COMPARING NDVI ACROSS GEOGRAPHIC AREA COORDINATION CENTERS

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ABSTRACT

Restoring burned areas to pre-fire conditions represents a large effort for land managers and requires an understanding of the spatial and temporal trends in vegetation health. Using remote sensing tools such as NDVI can help inform decision-makers about trends in vegetation health specific to a burned area. This study used the NDVI Baseline dataset containing a decade of scaled NDVI data for the entire western United States. NDVI trend was determined by extracting NDVI values at randomly selected sample points distributed across seven Geographic Area Coordination Center (GACC) polygons within the study area. These data indicate NDVI fundamentally differs between GACCs and are well correlated with ecological regions. Across the study area, annual NDVI is considered stable having a mean trendline slope of -0.29 (the absolute mean slope was 6.03). Understanding NDVI trend within a management region can help land managers develop plans and goals that are compatible with specific landscapes and these data should be used to formulate post-wildfire recovery plans

INTRODUCTION

Following a wildfire, federal agencies are expected to return the landscape to pre-fire conditions, in which native plants are restored to the conditions at which they previously existed. Monitoring past and current spatial trends in vegetation health relative to a wildfire event is essential to optimize recovery plans and ensure ecosystems are recovering from wildfire without spending unnecessary resources trying to restore a landscape to an unattainable or unsustainable level of productivity. Spatial and temporal patterns in NDVI can provide information about the persistence and resilience of vegetation in response to known events such as wildfires (Lacouture et al., 2020).

Normalized difference vegetation index (NDVI) is an estimation of vegetative health. Healthy, photosynthetically active vegetation will have stronger near-infrared (NIR) reflectance while unhealthy vegetation will have stronger reflectance in the visible red band (R). The calculation for NDVI is (NIR-R)/(NIR+R). Thus, NDVI values approaching 1.0 represent healthy, dense vegetation while NDVI values approaching 0 represent unhealthy, sparse, dormant, and/or dead vegetation biomass. NDVI values approaching -1.0 tend to be indicative of water bodies, urbanized areas, or otherwise barren land (NASA Earth Observatory, 2000).

The study used Geographic Area Coordination Centers (GACCs) polygons to assess NDVI trends across the western United States. There are seven GACCs within the study area, namely the Great Basin, Northern California, Northern Rockies, Northwest, Rocky Mountain, Southern California, and Southwest regions (Figure 1). These regions delineate areas of wildfire management based on logistics such as resources, personnel, and biophysical conditions. Within each GACC, all fire activity is reported and monitored using real-time observations and existing authoritative datasets, which in turn, are used to predict future conditions and fire risk within the region (National Interagency Fire Center, 2024).

Figure 1. Seven of the eleven GACC regions as delineated by the National Interagency Fire Center (NIFC) and clipped to the NASA RECOVER AOI. These areas define the extent of the NDVI analysis.

Characterizing NDVI trends within each GACC region begins to quantify how vegetation --and subsequently fire regimes-- differ between regions. These trends can serve as an indicator of fire susceptibility as well as a potential goal for recovery. It may be expected that fires will occur more commonly where NDVI quickly declines from relatively high values early in the growing season, indicating greater proportions of dry or dead vegetation biomass (fuel) within the region. However, high NDVI values may also indicate higher fuel load and in the event of a fire, a potential increase in fire severity. It is important to note that NDVI values do not directly correlate with fuel load or fuel continuity but can be used to inform land managers along with *in situ* observations. Considering the implications of vegetation type, abundance, and health is important when interpreting NDVI values for fire management.

To assist land managers with acquisition and use of NDVI imagery, the NASA RECOVER project created the NDVI Baseline dataset. The NDVI Baseline is a multidimensional raster dataset that describes NDVI both spatially (across the western United States) and temporally (2013-2022). These data represent NDVI values using a scaling factor of 10,000 and are stored as 16-bit signed integer to reduce the overall storage size. The NDVI Baseline only records NDVI values in the months of April through September to capture the entirety of the growing season while minimizing the influence of snow and ice in annual NDVI interpretations. Along with the complete multidimensional dataset, RECOVER provides a one-dimensional raster layer for each statistic type calculated from the full NDVI Baseline. These are the median, mean, standard deviation, maximum, and both upper- and lower-bound NDVI at 95% confidence intervals (NASA RECOVER, 2023).

The NDVI Baseline and GACC polygon areas were used to determine the absolute range and trend of NDVI over time. The results from this study can be used to inform decisions regarding post-fire management and recovery.

METHODS

The median NDVI within each GACC was determined using the GACC polygons as zones within the zonal statistics geoprocessing tool in ArcGIS Pro. This analysis calculated the minimum, maximum, range, mean, and standard deviation of the NDVI median. These statistics were then used to calculate the quartiles and the interquartile range (IQR) and identify outliers/anomalous data in a series of boxplots (Peltier, 2007). The near outlier values (all values at least 1.5 IQRs below the 1st quartile or 1.5 IQRs above the 3rd quartile) were used to map regions within each GACC that had unusually low or high NDVI values.

To assess NDVI within each GACC both temporally and spatially, we drilled down through the entire multidimensional NDVI Baseline dataset to extract NDVI values through time at 3,500 randomly distributed sampling points across the study area. The minimum spacing between each sample point was set to 24,375 meters in order to most efficiently fit and evenly distribute all 3,500 sampling points. The area of each GACC varies significantly, so not all GACCs have the same number of samples, but the density and spacing of sample points remain consistