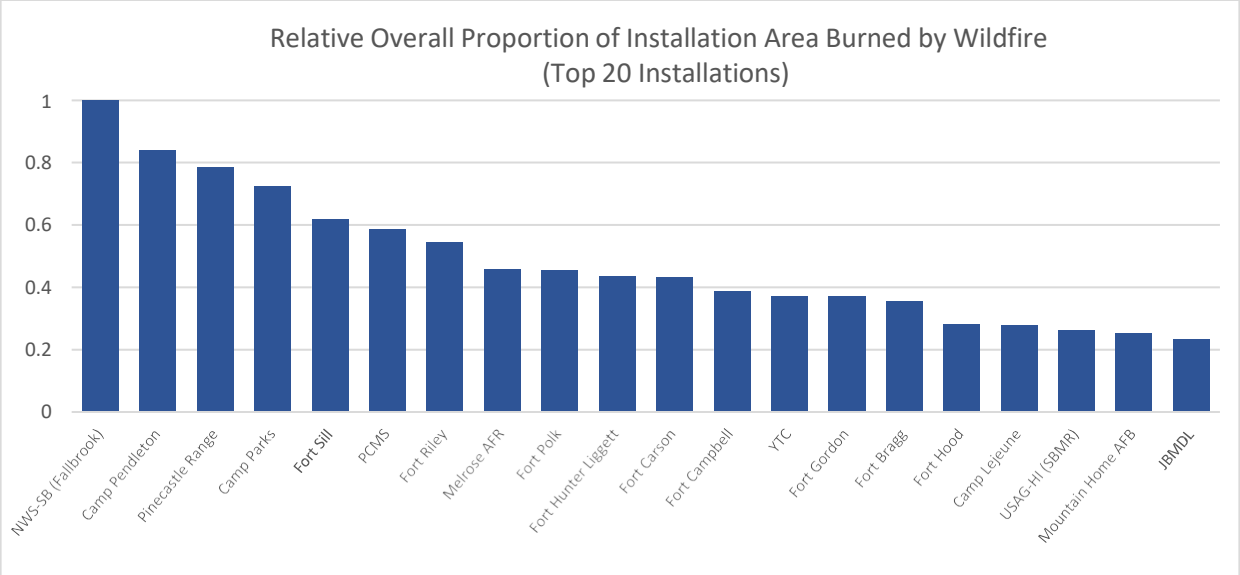


Figure 85. The relative unique acreage burned by wildfires, or portions of wildfires, occurring on-installation, normalized by that installation's area 2005 – 2014. Data have been rescaled relative to the maximum proportion from NWS Seal Beach Det Fallbrook after removing the outlier installations from the calculation.

INSTALLATION CLUSTERS

The above metrics characterize individual aspects of fire hazard for each installation, but making overall conclusions utilizing 10 separate characteristics across numerous installations is difficult. The results in Table 20 utilize the output from the K-mean clustering after outliers were removed. Each group contains installations that are more alike to each other than they are to installations in other groups. In addition to facilitating prioritization among installations, the groupings also identify installations that share common hazard characteristics.

Table 20. Cross-Branch installation groups formed by K-means clustering, after excluding the outlier installations which have high, outlier values for many metrics. Here, the outlier installations are identified in their own group.

Group ID	Installations
A	ARNOLD AFB
	ELLSWORTH AFB
	FORT RUCKER
	FORT STEWART
	POINT OF MARSH TARGET AREA
	USAG HAWAII PTA
	VANDENBERG AFB
B	CAMP LEJEUNE
	CAMP PARKS
	FORT CARSON
	FORT DRUM
	FORT GORDON
	FORT RILEY
	JB LEWIS MCCHORD
C	ABERDEEN PROVING GROUND
	BARKSDALE AFB
	BEALE AFB
	CAMP MACKALL
	CAPE CANAVERAL AFS
	CHOC MT AIR GNRY RNG
	DIXIE TARGET RANGE

Group ID	Installations
	FORT DEVENS
	FORT IRWIN
	FORT JACKSON
	FORT KNOX
	FORT LEONARD WOOD
	FORT MCCOY
	JB CAPE COD
	JB MCGUIRE DIX LAKEHURST
	JB SAN ANTONIO
	KIRTLAND AFB
	MCB HAWAII KANEOHE BAY
	MCB QUANTICO
	MELROSE AFR
	MOODY AFB GRAND BAY
	NALF ORANGE
	NAS CORPUS CHRISTI
	NAS FALLON
	NAS KINGSVILLE
	NAS MERIDIAN
	NAS PENSACOLA
	NAVSUPPDET MONT MAGNA UTAH
	NCBC GULFPORT
	NSA CRANE
	NWS CHARLESTON
	NWS EARLE
	PECR
	POINT MUGU
	REDSTONE ARSENAL
	SAN CLEMENTE
	SAN NICOLAS ISLAND
	TYNDALL AFB
	USAF ACADEMY
	USAG HAWAII SCHOFIELD
	WHITE SANDS MISSILE RANGE
	YUMA PROVING GROUND
D	CAMP PENDLETON
	FORT BLISS
	FORT BRAGG
	FORT CAMPBELL
	FORT HOOD
	FORT POLK
	FORT SILL
E	FORT HUACHUCA
	FORT HUNTER LIGGETT
	HILL AFB UTTR
	MOUNTAIN HOME AFB
	NAWS CHINA LAKE
	NWS SEAL BEACH DET FALLBROOK
	PINECASTLE RANGE
	PINON CANYON
Outliers	AVON PARK AFR
	BARRY GOLDWATER AFR
	DARE COUNTY BOMBING RANGE
	DUGWAY PROVING GROUND
	EGLIN AFB HURLBURT AFB

Group ID	Installations
	FORT AP HILL
	FORT BENNING
	FORT WAINWRIGHT
	MCAS MIRAMAR
	NTTR
	NWSTF BOARDMAN
	SAYLOR CREEK BOMBING RANGE

The means of each group for each metric are shown in Table 21. The highest group mean was 0.789, Group D's TCL. The lowest group mean was 0.007, for Group A's MC, though there were several other very low means, all also in Group A.

For this analysis to be valid, the within-group variability must be considered when evaluating the significance of the differences among them. The Kruskal-Wallis post-hoc test found that all variables provided statistically significant differentiation among clusters. Full results of pairwise tests for significance (Dunn's Test) are in Appendix A – Kruskal-Wallis and Dunn's Tests.

Table 21. Cross-Branch group means for each metric.

	A	B	C	D	E
Relative Total Count of All Wildfires Inside the Installation	0.008	0.416	0.067	0.661	0.056
Relative Median Count per Year of Wildfires Inside the Analysis Area	0.007	0.439	0.093	0.692	0.137
Relative Total Count of Large Wildfires Inside the Installation	0.018	0.288	0.028	0.789	0.102
Relative Proportion of all Wildfires Inside the Installation That Are Large	0.476	0.171	0.079	0.340	0.362
Relative Total Count of Wildfires Inside the Installation Close to the Boundary	0.013	0.597	0.059	0.400	0.067
Relative Total Count of Transboundary Wildfires	0.041	0.102	0.075	0.375	0.464
Relative Median Fire Size Across the Analysis Area	0.533	0.058	0.055	0.134	0.466
Relative 90th Percentile Fire Size Across the Analysis Area	0.155	0.065	0.071	0.163	0.650
Relative Total Wildfire Acreage Within the Installation Boundary	0.008	0.237	0.023	0.681	0.262
Relative Overall Proportion of Installation Area Burned by Wildfire	0.035	0.377	0.071	0.424	0.427

Although K-means clusters are often described using the group mean, the range of values within a group for each metric is also informative. The mean and distribution of each group's values for each metric are shown in Figure 85 – Figure 94. Categorized wildland fire hazard was assigned after evaluating the means and distributions for each group among the metrics.

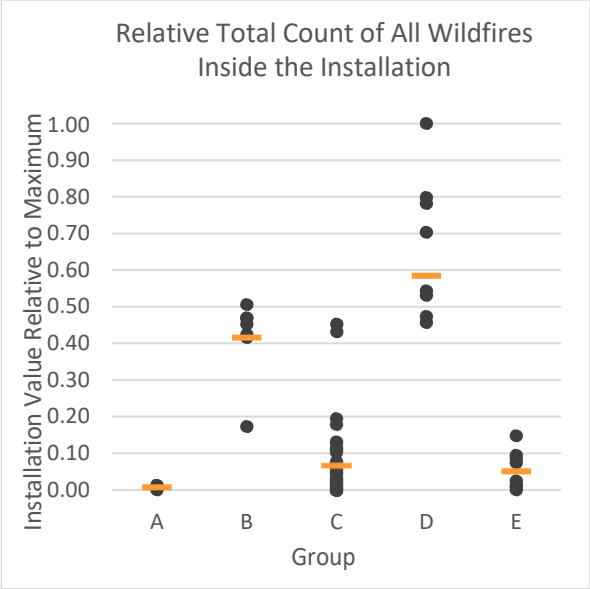


Figure 86. Clusters of the relative total count of detected wildfires whose perimeters are entirely contained within the installation boundary. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

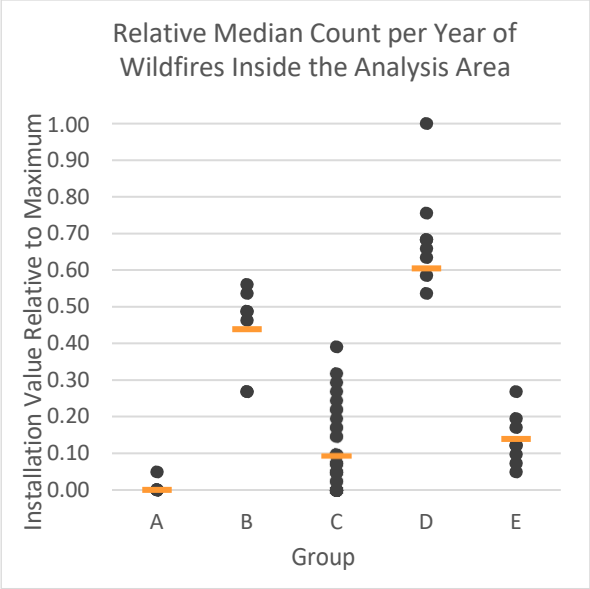


Figure 87. Clusters of the relative median count per year of detected wildfires within the analysis area. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

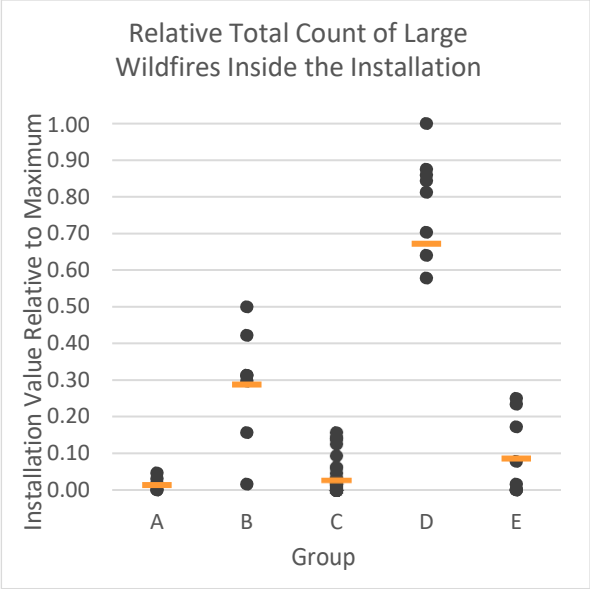


Figure 88. Clusters of the relative total large fire (>300 acres) count whose perimeters are entirely contained within the installation boundary. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

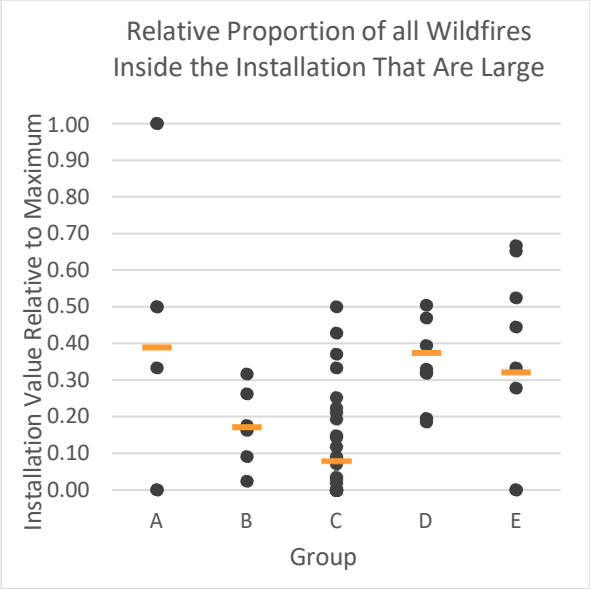


Figure 89. Clusters of the relative proportion of detected wildfires whose perimeters are entirely contained within the installation boundary that were at least 300 acres ("large"). Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

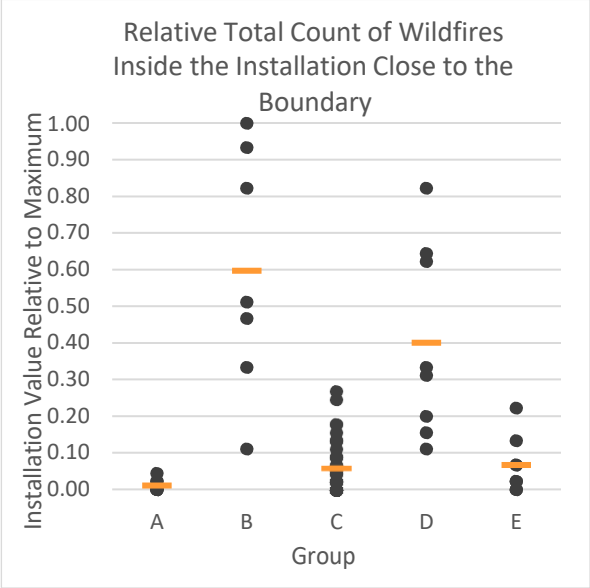


Figure 90. Clusters of the relative count of on-installation detected wildfires whose perimeters, while entirely contained within the installation boundary, extended within ate least 0.5 mi of the installation boundary. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

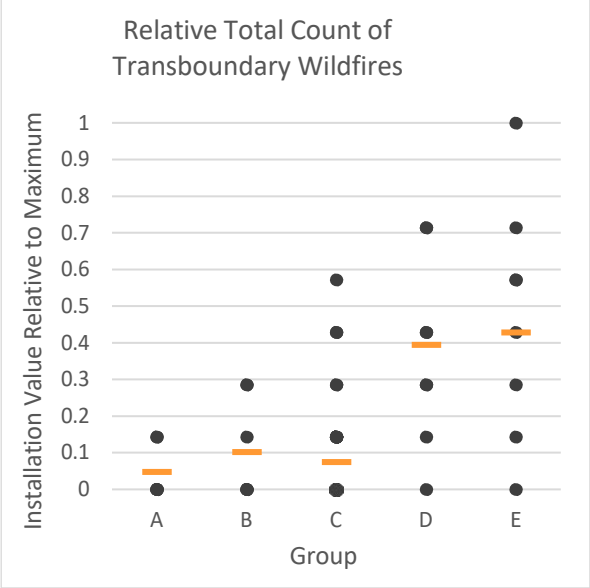


Figure 91. Clusters of the relative total count of detected wildfires that extend across an installation's boundary. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

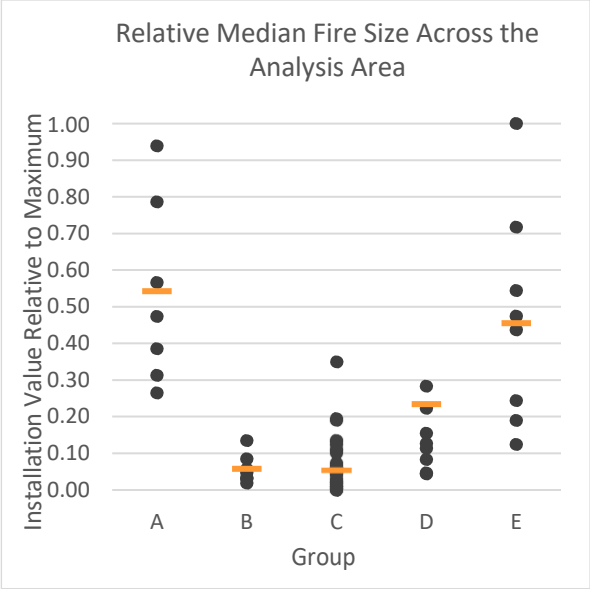


Figure 92. Clusters of the relative median fire size of detected wildfires occurring anywhere in the analysis area (on-installation and/or within the surrounding 5-mile buffer). Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

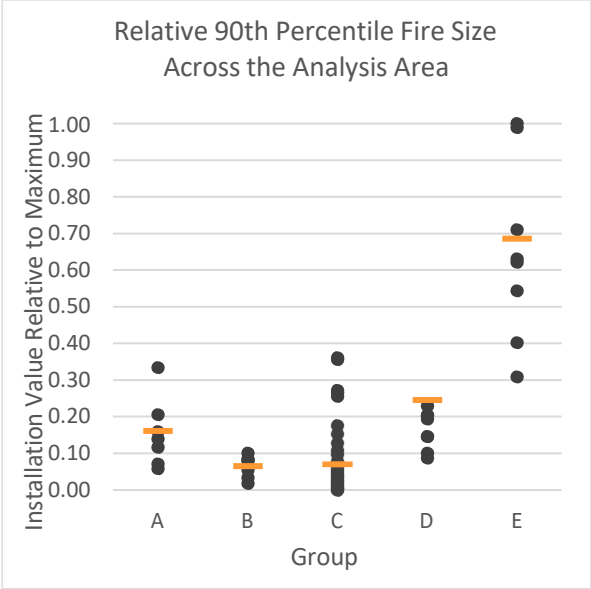


Figure 93. Clusters of the relative 90th percentile of detected wildfires occurring anywhere in the analysis area. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

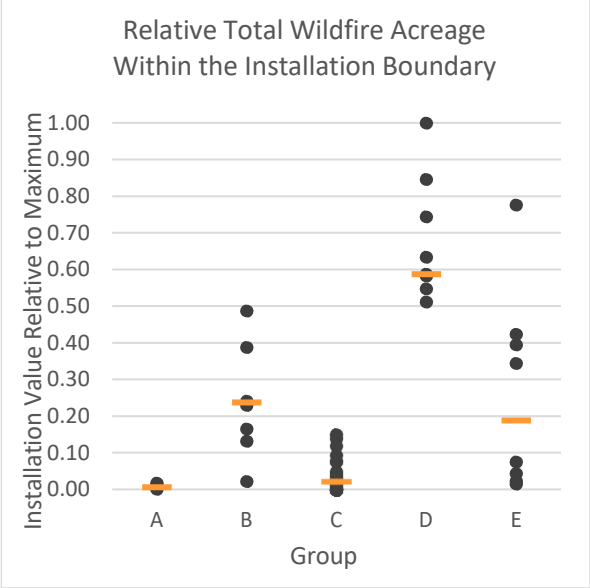


Figure 94. Clusters of the relative total acreage, across the entire study period, of detected wildfires, or portions of detected wildfires, occurring on-installation. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

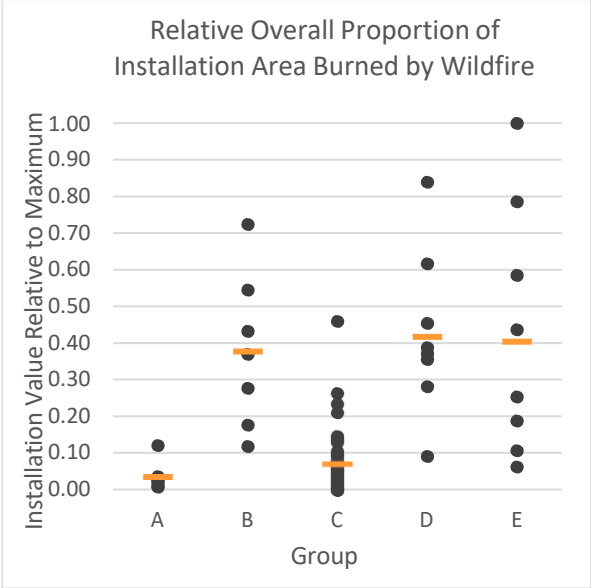


Figure 95. Clusters of the relative unique acreage, across the entire study period, of detected wildfires, or portions of wildfires, occurring on-installation, normalized by that installation's area. Data have been rescaled relative to the maximum value observed after removing the outlier installations from the calculation. Installations were grouped by K-means clustering. Dots represent individual installation values and bars represent the group mean.

INITIAL CATEGORIZATION BY CLUSTER

Triaging the installations included considering each group's distribution across the metrics as shown in the figures above. These measures highlighted the likenesses and differences among them and informed the final categorization of each group.

Group A had relatively low or low-moderate values for all but two metrics. Group A had the highest PL mean of any group, and also included the installation with the single highest value. The range of values for this metric within the group was large, but tended toward elevated values. This group also had the highest mean for MS, and all installations had elevated values.

However, the meaning of these metrics can be lost when applied to installations with small numbers of fires detected. Every installation in Group A had fewer than 10 total fires detected within the entire analysis period of 10 years and its TC was the lowest of any group as a result. This indicated that the two elevated metrics (PL and MS), may not represent a broad wildfire hazard, but rather a conditional wildfire hazard, meaning that fires were rare, but when they occurred, they were likely to be large.

Group A's 90th PS values were in the low to moderate range, indicating that their largest fires were unlikely to reach the scale occurring at other installations, but that fires at these installations tended to be larger than average.

Although these installations tended to experience few fires, the data suggested that there was potential for substantial fire growth on the rare occasions when fires do occur. This warranted a moderate categorization for Group A.

Group B had numerous metrics that ranged from low to moderate, and one metric that was high. These installations tended towards moderate numbers of fires (TC, MC) and generally low fire sizes (PL, MS, 90th PS), though the TCL mean was at the low end of moderate. Though this group did have the second highest mean for TC, MC, TCL, and TA, the values were only moderate relative to the highest value for each metric.

The TCC and PAB both had a wide range of values from low to high, with high and moderate group means respectively, including three of the four highest TCC installation values of all installations.

Group B's elevated, but not notably high, values across several fire size metrics indicated a potential for numerous fires to grow to moderate sizes. The close boundary metrics indicated a potential for transboundary fires, although transboundary fires had not occurred yet at most of these installations as evidenced by the generally low TCT. The similarity between the PAB and the TA indicated that fires were dispersed across the installations, with each fire likely to burn area that was not burned in other fires during the analysis period. This is likely a more difficult management situation than installations where fires repeatedly occur in the same general location. Given these considerations, Group B was categorized as facing a moderate wildfire hazard.

With 42 installations, Group C was by far the largest group created by the K-means clustering analysis. Although in Figure 85 through Figure 95 Group C contained installations with some moderate values, the vast majority of installation values were in the very low to low portion of the spectrum. This was reflected in uniformly low group means.

Although most metrics showed some moderate values, most installations had a moderate value in only one metric, if any. No installation in Group C had multiple moderate value metrics, and no installations had any metrics that were high. Because of the overwhelming preponderance of low values, Group C was categorized as low.

Group D had moderate to high values for numerous metrics. Of particular note were the very high fire numbers (TC, MC) combined with the high TCL and moderate PL. Because the total count was so high, the PL was low to moderate.

Both the TCC and the TCT varied widely, although installations within Group D that tended to have elevated values in one of these metrics generally had lower values in the other. Nevertheless, this result indicated significant potential for transboundary fires, including some that have been realized at some installations (per the TCT results).

The MS and 90th PS were relatively low, likely a result of the high fire counts. However, with so many fires, the frequency of observations of moderate fire sizes was much higher than at installations in other groups.

The mean TA was the highest of any group, partly a result of the sheer number of fires detected, with no installations falling into the bottom half of that spectrum. Conversely, the PAB spanned almost the entire spectrum, with three of the seven installations in the high half of the range.

The high fire counts and moderate fire sizes, which in conjunction led to the highest total acreage mean of any group, are reason for significant concern about the fire situation at these installations. Alone, this result would be enough to categorize Group D as subject to high wildfire hazard, but with no metrics that are particularly low, there is little question that Group D warrants a categorization of high.

Group E had some of the most within-metric variability of any group. The group tended to have fewer, but larger, fires. The TC, MC, and TCL means were relatively low. Contrasting with relatively few on-installation fires, the elevated TCT was notable as it indicated that even with few fires, these installations were regularly experiencing transboundary fires.

The PL ranged from low to moderate. Similarly, the MS and 90th PS included some very high results. However, there were fewer than 10 fires detected at 4 of the 8 installations in this group, calling into question the meaningfulness of these fire size results. The total acreage and overall proportion metrics ran the gamut from low to high, tending toward moderate.

With the highly variable results, and a lack of detected fires at some installations to give confidence to the fire size metric results, it was difficult to clearly define a category for this group. However, with such low fire counts, the transboundary fire issue that these installations appear to be facing is a significant concern. In addition, in reviewing the large fire results for the individual installations within this group that had sufficient numbers of fires to give confidence to those results, it was clear that these installations face the prospect of large fires. These installations were some of the highest results in the 90th PS and MS. This makes it clear that at least these four installations within this group have the potential to experience large fires, but within the context of a low total fire load. This led to a wildfire hazard categorization of moderate.

CATEGORIZATION REVISIONS

Within each initial cluster, the installations were determined by the algorithm to be more similar to each other than to other installations. However, as shown in Figure 85 - Figure 94, some groups had high within-group variability for at least some of the metrics. Because of this within group variability, each installation was reviewed against its group's initial categorization, and adjusted if that classification was not justified by these data and subject matter expert opinion. Upon review, one installation was changed from moderate to low, and four installations that were initially categorized as low were moved to the moderate category.

Arnold AFB had a moderate large fire proportion and a slightly elevated median fire size (the lowest of Group A), both of which are more reflective of the very low fire counts than a strong tendency for large

fires. Because the other metrics for Arnold AFB were extremely low, it was moved from moderate to the low category.

From Group C, Aberdeen Proving Ground, Fort Jackson, Melrose AFR, and White Sands Missile Range all had multiple metrics which warranted their re-categorization from the low to the moderate category. Aberdeen Proving Ground had moderate or moderate-high TC and MC; Fort Jackson had elevated values for both of those metrics as well as TCC; Melrose AFR had moderate-high values for the TCT and the PAB; White Sands Missile Range had elevated values for the PL, TCT, and 90th PS. Although the reasons varied, all these installations had multiple values that indicated a different enough hazard from the remainder of Group C to warrant a moderate categorization.

OUTLIER INSTALLATIONS

Twelve installations were removed from the analysis due to being identified as statistical outliers for one or more metrics. These installations are discussed below in alphabetical order.

Avon Park AFR had outlier values for TC and MC. Both of these were the second highest of any installation in the study. It also had relatively high values for the TCL and the fourth highest TCC of any installation. The TCT, PL, MS and 90th PS were relatively low, but the very high number of fires combined with these relatively small fire sizes to produce moderate results for TA and PAB. Because of the number of fires and acreage burned, as well as the high TCC value, Avon Park was categorized as facing a high wildfire hazard.

Barry M. Goldwater AFR was an outlier for 90th PS. It also had a relatively high value for the TA. The PL was moderate, as was the TCT and MS. Other metrics were relatively low. This indicated that fires were infrequent, but had the potential (though not necessarily a likelihood) to grow very large. Barry M. Goldwater also is located within the desert southwest, which experienced an unusual rainfall pattern in the winter of 2004 – 2005 that resulted in extensive vegetation cover where normally cover is insufficient to carry fire. This resulted in a larger than normal number of fires and several large fires in 2005 that would not normally be possible. Large fires in 2005 led to the 90th PS, MS, and TA results, as well as to fires that crossed the boundary. Eliminating the anomalous 2005 results removed 88% of all detected fires. The remaining fires were much smaller than those that occurred in 2005. Thus, in the absence of the unusual flush of vegetation that occurred in 2005, Barry M. Goldwater AFR experienced few wildfires and was categorized as low, though in the rare years when flushes of vegetation occur, this categorization would not be accurate.

Dare County Bombing Range was an outlier for 90th PS. It also had a high value for the PAB. However, all other metrics were either very low or moderate, even when compared to non-outlier installations. The moderate metrics were influenced by the very small fire count and are questionable indicators of fire potential. With a very low number of fires but several moderately large fires and one very large fire, indicating potential for large fires, Dare County Bombing Range was categorized as moderate.

Dugway Proving Ground was an outlier for 90th PS. It also had a high value for TCT and moderate values for the PL, MS, TA. Other metrics were low. Because of the mix of low fire numbers, but demonstrated large-fire and transboundary potential, Dugway Proving Ground was categorized as facing a moderate wildfire hazard.

Eglin AFB and Hurlburt AFB was an outlier for the MC, which was the third highest of any installation in the study. It also had high values for the TC, TCL, and TCC. Its pattern of elevated and low metrics was very similar to Avon Park AFB, with low values for PL, MS and 90th PS, likely driven by the very high fire counts. The TA was similar to that of Avon Park AFB (moderate), although the PAB was lower at Eglin which is a significantly larger installation. Nevertheless, the high fire counts and elevated acreage burned warranted categorization as high wildfire hazard.

Fort AP Hill was an outlier for the TCC, which was the second highest of any installation in the study. It did not have any other metrics with high values. It had moderate TC, MC, and TCL, as well as a moderate PAB. The remaining metrics were low. Although there were moderate numbers of fires, the fire sizes were small enough that the total on-installation acreage was still relatively low. Because of the limited elevated metrics, Fort AP Hill was categorized as moderate.

Fort Benning was an outlier for TC, MC, and TCC. Fort Benning was the highest installation in the study in all of these measures. No other metrics were high, but it had moderate values for TCL, TA, and PAB. Similar to other installations with very high fire counts, the MS and 90th PS were low, but the number of fires was sufficient to result in significant TA and PAB. Because of the very high fire counts and resulting elevated acreage, Fort Benning warranted categorization high wildfire hazard.

Fort Wainwright had the inverse situation of Avon Park AFB, Eglin AFB and Hurlburt AFB, and Fort Benning. Instead of many fires that were not particularly large, Fort Wainwright had few fires that grew to extremely large sizes. Fort Wainwright had outlier values for the MS, 90th PS, and the TA. Even though relatively few fires were detected, the PAB was moderate, a significant finding for such a large installation. It also had high values for PL and TCT. Because of the extreme fire sizes and repetitive transboundary fires, Fort Wainwright was categorized as having high wildfire hazard.

MCAS Miramar had an outlier value for the 90th PS and low values for all other metrics. The 90th PS was driven by one significant fire, of which a very small portion reached into the 5-mile buffer. This fire did not impact MCSAS Miramar directly. Otherwise, the on-installation wildfire history is minimal when compared to other installations. Because only one metric was elevated, and that was driven by a fire almost entirely outside the study area, MCAS Miramar was categorized as low wildfire hazard.

NTTR was an outlier for the TCT, with the second highest value in the study, and, in a pattern similar to Fort Wainwright, had low fire counts and large fire sizes. NTTR had moderate values for the PL, MS, 90th PS, and the TA. However, as the largest installation in the study, it had a relatively low PAB. The large number of transboundary fires is cause for concern, as is the size of fires, though the number of fires is quite low. NTTR was categorized as having moderate wildfire hazard.

NWSTF Boardman had an outlier value for PAB. It also had a high value for the 90th PS, although the MS was low. The PL and TA were both moderate, and other metrics were relatively low. The data suggest NWSTF Boardman and its surrounding region have the potential for large fires, although their frequency is low. Because of this mix of low and high fire metrics, the wildfire hazard to NWSTF Boardman was categorized as moderate.

Saylor Creek Bombing Range had outlier values 90th PS and for TCT. For the latter metric, Saylor Creek had the highest value in the study. It also had high values for MS, TA, and PAB. Although the TC was at the low end of the spectrum, though still sufficient to support confidence in other metrics, the PL was moderate. Some of the largest fires in the study were detected on or near Saylor Creek Bombing Range. These data indicated that though Saylor Creek Bombing Range did not tend to have many fires, fires that occur are likely to grow to significant, and sometimes very large, sizes. Fort these reasons, Saylor Creek Bombing Range was categorized as facing a high fire hazard.

CATEGORIZATION AND DISCUSSION

The wildfire hazard categorization of each Cross-Branch installation, as determined by this analysis, is shown in Table 22. These categorizations reflect the aggregation of the 10 metrics characterizing aspects of wildland fire and the adjustments made due to expert input.

This analysis identified 13 installations as having a high wildland fire hazard, 31 as moderate, 40 as low, and 61 as having a negligible wildfire hazard based on detected fires from 2005-2014. The installations

categorized as high had high and/or outlier values for numerous metrics, whereas the moderate installations tended to have elevated values for some metrics and low values for others, or more moderate values across all metrics. The installations categorized as low had few, if any, elevated metrics.

Thirty-five installations had zero fires detected anywhere in the analysis area, and an additional 26 installations had detected fires in the 5-mile buffer surrounding the installation but not that reached onto the installation itself. These installations are categorized as negligible.

Table 22. Cross-Branch installation wildfire hazard categorization. No fires were detected wholly or partially within any installation in the negligible category. Outlier installations are marked with an asterisk.

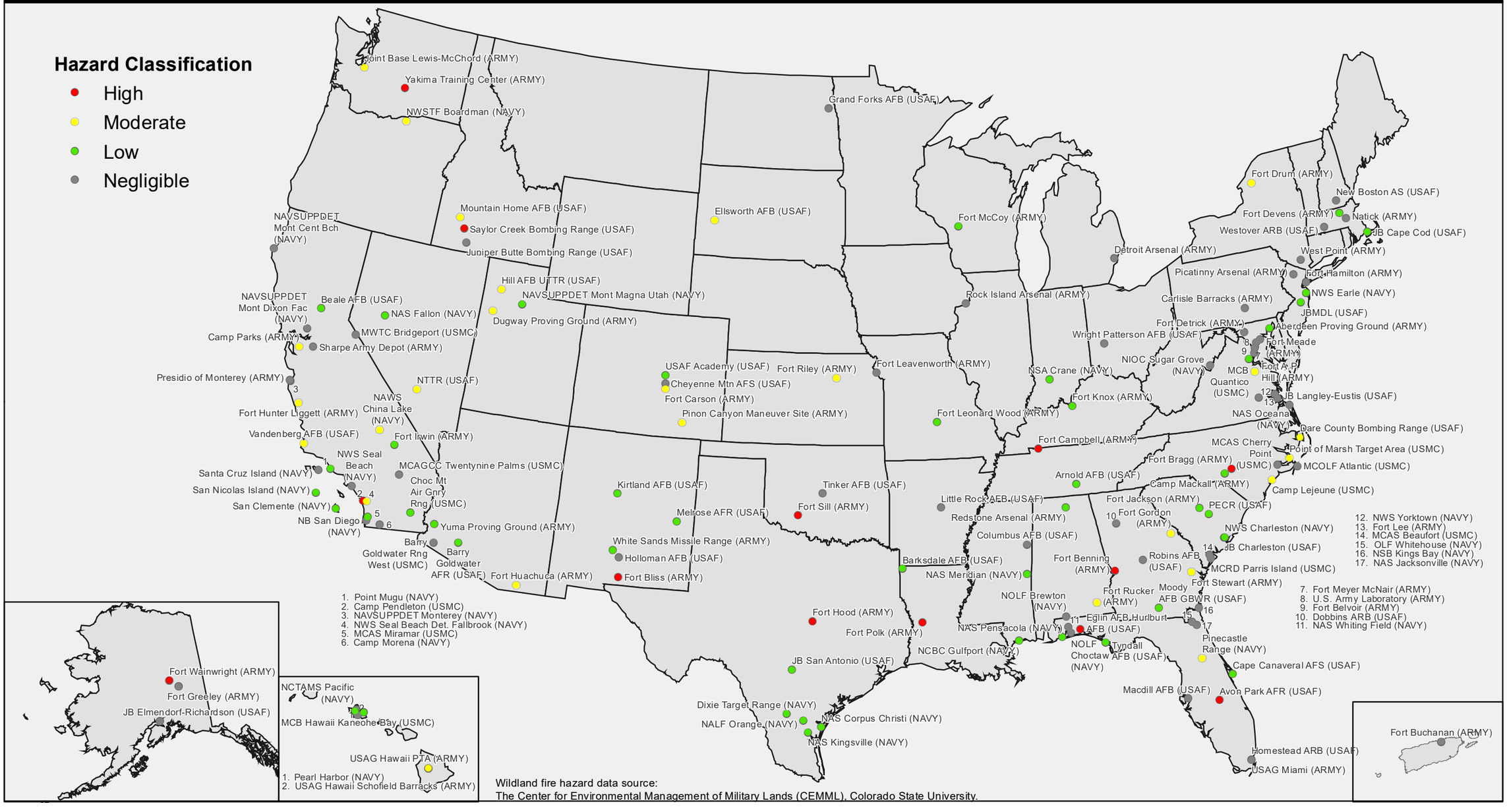
HIGH	MODERATE	LOW	NEGLIGIBLE
AVON PARK AFR*	ABERDEEN PROVING GROUND	ARNOLD AFB	ADELPHI
CAMP PENDLETON	BARRY GOLDWATER AFR*	BARKSDALE AFB	BARRY GOLDWATER RANGE WEST
EGLIN AFB HURLBURT AFB*	CAMP LEJEUNE	BEALE AFB	CAMP MORENA
FORT BENNING*	CAMP PARKS	CAMP MACKALL	CARLISLE BARRACKS
FORT BLISS	DARE COUNTY BOMBING RANGE*	CAPE CANAVERAL AFS	CHEYENNE MTN AFS
FORT BRAGG	DUGWAY PROVING GROUND*	CHOC MT AIR GNRY RNG	COLUMBUS AFB
FORT CAMPBELL	ELLSWORTH AFB	DIXIE TARGET RANGE	DETROIT ARSENAL
FORT HOOD	FORT AP HILL*	FORT DEVENS	DOBBINS ARB
FORT POLK	FORT CARSON	FORT IRWIN	FORT BELVOIR
FORT SILL	FORT DRUM	FORT KNOX	FORT BUCHANAN
FORT WAINWRIGHT*	FORT GORDON	FORT LEONARD WOOD	FORT DETRICK
SAYLOR CREEK BOMBING RANGE*	FORT HUACHUCA	FORT MCCOY	FORT GREELY
YAKIMA TRAINING CENTER	FORT HUNTER LIGGETT	JB CAPE COD	FORT HAMILTON
	FORT JACKSON	JB MCGUIRE DIX LAKEHURST	FORT LEAVENWORTH
	FORT RILEY	JB SAN ANTONIO	FORT LEE
	FORT RUCKER	KIRTLAND AFB	FORT MEADE
	FORT STEWART	MCAS MIRAMAR*	FORT MYER MCNAIR
	HILL AFB UTTR	MCB HAWAII KANEOHE BAY	GRAND FORKS AFB
	JB LEWIS MCCHORD	MCB QUANTICO	HOLLOMAN AFB
	MELROSE AFR	MOODY AFB GRAND BAY	HOMESTEAD ARB
	MOUNTAIN HOME AFB	NALF ORANGE	JB CHARLESTON
	NAWS CHINA LAKE	NAS CORPUS CHRISTI	JB ELMENDORF RICHARDSON
	NTTR*	NAS FALLON	JB LANGLEY FORT EUSTIS
	NWS SEAL BEACH DET FALLBROOK	NAS KINGSVILLE	JUNIPER BUTTE BOMBING RANGE
	NWSTF BOARDMAN*	NAS MERIDIAN	LITTLE ROCK AFB
	PINECASTLE RANGE	NAS PENSACOLA	MACDILL AFB
	PINON CANYON	NAVSUPPDET MONT MAGNA UTAH	MCAGCC TWENTYNINE PALMS
	POINT OF MARSH TARGET AREA	NCBC GULFPORT	MCAS BEAUFORT
	USAG HAWAII PTA	NSA CRANE	MCAS CHERRY POINT
	VANDENBERG AFB	NWS CHARLESTON	MCOLF ATLANTIC
	WHITE SANDS MISSILE RANGE	NWS EARLE	MCRD PARRIS ISLAND
		PECR	MWTC BRIDGEPORT
		POINT MUGU	NAS JACKSONVILLE
		REDSTONE ARSENAL	NAS OCEANA
		SAN CLEMENTE	NAS WHITING FIELD

SAN NICOLAS ISLAND	NATICK
TYNDALL AFB	NAVSUPPDET MONT CENT BCH
USAF ACADEMY	NAVSUPPDET MONT DIXON FAC
USAG HAWAII SCHOFIELD	NAVSUPPDET MONTEREY
YUMA PROVING GROUND	NB SAN DIEGO
	NCTAMS PACIFIC
	NEW BOSTON AS
	NIOC SUGAR GROVE
	NOLF BREWTON
	NOLF CHOCTAW
	NSB KINGS BAY
	NWS SEAL BEACH
	NWS YORKTOWN
	OLF WHITEHOUSE
	PEARL HARBOR
	PICATINNY ARSENAL
	PRESIDIO MONTEREY
	ROBINS AFB
	ROCK ISLAND ARSENAL
	SANTA CRUZ ISLAND
	SHARPE ARMY DEPOT
	TINKER AFB
	USAG MIAMI
	WEST POINT
	WESTOVER ARB
	WRIGHT PATTERSON AFB

Cross-Branch

Wildfire Hazard Classification

Figure 96



Wildland fire hazard data source:
The Center for Environmental Management of Military Lands (CEMML), Colorado State University.

CROSS-BRANCH COMPARISONS

All else being equal, the proportion of each branch's installations in each category (high, moderate, low, and negligible) should equal the proportion of each branch's installations in the entire analysis. Deviations from these percentages indicate a disproportionate level of wildfire hazard for that branch. Each branch's expected percentage and actual percentage per category are shown in Table 23.

Army installations comprised 37% of the 145 installations in the Cross-Branch analysis, yet accounted for 69% of the high category and 55% of the moderate category installations. Conversely, Navy installations comprised 26% of all Cross-Branch installations, yet only accounted for 13% of the moderate category, and none of the high category installations. The Air Force and Marine Corps installations were distributed more closely to their expected percentages. Very generally speaking, this indicates that the Army faces a disproportionately high wildfire hazard, while the Navy faces a disproportionately low wildfire hazard.

Table 23. Branch percentages of all installations and corresponding percentage of each Cross-Branch hazard category. All else equal, the Cross-Branch category percentages would be expected to match the percent of installations in each branch.

		Army	Air Force	Navy	Marine Corps
Total % of Installations		0.37	0.28	0.26	0.10
Cross-Branch %	High	0.69	0.23	0.00	0.08
	Moderate	0.55	0.26	0.13	0.06
	Low	0.23	0.30	0.38	0.10
	Negligible	0.31	0.28	0.30	0.11

However, a branch's overall wildfire hazard is comprised of that from individual installations, which the previous analyses demonstrate can vary widely within a branch. Thus, considering each installation's category within its own branch as well as within the Cross-Branch analysis is also informative for inter-branch evaluations. A full list of installations and their within-branch and Cross-Branch categorizations can be found in Appendix C – Installation Category by Branch and Cross-Branch Analyses. Table 24 shows the composite changes in installation categorization from the within-branch to the Cross-Branch categorizations for each branch.

The majority of movement between categorizations was to a less hazardous categorization in the Cross-Branch analysis than what was assigned solely considering other installations of the same branch. For example, all of the installations that were high in the Navy analysis were recategorized as moderate in the Cross-Branch analysis. Conversely, there were 5 Army installations that, within the Army branch analysis were categorized as low but fell into the moderate category when compared across all branches. All branches had within-branch categorizations of high and moderate that transitioned to moderate or low in the Cross-Branch analysis. Only the Army and Air Force had installations with within-branch categorizations of low fall into the Cross-Branch moderate category. The few installations that had both a negligible and low or moderate categorization reflect the different analysis period of the Cross-Branch (2005 – 2014, due to Army data limitations) from that of the Air Force, Navy, and Marine Corps (2004 – 2014).

Table 24. Categorization changes between within-branch and Cross-Branch analysis results. Cell values are the number of installations with each combination of within-branch and Cross-Branch categorization. Yellow indicates the branch and Cross-Branch categorizations were the same; green indicates that the Cross-Branch categorization was less hazardous than the categorization from the individual branch; red indicates that the Cross-Branch categorization was a greater hazard than the within-branch category.

OVERALL		**Cross-Branch Category**			
		High	Moderate	Low	Negligible
Within-Branch Category	High	13	11	1	0
	Moderate	0	14	15	1
	Low	0	6	24	2
	Negligible	0	0	0	58
ARMY		**Cross-Branch Category**			
		High	Moderate	Low	Negligible
Within-Branch Category	High	9	4	0	0
	Moderate	0	8	0	0
	Low	0	5	9	0
	Negligible	0	0	0	19
AIR FORCE		**Cross-Branch Category**			
		High	Moderate	Low	Negligible
Within-Branch Category	High	3	3	1	0
	Moderate	0	4	6	0
	Low	0	1	5	0
	Negligible	0	0	0	17
NAVY		**Cross-Branch Category**			
		High	Moderate	Low	Negligible
Within-Branch Category	High	0	3	0	0
	Moderate	0	1	6	1
	Low	0	0	9	0
	Negligible	0	0	0	17
MARINE CORPS		**Cross-Branch Category**			
		High	Moderate	Low	Negligible
Within-Branch Category	High	1	1	0	0
	Moderate	0	1	3	0
	Low	0	0	1	2
	Negligible	0	0	0	5

CONCLUSIONS

This project strove to categorize DoD installations by the threat of wildfire each faces, utilizing a comparable sample of remotely sensed fires. Overall, the Army had a disproportionate number of installations categorized as high or moderate in the Cross-Branch analysis, while Navy installations were disproportionately categorized as low or negligible. All branches but the Navy had at least one installation categorized as high in the Cross-Branch analysis.

In the Cross-Branch analysis, the high hazard installations are, in alphabetical order, Avon Park AFR, Camp Pendleton, Eglin AFB and Hurlburt AFB, Fort Benning, Fort Bliss, Fort Bragg, Fort Campbell, Fort Hood, Fort Polk, Fort Sill, Fort Wainwright, Saylor Creek Bombing Range, and Yakima Training Center. These represent the Air Force, Army, and Marine Corps. These installations had some of the highest individual metric values on the study as well as numerous metrics that were high or moderate. These installations were the most likely across all four branches to experience numerous wildfires, large wildfires, transboundary wildfires, or some combination thereof.

The moderate category included installations from all four branches. These installations also had elevated values for multiple metrics and it may be worth further examination of the threats posed to these installations, in addition to those categorized as exposed to high wildfire hazard, to understand the unique wildfire situation faced by each installation. Because the moderate installations face fewer elevated wildland fire hazard metrics, mitigating the wildfire hazard at these installations without major disruptions to the military mission may be more straightforward, and possibly more cost-effective, than trying to mitigate fires at those designated as high wildfire hazard where mitigation measures may require extensive precautions, engineering, vegetation management and other intervention.

In every analysis in this study, more installations fell into the negligible category than into any other individual category, from 35% - 46% of the installations in each analysis. At these installations, there were no fires detected anywhere within the installation boundary at any time during the study period. It is likely that these installations require little or no wildfire mitigation measures, or that the measures currently in place are so effective as to essentially eliminate fires large enough or frequent enough to be detected by the methodology of this study.

At every other installation in the study, a realized wildfire hazard was represented by at least one fire that had actually burned on the installation. That result demonstrates there is at least minor wildfire potential at those installations, a meaningful difference from those installations rated as negligible.

It is also important to note that installations in the same wildfire hazard category may be categorized as such for very different reasons. The wildfire hazard faced by an installation with a high number of small to moderate sized fires faces a very different threat than one that experiences large, but rare, fires. The mitigation measures necessary, their effectiveness, and their cost, are likely to vary as well. The specific approach to hazard mitigation at any individual installation should be tailored to the threats faced by that installation and the values threatened.

This hazard analysis is not a risk assessment. It does not account for the values that potentially could be impacted by wildfire (e.g. structures, military infrastructure such as power lines or radar facilities, training assets including vegetation for cover and concealment, or federally protected species or cultural resources). Such an analysis at a national scale is formidable at a minimum, and likely impossible, due to the vast and detailed information required from each installation. However, those values should be considered to the degree feasible when applying the results from this study.

Additionally, there are reasons other than wildfire hazard to consider when determining the level of overall wildland fire support an installation may require. This assessment addresses potentially negative impacts from wildfires. Prescribed fire programs, for example, are utilized to improve land for training purposes or improve habitat to comply with regulatory requirements, in addition to managing fuels in the interest of reducing wildfire hazard and risk.

Military Readiness

Ultimately, the primary goal of wildland fire management at military installations is to ensure our nation's military men and women have the best possible training opportunities. This study will help ensure they have natural environments to maneuver through, ranges where they can fully utilize their military hardware, and installations that are regulatorily compliant ensuring as few restrictions on training as possible. The first step towards that goal is understanding where threats to that goal exist and focusing available resources there.

The results of this analysis are intended for use primarily at regional and national scales, both within and across DoD branches. Some installations may find them useful at the local level. Protecting the military mission requires applying the limited wildfire mitigation resources available where they are most needed. These results should be utilized as one component in decisions regarding distribution of those resources to installations with a goal of benefitting the military mission by reducing wildfire frequency, severity, and size while supporting a high level of combat readiness. Better targeting of wildfire mitigation resources will enhance military training by improving wildfire mitigation success, decreasing direct and indirect impacts to training. Data associated with this study will be available as a geodatabase, but access to the platform may be limited since the Wildland Fire Management Application (WFMAP) is restricted to only a few vetted Army personnel.

It is not recommended that these results be utilized as a cookie cutter to simply place installations into funding categories as there is far too much nuance in wildland fire management for such a simplistic approach. However, combined with other similar efforts, this study is intended to be a first step towards a detailed understanding of risk within DoD by providing an initial triage of installations. High hazard installations, and some moderate hazard installations, in this study should be considered for additional, more intense, and more detailed analysis to identify sources of hazard, analyze risk, and suggest mitigation measures as appropriate to the situation. These approaches can delve into the specifics of each installation, providing data and insights that can be brought to bear in installation Wildland Fire Management Plans, which are directly targeted at ensuring the sustainability of the military mission.

GLOSSARY OF TERMS

Cluster

Installation grouping produced by the K-Means algorithm.

Dunn's Test

A non-parametric pairwise multiple comparisons procedure based on rank sums, often used as a post hoc procedure following a Kruskal–Wallis test, showing significant differences among pairs. As such, it is a non-parametric analog to multiple pairwise t tests following rejection of an analysis of variance (ANOVA) null hypothesis.

Fire Behavior

The characteristics displayed by the fire(s) expressed in terms of flame length, rate of spread, and fireline intensity (heat per linear length of fire front per unit time) and other measures. More than one variable may be used to describe the fire behavior.

Fuel

Living and dead vegetation. Vegetation is referred to as fuel in the context of wildland fire because it is what burns and 'fuels' the wildfire.

Hazard

In the context of wildland fire, hazard is a component of wildfire risk and is defined by the combination of ignition potential and the breadth of potential fire behavior. It does not account for the potential impacts to valued resources. In this analysis, the hazard presents itself as a realized fire that burned a specified area as detected by satellite data analysis.

Group

Used synonymously with "cluster" to describe the aggregation of installations output by the K-means algorithm

K-Means

A statistical algorithm used to cluster data. The K-means algorithm involves randomly selecting K initial centroids where K is a user defined number of desired clusters. Each data point is then assigned to a closest centroid and the collection of points close to a centroid form a cluster. The centroid gets updated according to the points in the cluster and this process continues until the points stop changing their clusters.

Kruskal-Wallis Test

A non-parametric method for testing if samples originate from the same distribution. It is the non-parametric version of the parametric one-way ANOVA. A significant result indicates that at least one sample is different from the others, but does not identify how many or which pairs of groups differ.

Landsat

A satellite-based moderate-resolution land remote sensing program, operated as a joint initiative between the United States Geologic Survey (USGS) and the National Aeronautics and Space Administration (NASA). Eight Landsat missions have been launched, and are generally referred to by their number (e.g., Landsat 5 or Landsat 8). Landsat 7 and 8, which are used in this study, are currently in operation, but data archives are available for all missions.

Mean

The value calculated by summing all values in a set, and dividing by the count of values summed.

Median

In a set of data, the median is the value where 50% of the items in the dataset will be larger than it, and 50% will be smaller. It is also referred to as the 50th percentile. If a dataset has an even number of values, the median is calculated as the mean of the 2 values surrounding the midpoint.

Non-Parametric

Data that does not fit a well-understood distribution, such as a normal distribution. The data in this study is non-parametric and therefore non-parametric statistical tests for significant differences among pairs (Kruskal-Wallis and Dunn's) were used.

Percentiles

In a set of data, the 90th percentile value is that value where 90% of the values in the dataset will be smaller than that value, and only 10% will be larger. For example, we might be interested in the flame lengths of the most severe wildfires. If the 90th percentile flame length is eight feet, then 90% of the flame lengths observed are less than eight feet and only 10% are greater than eight feet. The 50th percentile is synonymous with the median value.

When describing the threat wildland fire poses to the human and natural environment, typically managers are interested in the more severe events, e.g. large, intense wildfires. These fires are low probability, but high consequence events and it is the nature of wildfire management to evaluate events that are unlikely, but highly undesirable if they were to occur. To address this focus on fires that are relatively unlikely, we use 'percentiles' to measure fire behavior and size within just the subset of fires that are very large and damaging.

Prescribed fire

A planned wildland fire, intentionally ignited for the purpose of achieving a specified management objective that is in accordance with applicable laws, policies, and regulations.

R

Software for computing statistics and graphics.

Return Interval

In the context of Landsat satellite imagery, this refers to the period of time between satellite passes over the same ground area.

Risk

A combination of the probabilities of event occurrence, magnitude, and outcome. In the case of wildfire, these are ignition potential, the breadth of potential fire behavior, and the values potentially impacted.

Wildfire

An unplanned, unwanted wildland fire. These may be caused by human activities or natural occurrences such as lightning.

Wildland Fire

Any fire deliberately or unintentionally ignited in vegetation or natural fuels. Wildland fire includes both wildfires and prescribed fires

ACRONYMS USED IN THIS REPORT

ANOVA	Analysis of Variance
APG	Aberdeen Proving Ground
CEMML	Center for Environmental Management of Military Lands
DoD	Department of Defense
DPG	Dugway Proving Ground
IMCOM	Installation Management Command
JB	Joint Base
JBLM	Joint Base Lewis-McChord
MTBS	Montoring Trends in Burn Severity
NASA	National Aeronautics and Space Administration
PCMS	Pinyon Canyon Maneuver Site
PECR	Poinsett Electronic Combat Range
PTA	Pohakuloa Training Area
SBMR	Schofield Barracks Military Reservation
USAG	United States Army Garrison
USGS	United States Geologic Survey
WSMR	White Sands Missile Range
YPG	Yuma Proving Ground
YTC	Yakima Training Center

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APPENDIX A – KRUSKAL-WALLIS AND DUNN'S TEST RESULTS

Because this dataset was non-parametric, the non-parametric Kruskal-Wallis and Dunn's tests were used to determine differences among the means of all pairwise comparisons. If the metric was shown by the Kruskal –Wallis test to be statistically valid for separating among clusters, the Dunn's test results are meaningful. Results are shown in Table A - 1 through Table A - 5. Correction methods to control the family-wise error rate and false discover rate were not applied.

Table A - 1. P-value results for Kuskal-Wallis analysis of variance test for each metric within each branch and the Cross-Branch analysis. The only non-significant result (marked with an asterisk) was the 90th Percentile Fire Size metric in the Air Force analysis. These results indicate that all metrics, except for the lone Air Force result, were statistically meaningful in differentiating amongst clusters (groups). There were an insufficient number of installations in the Marine Corps to statistically evaluate clustering.

Metric	Air Force	Army	Navy	Cross Branch
Total count of all wildfires inside the installation (TC)	0.0202	0.0002	0.0257	0.0000
Median count per year of wildfires inside the analysis area (MC)	0.0416	0.0002	0.0770	0.0000
Total count of large wildfires inside the installation (TCL)	0.0319	0.0002	0.0012	0.0000
Proportion of all wildfires inside the installation that are large (PL)	0.0276	0.0070	0.0014	0.0001
Total count of wildfires inside the installation close to the boundary (TCC)	0.0422	0.0001	0.0217	0.0000
Total count of transboundary wildfires (TCT)	0.0637	0.0045	0.0422	0.0001
Median fire size across the analysis area (MS)	0.0417	0.0007	0.0246	0.0000
90th percentile fire size across the analysis area (90th)	0.1401*	0.0050	0.0113	0.0000
Total wildfire acreage within the installation boundary (TA)	0.0230	0.0001	0.0256	0.0000
Overall proportion of installation area burned by wildfire (PAB)	0.0527	0.0019	0.0077	0.0000

Table A - 2. Air Force Dunn's Tests results (p-values, uncorrected) for pairwise comparisons among groups formed by K-means clustering. 90th Percentile Fire Size was found to be non-significant in the Air Force Branch Kruskall-Wallis test and is marked with an asterisk.

	Pairwise Group Comparisons																				
Metric	A-B	A-C	B-C	A-D	B-D	C-D	A-E	B-E	C-E	D-E	A-F	B-F	C-F	D-F	E-F	A-G	B-G	C-G	D-G	E-G	F-G
Relative Total Count of All Wildfires Inside the Installation	0.40	0.02	0.11	0.42	0.84	0.05	0.01	0.08	0.89	0.03	0.01	0.14	0.49	0.03	0.39	0.04	0.22	0.54	0.09	0.44	1.00
Relative Median Count per Year of Wildfires Inside the Analysis Area	0.30	0.77	0.26	0.09	0.63	0.10	0.16	0.58	0.14	0.81	0.11	0.70	0.12	0.90	0.75	0.44	0.07	0.74	0.01	0.04	0.01
Relative Total Count of Large Wildfires Inside the Installation	0.09	0.37	0.62	1.00	0.04	0.31	0.05	0.57	0.36	0.03	0.28	0.34	0.85	0.15	0.17	0.02	0.48	0.29	0.00	1.00	0.07
Relative Proportion of all Wildfires Inside the Installation That Are Large	0.01	0.41	0.22	1.00	0.00	0.36	0.19	0.46	0.67	0.14	0.29	0.05	0.91	0.16	0.51	0.04	0.69	0.37	0.01	0.68	0.14
Relative Total Count of Wildfires Inside the Installation Close to the Boundary	1.00	0.63	0.63	0.67	0.67	0.39	0.06	0.06	0.24	0.02	0.14	0.14	0.55	0.01	0.35	0.09	0.09	0.38	0.02	0.63	0.61
Relative Total Count of Transboundary Wildfires	0.71	0.19	0.32	0.01	0.04	0.63	0.32	0.49	0.79	0.41	0.01	0.02	0.54	0.81	0.34	0.45	0.71	0.49	0.10	0.70	0.07
Relative Median Fire Size Across the Analysis Area	0.40	0.76	0.70	0.10	0.52	0.36	0.36	0.82	0.60	0.81	0.03	0.25	0.19	0.51	0.54	0.78	0.26	0.59	0.05	0.25	0.01
Relative 90th Percentile Fire Size Across the Analysis Area*	0.34	0.43	1.00	0.54	0.60	0.69	0.03	0.16	0.22	0.05	0.01	0.13	0.25	0.01	0.67	0.11	0.53	0.61	0.20	0.37	0.44
Relative Total Wildfire Acreage Within the Installation Boundary	1.00	0.32	0.32	0.06	0.06	0.01	0.49	0.49	0.79	0.03	0.88	0.88	0.22	0.02	0.37	0.93	0.93	0.28	0.07	0.44	0.96
Relative Overall Proportion of Installation Area Burned by Wildfire	0.51	0.28	0.59	0.19	0.04	0.03	0.36	0.70	0.89	0.04	0.96	0.46	0.24	0.08	0.32	0.11	0.35	0.82	0.00	0.70	0.06

Table A - 3. Air Force Dunn's Tests results (p-values, uncorrected) for pairwise comparisons among groups formed by K-means clustering.

	Pairwise Group Comparisons									
Metric	A - B	A - C	A - D	A - E	B - C	B - D	B - E	C - D	C - E	D - E
Relative Total Count of All Wildfires Inside the Installation	0.268	0.075	0.002	0.000	0.786	0.094	0.015	0.046	0.001	0.454
Relative Median Count per Year of Wildfires Inside the Installation	0.434	0.262	0.018	0.000	0.945	0.176	0.010	0.073	0.000	0.179
Relative Total Count of Large Wildfires Inside the Installation	0.153	0.432	0.069	0.000	0.315	0.861	0.070	0.143	0.000	0.054
Relative Proportion of all Wildfires Inside the Installation That Are Large	0.668	0.026	0.036	0.784	0.013	0.018	0.464	0.794	0.014	0.030
Relative Total Count of Wildfires Inside the Installation Close to the Boundary	0.288	0.612	0.000	0.006	0.415	0.037	0.196	0.000	0.002	0.254
Relative Total Count of Transboundary Wildfires	0.021	0.588	0.707	0.170	0.001	0.006	0.176	0.913	0.011	0.055
Relative Median Fire Size Across the Analysis Area	0.676	0.002	0.000	0.035	0.023	0.003	0.150	0.173	0.278	0.035
Relative 90th Percentile Fire Size Across the Analysis Area	0.202	0.084	0.048	0.784	0.002	0.002	0.092	0.518	0.068	0.042
Relative Total Wildfire Acreage Within the Installation Boundary	0.006	0.381	0.074	0.000	0.012	0.216	0.726	0.184	0.000	0.045
Relative Overall Proportion of Installation Area Burned by Wildfire	0.032	0.348	0.008	0.002	0.086	0.835	0.726	0.017	0.003	0.881

Table A - 4. Navy Dunn's Tests results (p-values, uncorrected) for pairwise comparisons among groups formed by K-means clustering.

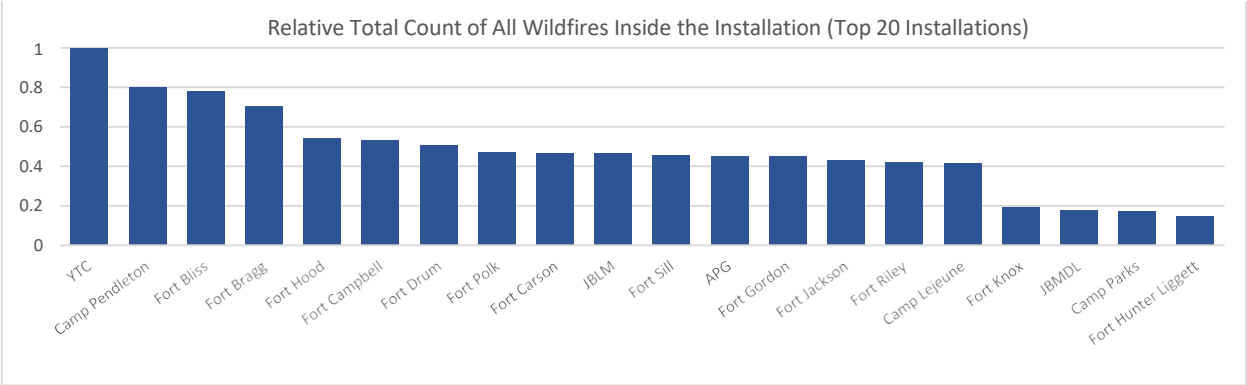
	Pairwise Group Comparisons									
Metric	A-B	A-C	B-C	A-D	B-D	C-D	A-E	B-E	C-E	D-E
Relative Total Count of All Wildfires Inside the Installation	0.32	0.00	0.01	0.14	0.40	0.30	0.06	0.19	0.54	0.72
Relative Median Count per Year of Wildfires Inside the Analysis Area	0.00	0.14	0.17	0.13	0.46	0.77	0.02	0.81	0.23	0.44
Relative Total Count of Large Wildfires Inside the Installation	1.00	1.00	1.00	0.01	0.00	0.01	0.01	0.00	0.01	1.00
Relative Proportion of all Wildfires Inside the Installation That Are Large	1.00	1.00	1.00	0.01	0.00	0.01	0.01	0.00	0.01	1.00
Relative Total Count of Wildfires Inside the Installation Close to the Boundary	0.56	0.10	0.01	0.95	0.67	0.12	0.50	0.78	0.03	0.58
Relative Total Count of Transboundary Wildfires	0.13	0.01	0.08	0.75	0.10	0.01	0.26	0.98	0.22	0.18
Relative Median Fire Size Across the Analysis Area	0.04	0.01	0.25	0.63	0.02	0.00	0.33	0.54	0.17	0.18
Relative 90th Percentile Fire Size Across the Analysis Area	0.54	0.00	0.00	0.17	0.30	0.27	0.55	0.86	0.06	0.49
Relative Total Wildfire Acreage Within the Installation Boundary	0.00	0.08	0.22	1.00	0.01	0.12	0.38	0.10	0.54	0.42
Relative Overall Proportion of Installation Area Burned by Wildfire	0.13	0.94	0.12	0.19	0.01	0.15	0.42	0.03	0.36	0.66

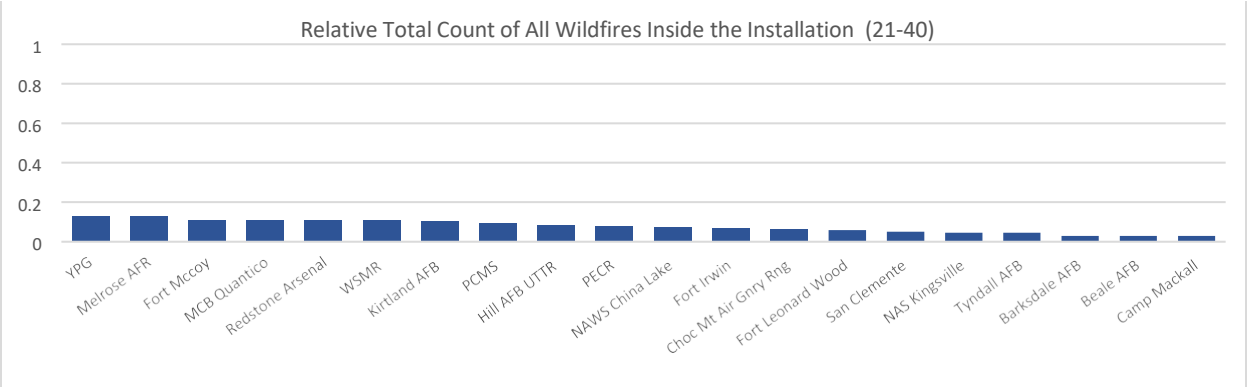
Table A - 5. Cross-Branch Dunn's Tests results (p-values, uncorrected) for pairwise comparisons among groups formed by K-means clustering.

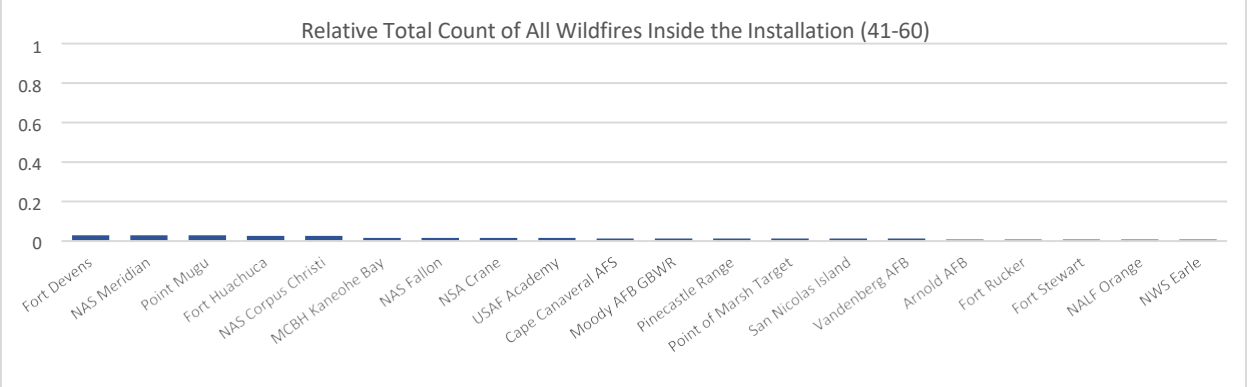
	Pairwise Group Comparisons									
Metric	A-B	A-C	B-C	A-D	B-D	C-D	A-E	B-E	C-E	D-E
Relative Total Count of All Wildfires Inside the Installation	0.00	0.04	0.00	0.00	0.48	0.00	0.11	0.01	0.99	0.00
Relative Median Count per Year of Wildfires Inside the Analysis Area	0.51	0.76	0.58	0.00	0.03	0.00	0.00	0.02	0.00	0.83
Relative Total Count of Large Wildfires Inside the Installation	0.02	0.62	0.00	0.00	0.28	0.00	0.31	0.14	0.06	0.01
Relative Proportion of all Wildfires Inside the Installation That Are Large	0.40	0.00	0.07	0.71	0.21	0.00	0.96	0.41	0.00	0.66
Relative Total Count of Wildfires Inside the Installation Close to the Boundary	0.00	0.04	0.00	0.00	0.44	0.00	0.01	0.07	0.17	0.01
Relative Total Count of Transboundary Wildfires	0.00	0.00	0.39	0.07	0.24	0.01	0.79	0.01	0.00	0.11
Relative Median Fire Size Across the Analysis Area	0.18	0.01	0.46	0.79	0.10	0.00	0.06	0.00	0.00	0.10
Relative 90th Percentile Fire Size Across the Analysis Area	0.00	0.18	0.00	0.00	0.73	0.00	0.19	0.00	0.74	0.01
Relative Total Wildfire Acreage Within the Installation Boundary	0.00	0.37	0.00	0.00	0.87	0.00	0.00	0.90	0.00	0.77
Relative Overall Proportion of Installation Area Burned by Wildfire	0.01	0.87	0.00	0.00	0.25	0.00	0.02	0.81	0.00	0.15

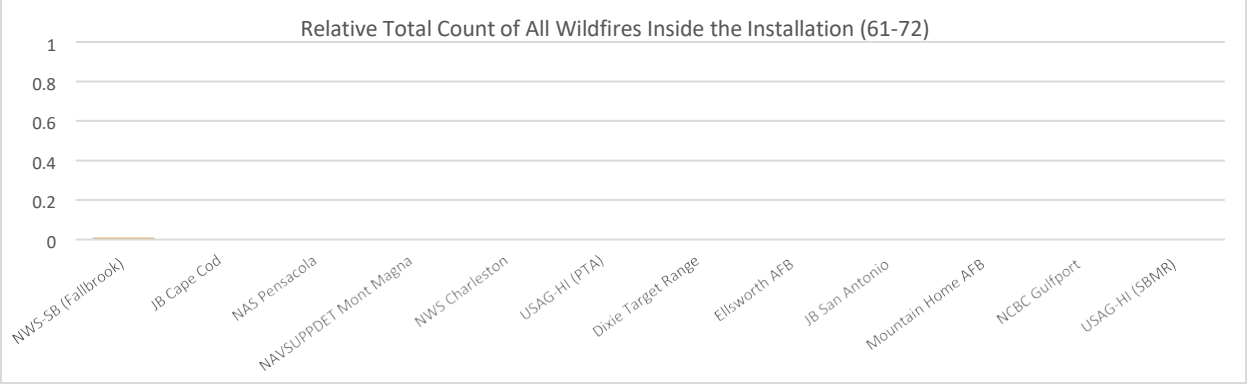
APPENDIX B – CROSS-BRANCH GRAPHS

B.1 RELATIVE TOTAL COUNT OF ALL WILDFIRES INSIDE THE INSTALLATION

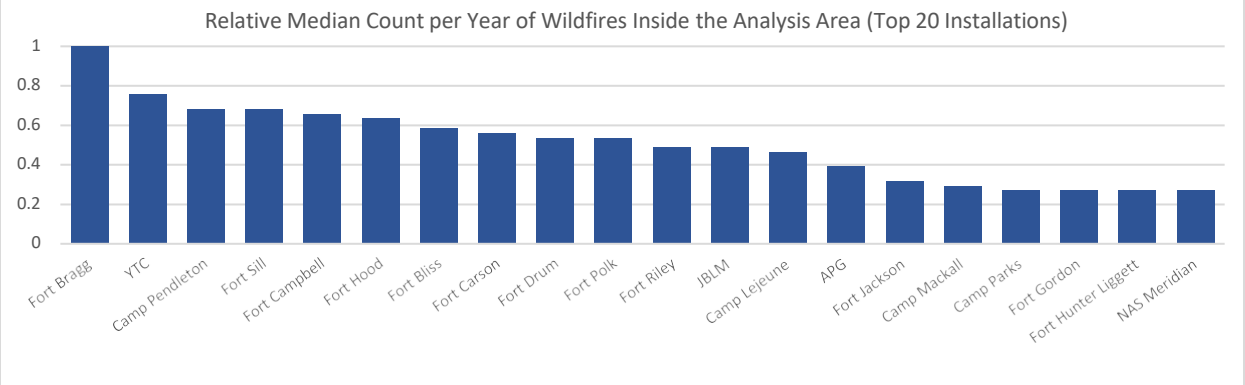


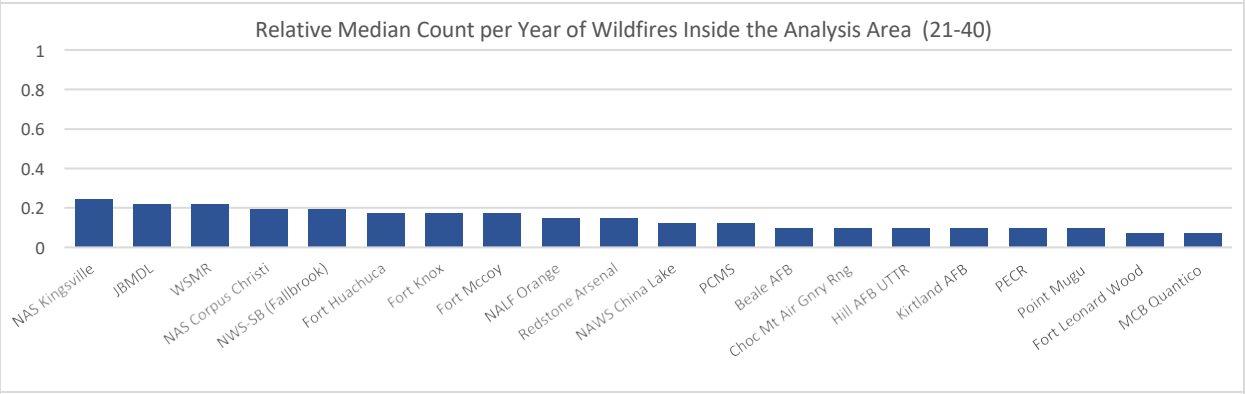


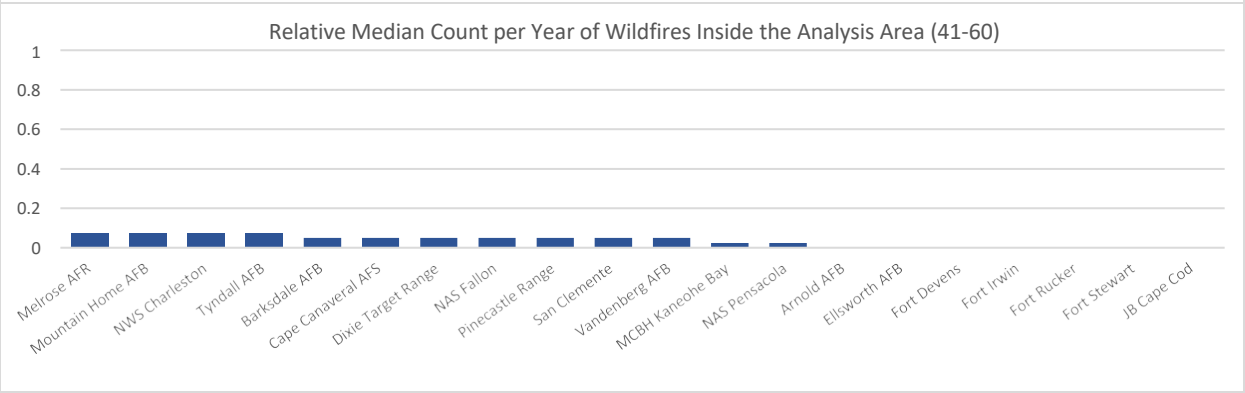


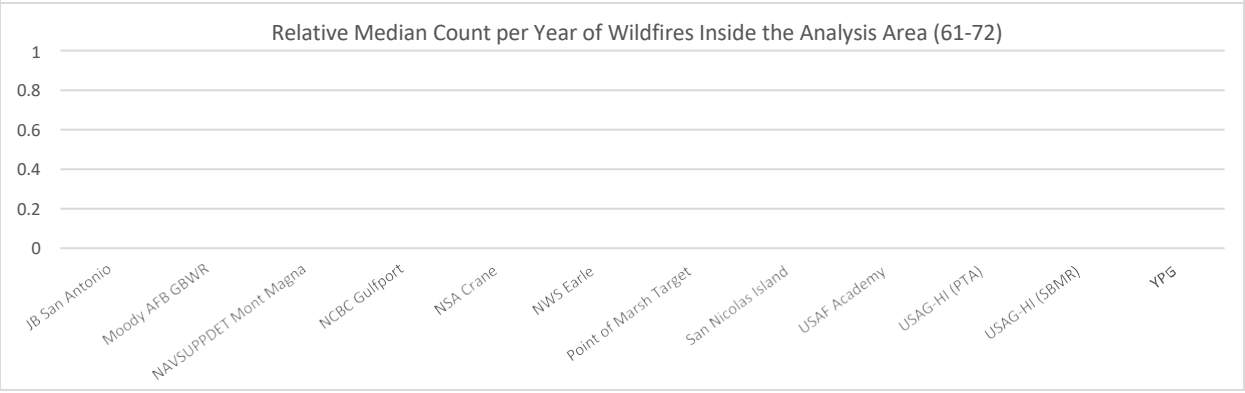


B.2 RELATIVE MEDIAN COUNT PER YEAR OF WILDFIRES INSIDE THE ANALYSIS AREA

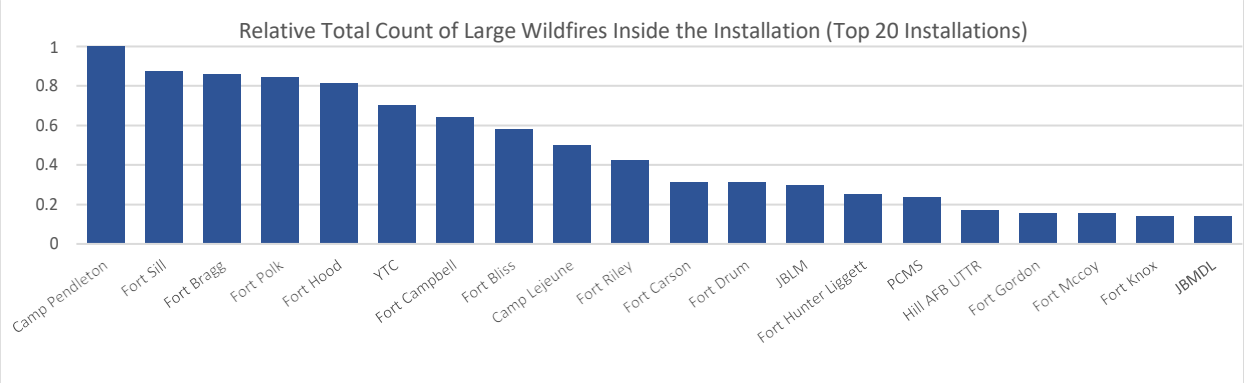


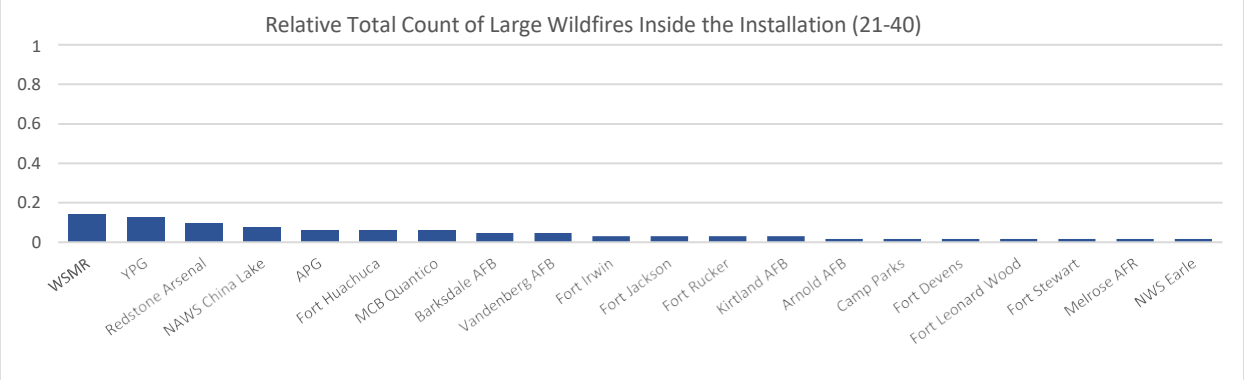


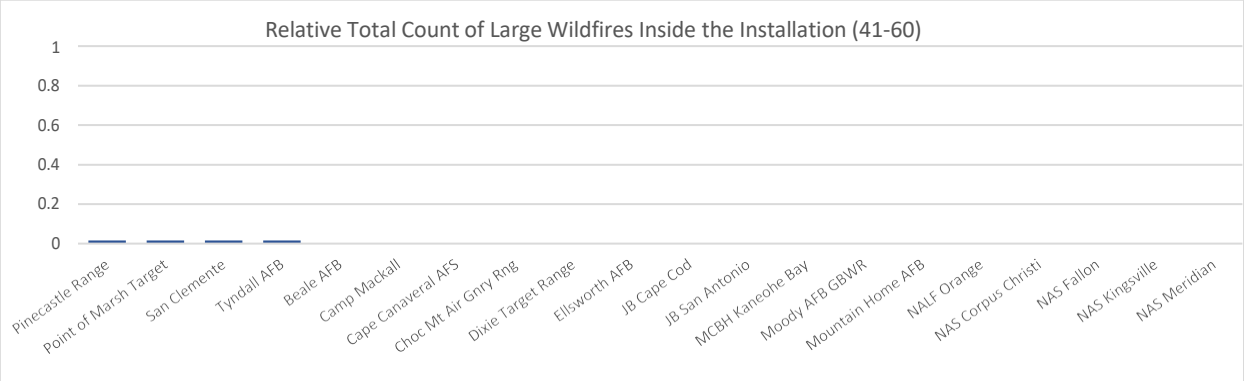


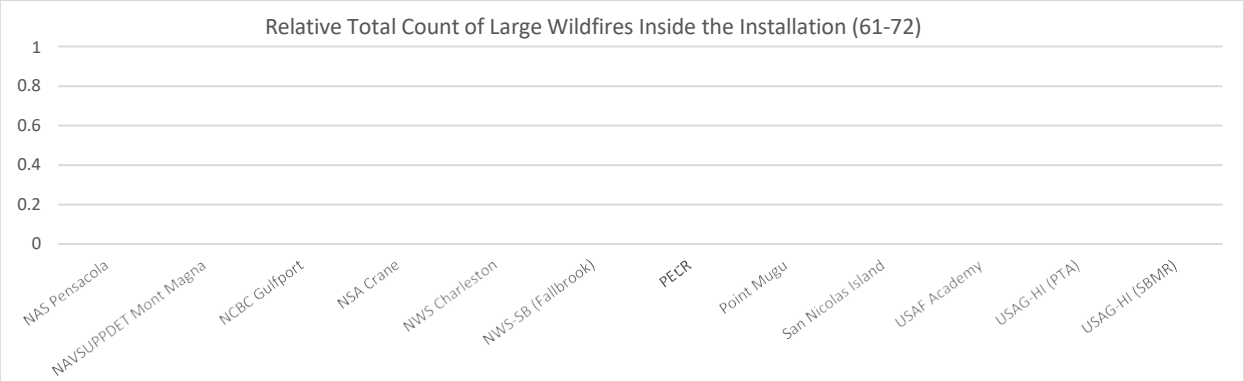


B.3 RELATIVE TOTAL COUNT OF LARGE WILDFIRES INSIDE THE INSTALLATION

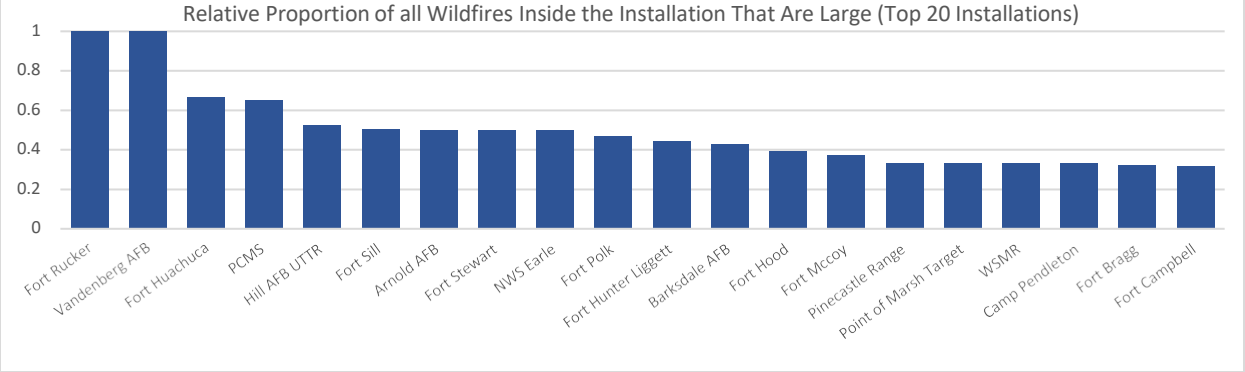


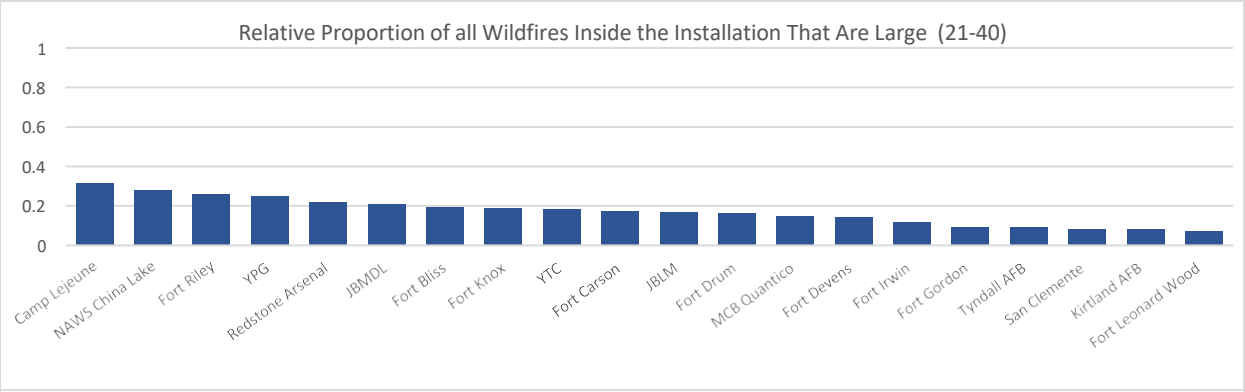


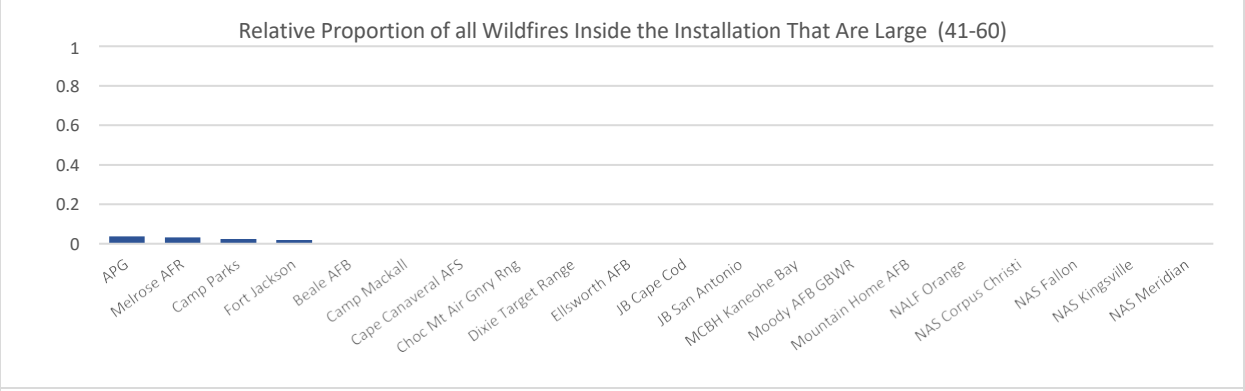


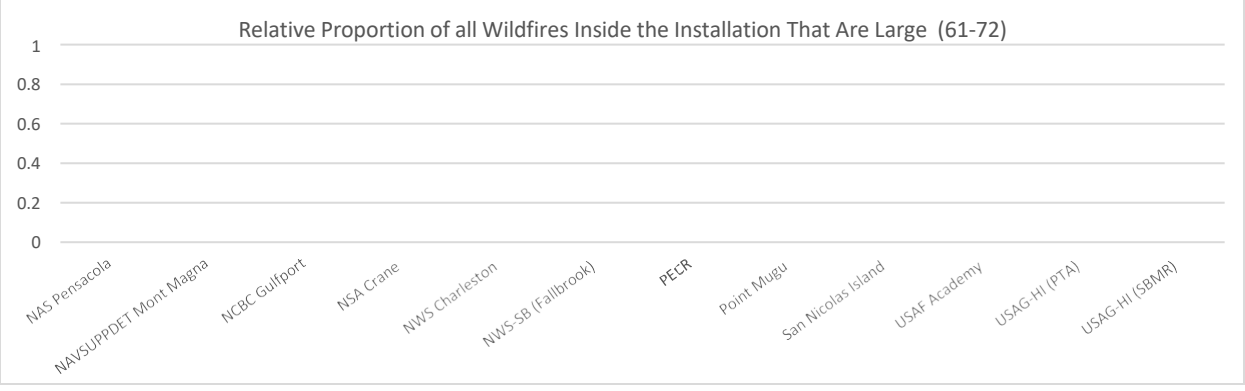


B.4 RELATIVE PROPORTION OF ALL WILDFIRES INSIDE THE INSTALLATION THAT ARE LARGE

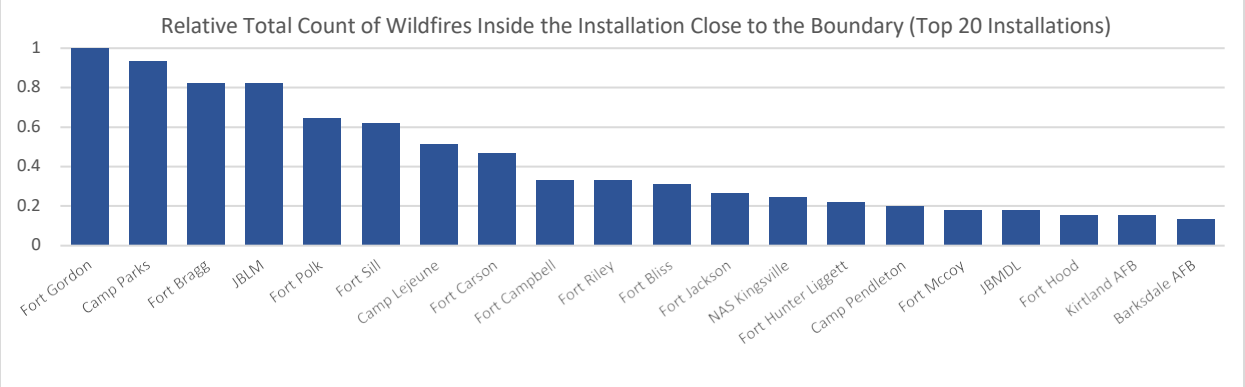


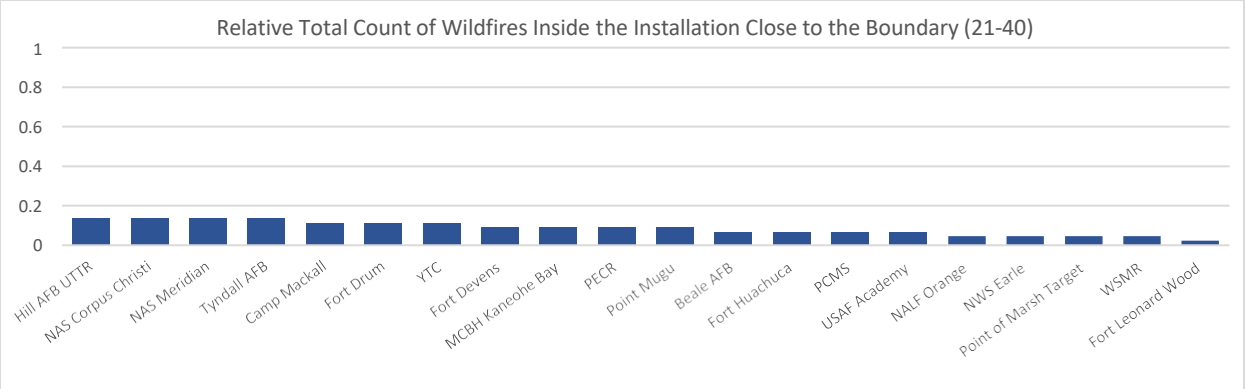


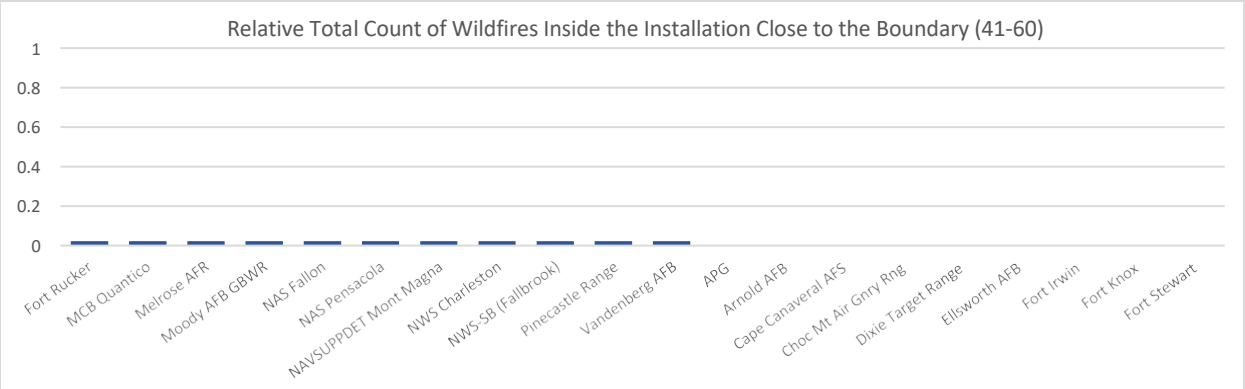


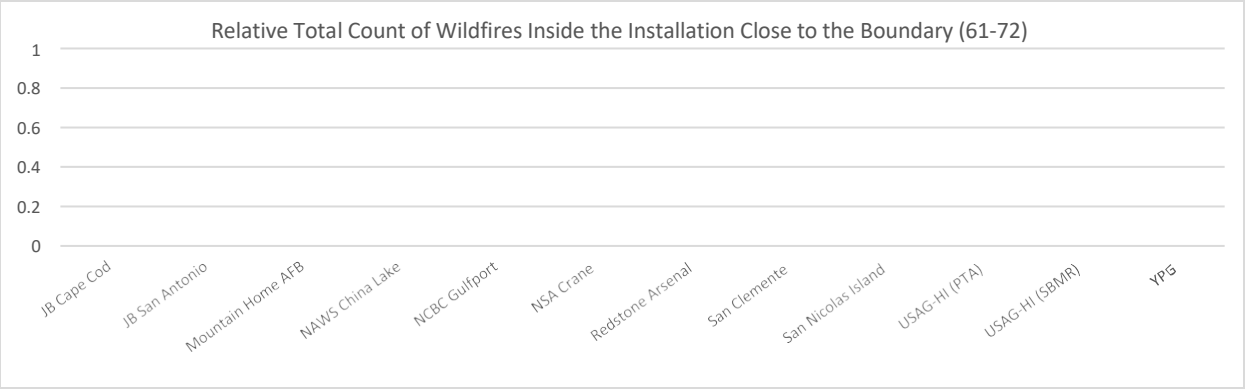


B.5 RELATIVE TOTAL COUNT OF WILDFIRES INSIDE THE INSTALLATION CLOSE TO THE BOUNDARY

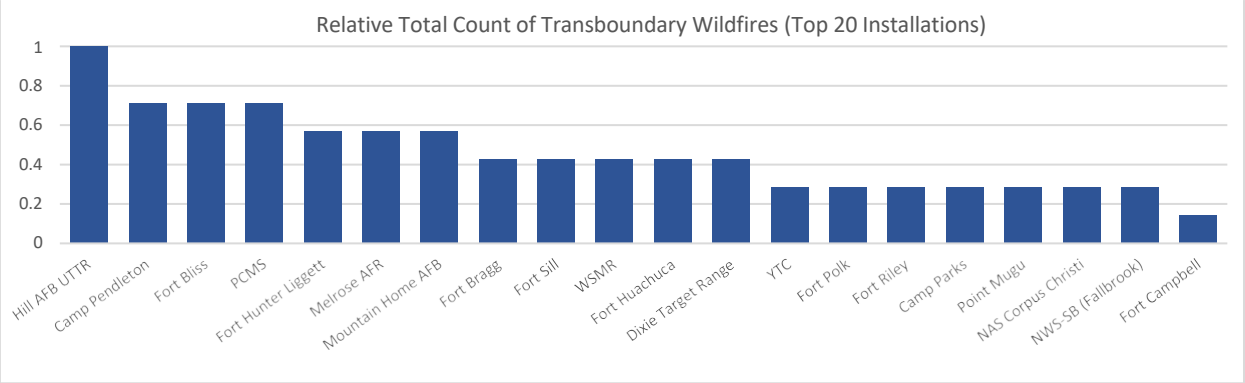


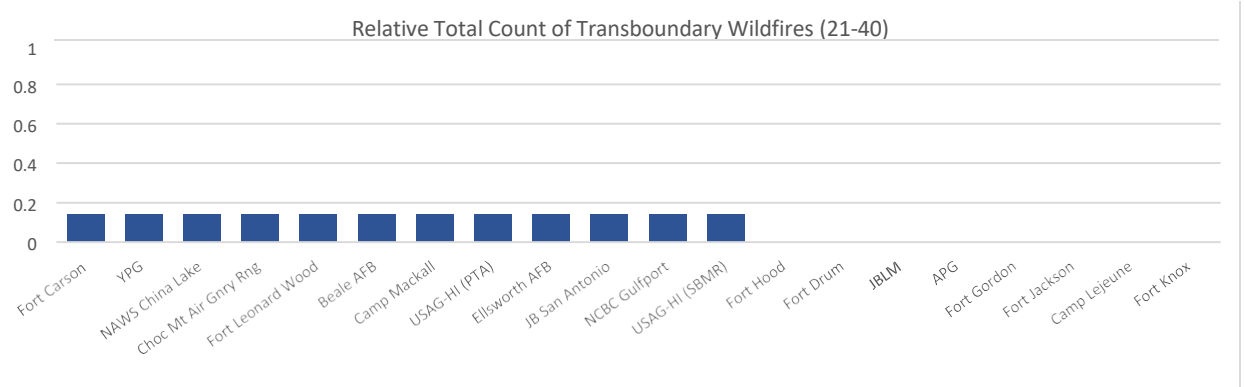


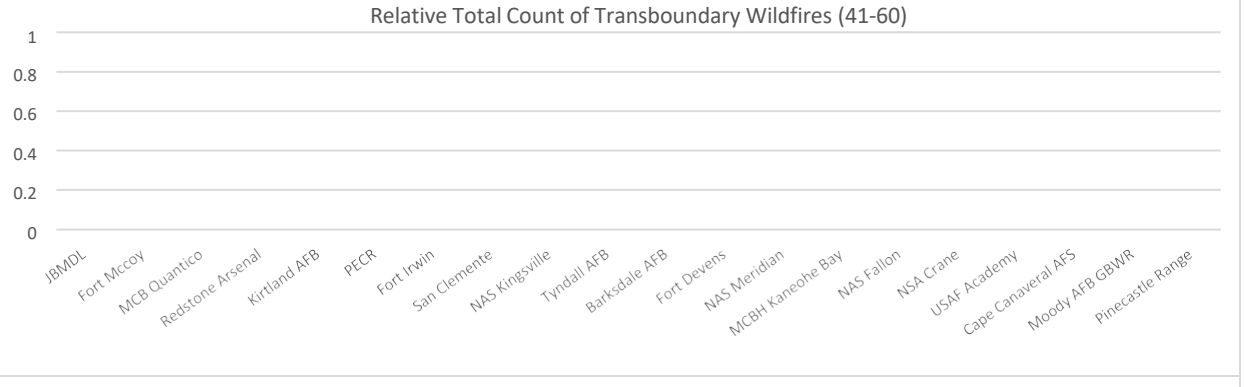


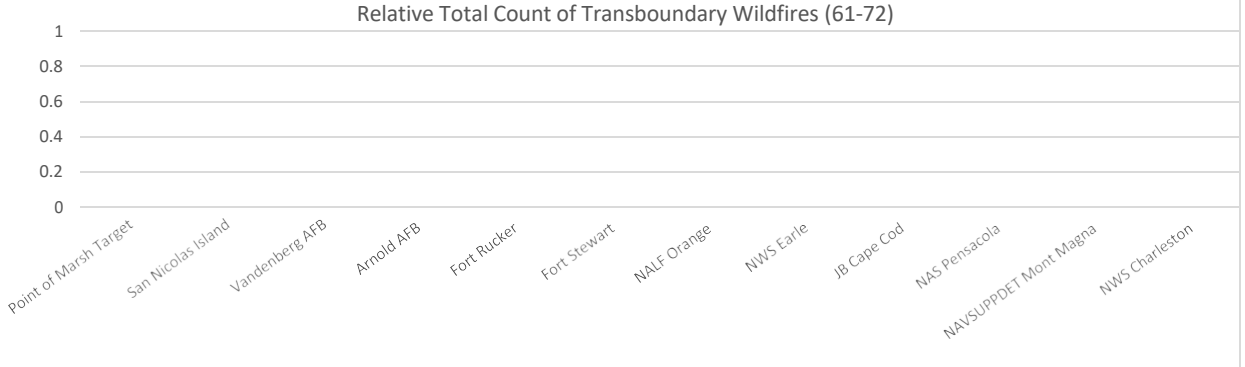


B.6 RELATIVE TOTAL COUNT OF TRANSBOUNDARY WILDFIRES

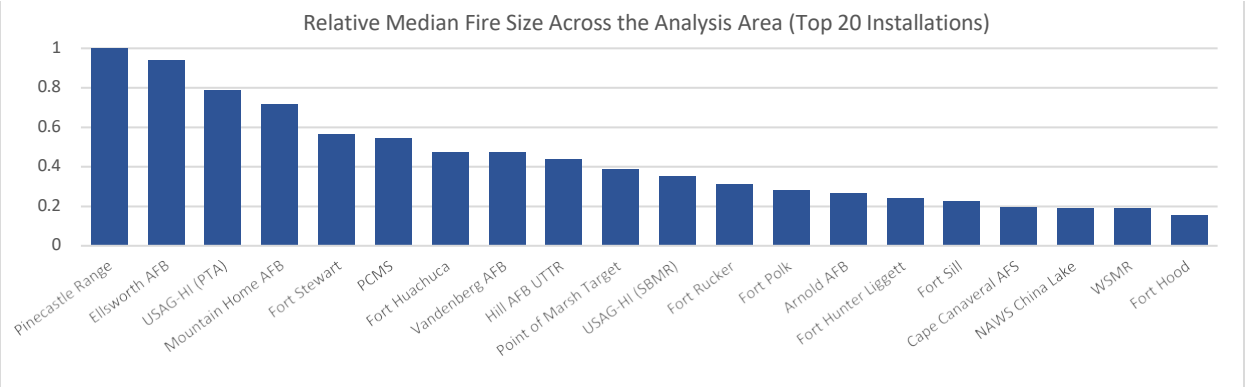


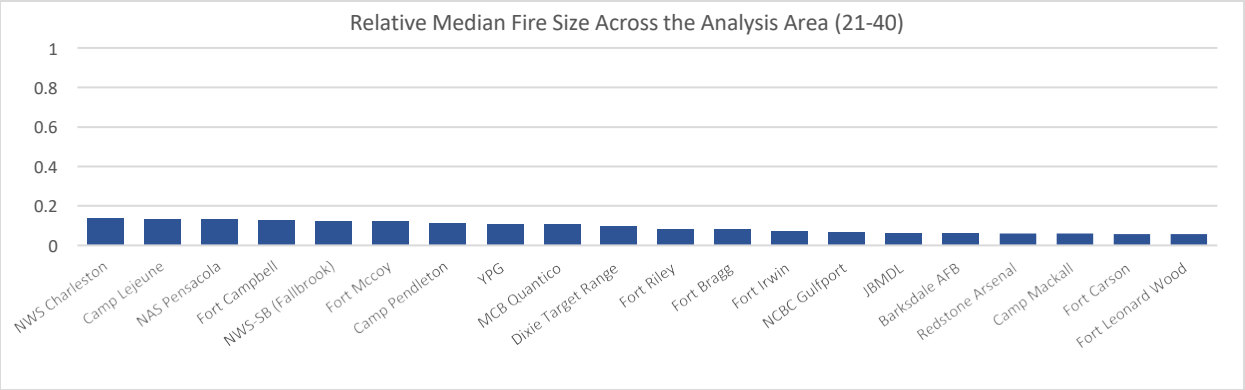


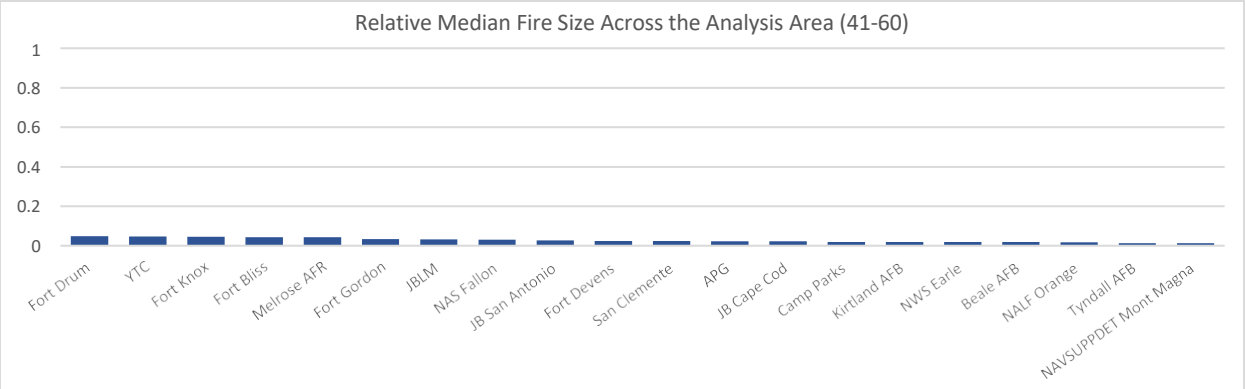


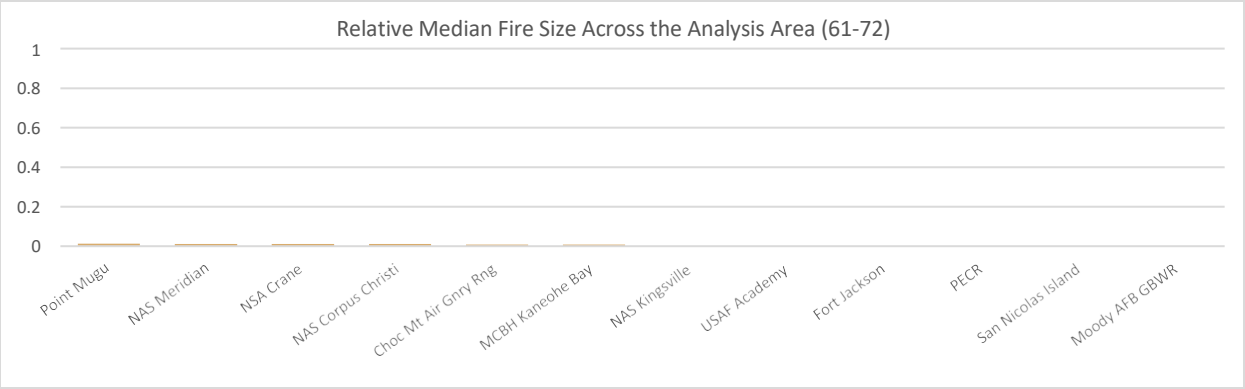


B.7 RELATIVE MEDIAN FIRE SIZE ACROSS THE ANALYSIS AREA

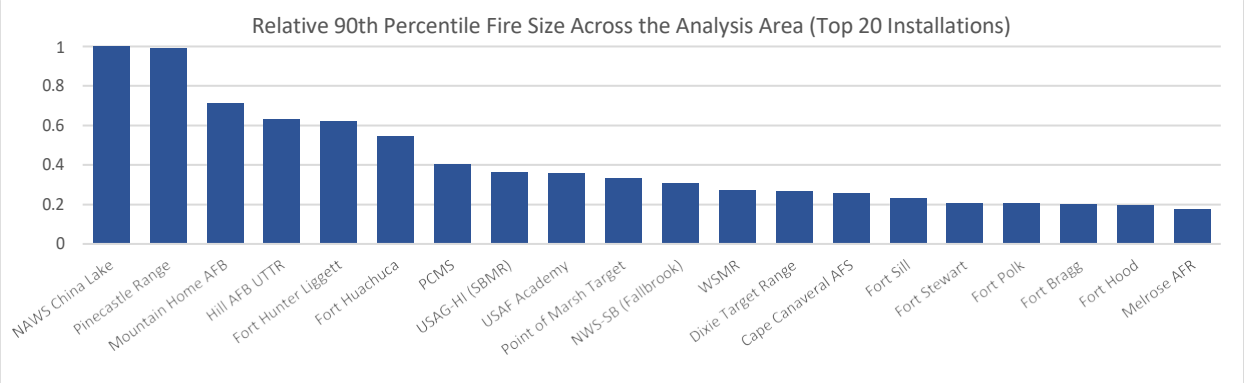


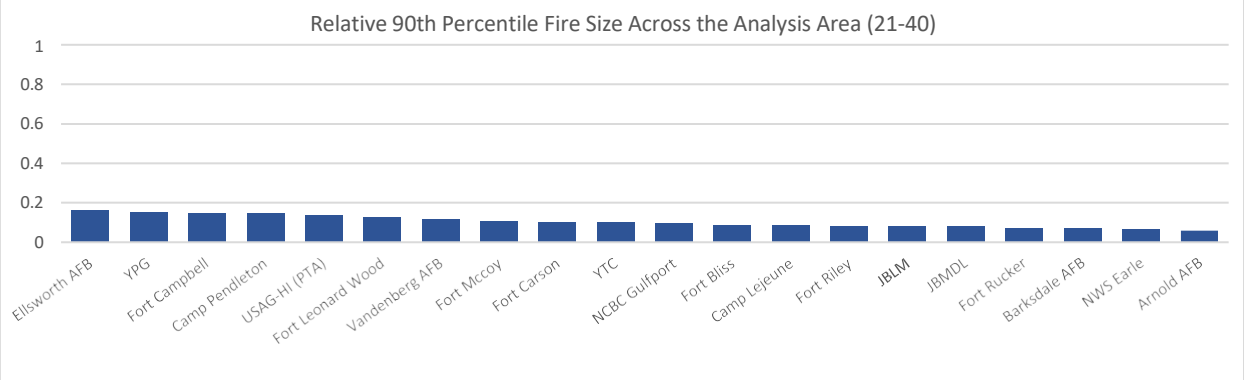


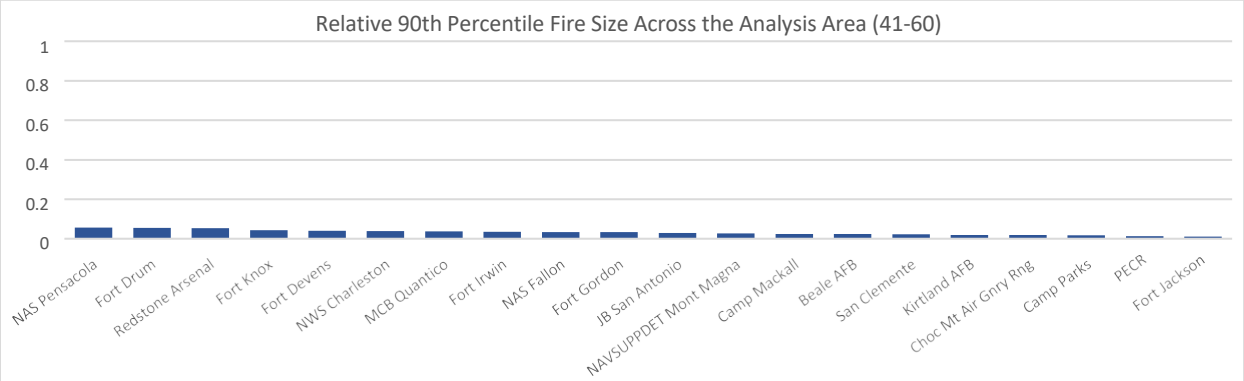


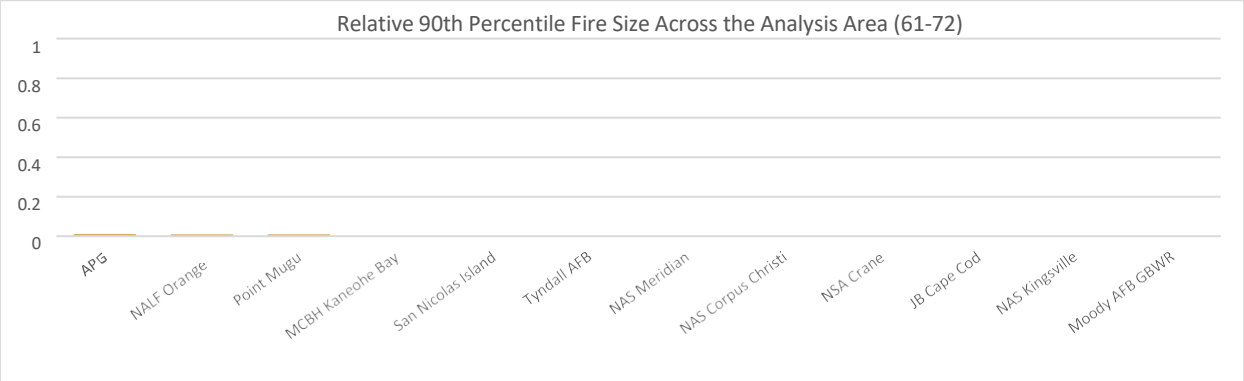


B.8 RELATIVE 90TH PERCENTILE FIRE SIZE ACROSS THE ANALYSIS AREA

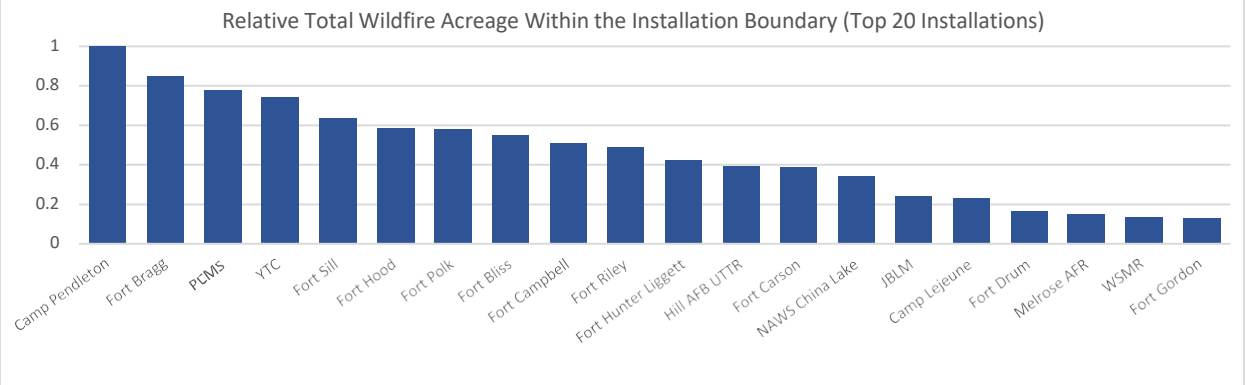


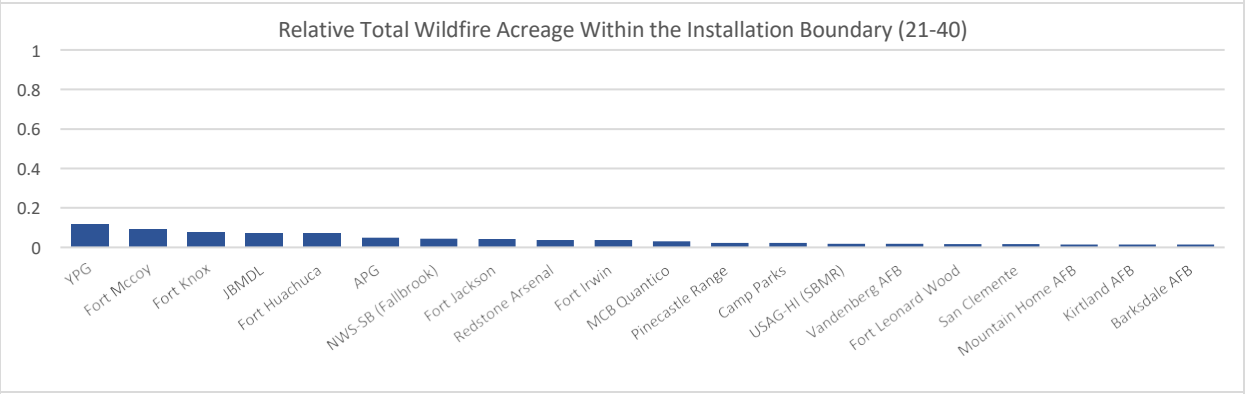


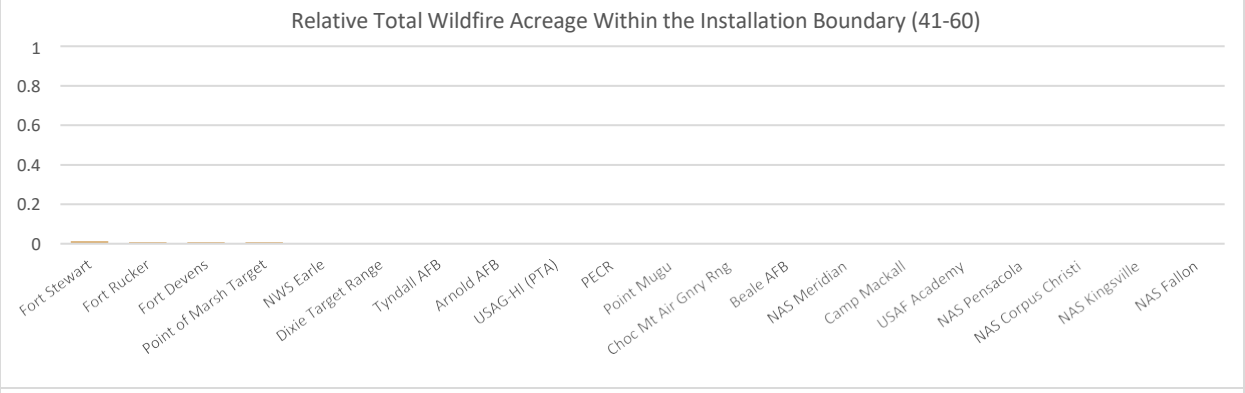


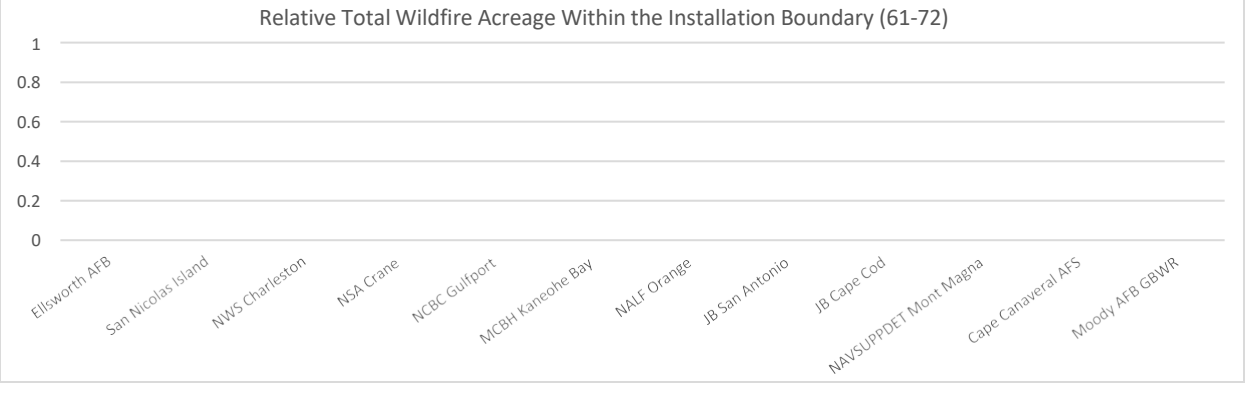


B.9 RELATIVE TOTAL WILDFIRE ACREAGE WITHIN THE INSTALLATION BOUNDARY

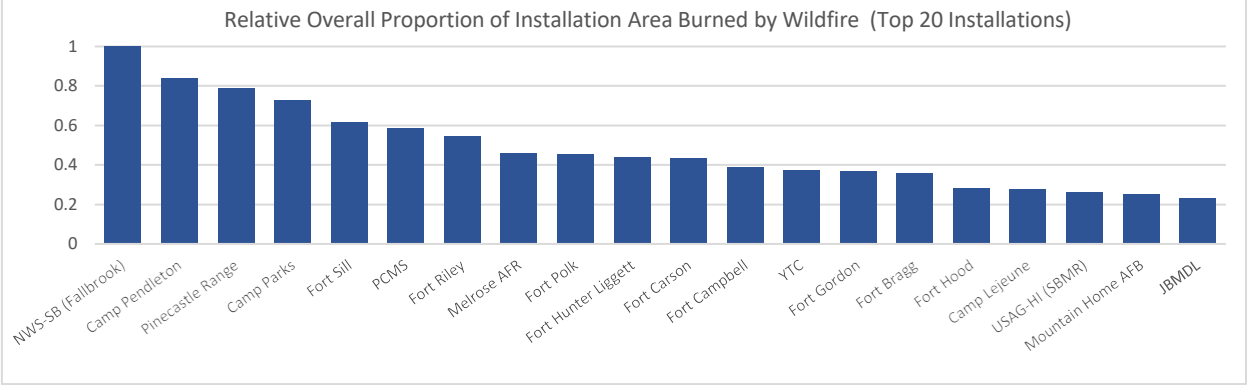


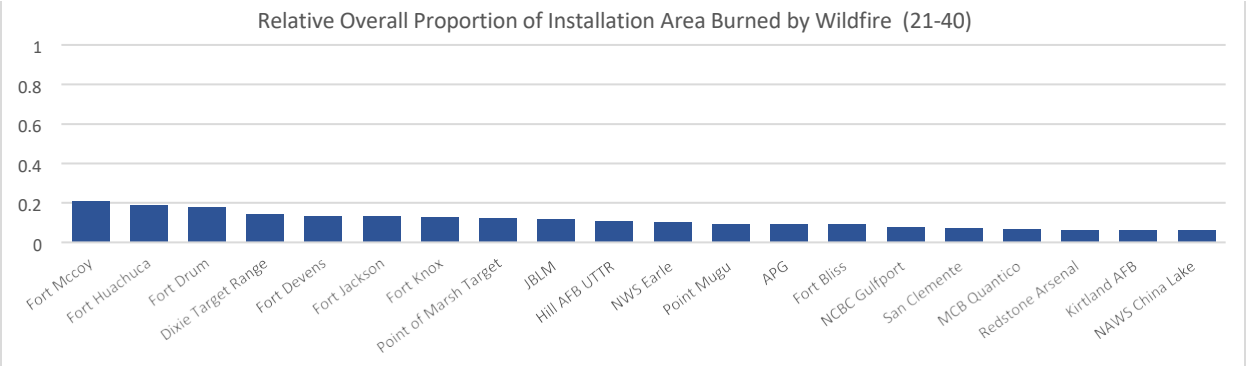


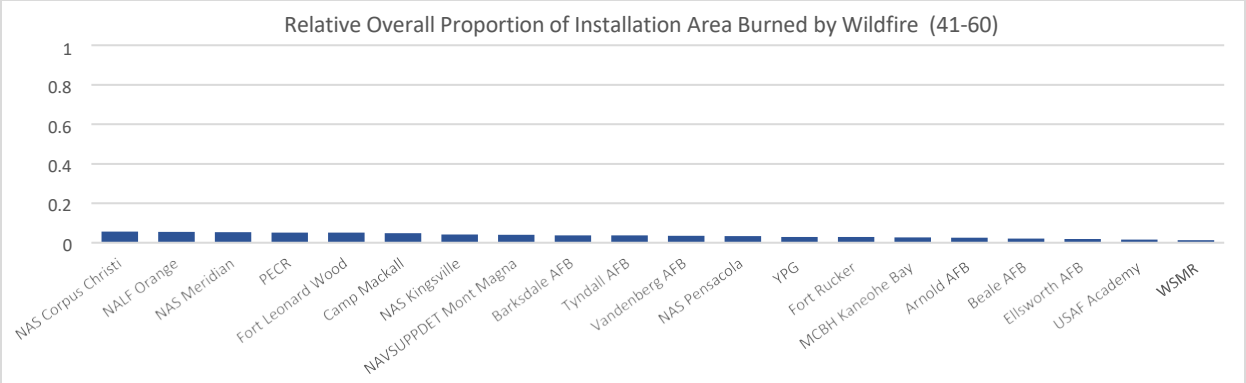


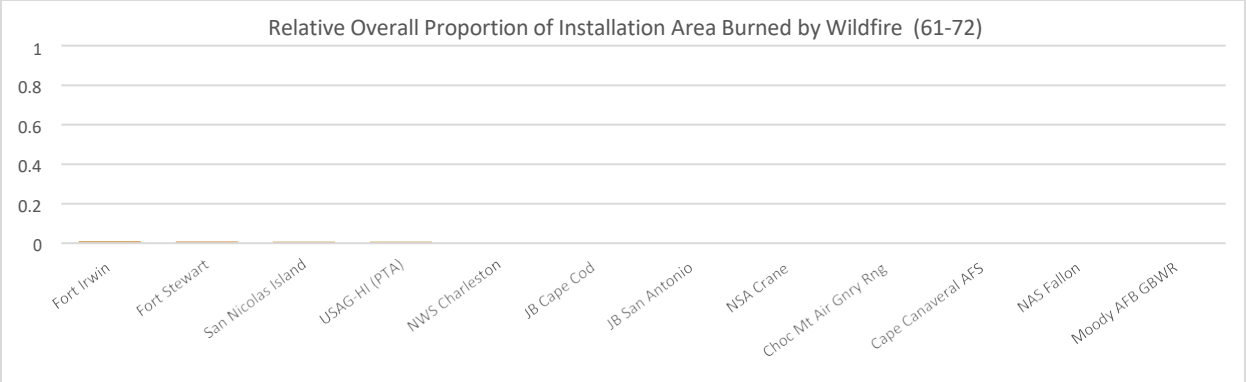


B.10 RELATIVE OVERALL PROPORTION OF INSTALLATION AREA BURNED BY WILDFIRE









APPENDIX C – INSTALLATION CATEGORY BY BRANCH AND CROSS-BRANCH ANALYSES

Table C - 1. Categorization results for each installation from the individual branch assessments and the Cross-Branch analysis.

INSTALLATION	BRANCH	BRANCH CATEGORY	CROSS-BRANCH CATEGORY	STATE	UTM ZONE	ANALYZED ACREAGE
ABERDEEN PROVING GROUND	ARMY	LOW	MODERATE	MD	18	71,908
ADELPHI	ARMY	NEGLIGIBLE	NEGLIGIBLE	MD	18	201
CAMP MACKALL	ARMY	LOW	LOW	NC	17	7,957
CAMP PARKS	ARMY	MODERATE	MODERATE	CA	10	2,479
CARLISLE BARRACKS	ARMY	NEGLIGIBLE	NEGLIGIBLE	PA	18	452
DETROIT ARSENAL	ARMY	NEGLIGIBLE	NEGLIGIBLE	MI	17	184
DUGWAY PROVING GROUND	ARMY	HIGH	MODERATE	UT	12	1,373,078
FORT AP HILL	ARMY	MODERATE	MODERATE	VA	18	74,626
FORT BELVOIR	ARMY	NEGLIGIBLE	NEGLIGIBLE	VA	18	8,322
FORT BENNING	ARMY	HIGH	HIGH	GA	16	182,461
FORT BLISS	ARMY	HIGH	HIGH	TX	13	1,114,107
FORT BRAGG	ARMY	HIGH	HIGH	NC	17	152,823
FORT BUCHANAN	ARMY	NEGLIGIBLE	NEGLIGIBLE	PR	19	757
FORT CAMPBELL	ARMY	HIGH	HIGH	TN	16	104,607
FORT CARSON	ARMY	MODERATE	MODERATE	CO	13	137,926
FORT DETRICK	ARMY	NEGLIGIBLE	NEGLIGIBLE	MD	18	1,149
FORT DEVENS	ARMY	LOW	LOW	MA	19	9,251
FORT DRUM	ARMY	LOW	MODERATE	NY	18	109,675
FORT GORDON	ARMY	MODERATE	MODERATE	GA	17	55,483
FORT GREELY	ARMY	NEGLIGIBLE	NEGLIGIBLE	AK	6	6,832
FORT HAMILTON	ARMY	NEGLIGIBLE	NEGLIGIBLE	NY	18	168
FORT HOOD	ARMY	HIGH	HIGH	TX	14	212,484
FORT HUACHUCA	ARMY	MODERATE	MODERATE	AZ	12	81,115
FORT HUNTER LIGGETT	ARMY	HIGH	MODERATE	CA	10	162,070
FORT IRWIN	ARMY	LOW	LOW	CA	11	754,763
FORT JACKSON	ARMY	LOW	MODERATE	SC	17	51,866
FORT KNOX	ARMY	LOW	LOW	KY	16	108,735
FORT LEAVENWORTH	ARMY	NEGLIGIBLE	NEGLIGIBLE	KS	15	5,740
FORT LEE	ARMY	NEGLIGIBLE	NEGLIGIBLE	VA	18	5,687
FORT LEONARD WOOD	ARMY	LOW	LOW	MO	15	61,894
FORT MCCOY	ARMY	LOW	LOW	WI	15	59,660
FORT MEADE	ARMY	NEGLIGIBLE	NEGLIGIBLE	MD	18	5,252
FORT MYER MCNAIR	ARMY	NEGLIGIBLE	NEGLIGIBLE	VA	18	355
FORT POLK	ARMY	HIGH	HIGH	LA	15	193,159
FORT RILEY	ARMY	HIGH	MODERATE	KS	14	101,629

INSTALLATION	BRANCH	BRANCH CATEGORY	CROSS-BRANCH CATEGORY	STATE	UTM ZONE	ANALYZED ACREAGE
FORT RUCKER	ARMY	LOW	MODERATE	AL	16	58,394
FORT SILL	ARMY	HIGH	HIGH	OK	14	94,018
FORT STEWART	ARMY	LOW	MODERATE	GA	17	284,930
FORT WAINWRIGHT	ARMY	HIGH	HIGH	AK	6	928,878
JB LEWIS MCCHORD	ARMY	MODERATE	MODERATE	WA	10	91,252
NATICK	ARMY	NEGLIGIBLE	NEGLIGIBLE	MA	19	79
PICATINNY ARSENAL	ARMY	NEGLIGIBLE	NEGLIGIBLE	NJ	18	5,861
PINON CANYON	ARMY	HIGH	MODERATE	CO	13	235,373
PRESIDIO MONTEREY	ARMY	NEGLIGIBLE	NEGLIGIBLE	CA	10	401
REDSTONE ARSENAL	ARMY	LOW	LOW	AL	16	38,150
ROCK ISLAND ARSENAL	ARMY	NEGLIGIBLE	NEGLIGIBLE	IL	15	899
SHARPE ARMY DEPOT	ARMY	NEGLIGIBLE	NEGLIGIBLE	CA	10	720
USAG HAWAII PTA	ARMY	MODERATE	MODERATE	HI	5	109,811
USAG HAWAII SCHOFIELD	ARMY	LOW	LOW	HI	4	13,584
USAG MIAMI	ARMY	NEGLIGIBLE	NEGLIGIBLE	FL	17	1,949
WEST POINT	ARMY	NEGLIGIBLE	NEGLIGIBLE	NY	18	16,086
WHITE SANDS MISSILE RANGE	ARMY	MODERATE	MODERATE	NM	13	2,189,698
YAKIMA TRAINING CENTER	ARMY	HIGH	HIGH	WA	10	327,233
YUMA PROVING GROUND	ARMY	LOW	LOW	AZ	11	839,721
CAMP MORENA	NAVY	NEGLIGIBLE	NEGLIGIBLE	CA	11	62
DIXIE TARGET RANGE	NAVY	MODERATE	LOW	TX	14	7,848
NALF ORANGE	NAVY	LOW	LOW	TX	14	1,380
NAS CORPUS CHRISTI	NAVY	MODERATE	LOW	TX	14	4,494
NAS FALLON	NAVY	LOW	LOW	NV	11	227,912
NAS JACKSONVILLE	NAVY	NEGLIGIBLE	NEGLIGIBLE	FL	17	4,114
NAS KINGSVILLE	NAVY	MODERATE	LOW	TX	14	4,436
NAS MERIDIAN	NAVY	MODERATE	LOW	MS	16	8,066
NAS OCEANA	NAVY	NEGLIGIBLE	NEGLIGIBLE	VA	18	5,304
NAS PENSACOLA	NAVY	LOW	LOW	FL	16	8,036
NAS WHITING FIELD	NAVY	NEGLIGIBLE	NEGLIGIBLE	FL	16	5,438
NAVSUPPDET MONT CENT BCH	NAVY	NEGLIGIBLE	NEGLIGIBLE	CA	10	33
NAVSUPPDET MONT DIXON FAC	NAVY	NEGLIGIBLE	NEGLIGIBLE	CA	10	1,300
NAVSUPPDET MONT MAGNA UTAH	NAVY	LOW	LOW	UT	12	531
NAVSUPPDET MONTEREY	NAVY	NEGLIGIBLE	NEGLIGIBLE	CA	10	621
NAWS CHINA LAKE	NAVY	HIGH	MODERATE	CA	11	1,108,955
NB SAN DIEGO	NAVY	NEGLIGIBLE	NEGLIGIBLE	CA	11	2,562
NCBC GULFPORT	NAVY	LOW	LOW	MS	16	1,121
NCTAMS PACIFIC	NAVY	NEGLIGIBLE	NEGLIGIBLE	HI	4	762
NIOC SUGAR GROVE	NAVY	NEGLIGIBLE	NEGLIGIBLE	WV	17	116

INSTALLATION	BRANCH	BRANCH CATEGORY	CROSS-BRANCH CATEGORY	STATE	UTM ZONE	ANALYZED ACREAGE
NOLF BREWTON	NAVY	NEGLIGIBLE	NEGLIGIBLE	AL	16	658
NOLF CHOCTAW	NAVY	NEGLIGIBLE	NEGLIGIBLE	FL	16	1,430
NSA CRANE	NAVY	LOW	LOW	IN	16	61,828
NSB KINGS BAY	NAVY	NEGLIGIBLE	NEGLIGIBLE	GA	17	17,449
NWS CHARLESTON	NAVY	LOW	LOW	SC	17	16,791
NWS EARLE	NAVY	LOW	LOW	NJ	18	11,072
NWS SEAL BEACH	NAVY	NEGLIGIBLE	NEGLIGIBLE	CA	11	4,837
NWS SEAL BEACH DET FALLBROOK	NAVY	MODERATE	MODERATE	CA	11	8,907
NWS YORKTOWN	NAVY	NEGLIGIBLE	NEGLIGIBLE	VA	18	12,637
NWSTF BOARDMAN	NAVY	HIGH	MODERATE	OR	11	47,318
OLF WHITEHOUSE	NAVY	NEGLIGIBLE	NEGLIGIBLE	FL	17	2,576
PEARL HARBOR	NAVY	NEGLIGIBLE	NEGLIGIBLE	HI	4	1,184
PINECASTLE RANGE	NAVY	HIGH	MODERATE	FL	17	5,733
POINT MUGU	NAVY	MODERATE	LOW	CA	11	6,000
SAN CLEMENTE	NAVY	MODERATE	LOW	CA	11	43,361
SAN NICOLAS ISLAND	NAVY	LOW	LOW	CA	11	14,731
SANTA CRUZ ISLAND	NAVY	MODERATE	NEGLIGIBLE	CA	11	19
ARNOLD AFB	USAF	MODERATE	LOW	TN	16	39,040
AVON PARK AFR	USAF	HIGH	HIGH	FL	17	108,129
BARKSDALE AFB	USAF	MODERATE	LOW	LA	15	79,639
BARRY GOLDWATER AFR	USAF	MODERATE	MODERATE	AZ	12	1,050,360
BEALE AFB	USAF	MODERATE	LOW	CA	10	23,139
CAPE CANAVERAL AFS	USAF	LOW	LOW	FL	17	20,287
CHEYENNE MTN AFS	USAF	NEGLIGIBLE	NEGLIGIBLE	CO	13	532
COLUMBUS AFB	USAF	NEGLIGIBLE	NEGLIGIBLE	MS	16	5,287
DARE COUNTY BOMBING RANGE	USAF	MODERATE	MODERATE	NC	18	46,595
DOBBINS ARB	USAF	NEGLIGIBLE	NEGLIGIBLE	GA	16	1,680
EGLIN AFB HURLBURT AFB	USAF	HIGH	HIGH	FL	16	464,447
ELLSWORTH AFB	USAF	LOW	MODERATE	SD	13	5,466
GRAND FORKS AFB	USAF	NEGLIGIBLE	NEGLIGIBLE	ND	14	5,167
HILL AFB UTTR	USAF	HIGH	MODERATE	UT	12	377,543
HOLLOMAN AFB	USAF	NEGLIGIBLE	NEGLIGIBLE	NM	13	50,704
HOMESTEAD ARB	USAF	NEGLIGIBLE	NEGLIGIBLE	FL	17	1,943
JB CAPE COD	USAF	LOW	LOW	MA	19	20,619
JB CHARLESTON	USAF	NEGLIGIBLE	NEGLIGIBLE	SC	17	20,121
JB ELMENDORF RICHARDSON	USAF	NEGLIGIBLE	NEGLIGIBLE	AK	6	75,178
JB LANGLEY FORT EUSTIS	USAF	NEGLIGIBLE	NEGLIGIBLE	VA	18	11,120
JB MCGUIRE DIX LAKEHURST	USAF	HIGH	LOW	NJ	18	42,129
JB SAN ANTONIO	USAF	LOW	LOW	TX	14	45,865

INSTALLATION	BRANCH	BRANCH CATEGORY	CROSS-BRANCH CATEGORY	STATE	UTM ZONE	ANALYZED ACREAGE
JUNIPER BUTTE BOMBING RANGE	USAF	NEGLIGIBLE	NEGLIGIBLE	ID	11	12,034
KIRTLAND AFB	USAF	MODERATE	LOW	NM	13	46,168
LITTLE ROCK AFB	USAF	NEGLIGIBLE	NEGLIGIBLE	AR	15	6,197
MACDILL AFB	USAF	NEGLIGIBLE	NEGLIGIBLE	FL	17	5,694
MELROSE AFR	USAF	HIGH	MODERATE	NM	13	60,199
MOODY AFB GRAND BAY	USAF	LOW	LOW	GA	17	10,982
MOUNTAIN HOME AFB	USAF	MODERATE	MODERATE	ID	11	10,666
NEW BOSTON AS	USAF	NEGLIGIBLE	NEGLIGIBLE	NH	19	2,915
NTTR	USAF	HIGH	MODERATE	NV	11	2,950,831
PECR	USAF	MODERATE	LOW	SC	17	12,517
ROBINS AFB	USAF	NEGLIGIBLE	NEGLIGIBLE	GA	17	6,735
SAYLOR CREEK BOMBING RANGE	USAF	HIGH	HIGH	ID	11	110,093
TINKER AFB	USAF	NEGLIGIBLE	NEGLIGIBLE	OK	14	4,440
TYNDALL AFB	USAF	MODERATE	LOW	FL	16	28,129
USAF ACADEMY	USAF	LOW	LOW	CO	13	19,183
VANDENBERG AFB	USAF	MODERATE	MODERATE	CA	10	99,725
WESTOVER ARB	USAF	NEGLIGIBLE	NEGLIGIBLE	MA	18	2,380
WRIGHT PATTERSON AFB	USAF	NEGLIGIBLE	NEGLIGIBLE	OH	16	7,656
BARRY GOLDWATER RANGE WEST	USMC	NEGLIGIBLE	NEGLIGIBLE	AZ	12	698,257
CAMP LEJEUNE	USMC	HIGH	MODERATE	NC	18	123,069
CAMP PENDLETON	USMC	HIGH	HIGH	CA	11	126,988
CHOC MT AIR GNRY RNG	USMC	MODERATE	LOW	CA	11	460,346
MCAGCC TWENTYNINE PALMS	USMC	NEGLIGIBLE	NEGLIGIBLE	CA	11	597,371
MCAS BEAUFORT	USMC	NEGLIGIBLE	NEGLIGIBLE	SC	17	6,613
MCAS CHERRY POINT	USMC	NEGLIGIBLE	NEGLIGIBLE	NC	18	10,266
MCAS MIRAMAR	USMC	LOW	LOW	CA	11	22,562
MCB HAWAII KANEOHE BAY	USMC	MODERATE	LOW	HI	4	3,001
MCB QUANTICO	USMC	MODERATE	LOW	VA	18	58,924
MCOLF ATLANTIC	USMC	LOW	NEGLIGIBLE	NC	18	1,492
MCRD PARRIS ISLAND	USMC	NEGLIGIBLE	NEGLIGIBLE	SC	17	8,109
MWTC BRIDGEPORT	USMC	LOW	NEGLIGIBLE	CA	11	56
POINT OF MARSH TARGET AREA	USMC	MODERATE	MODERATE	NC	18	11,911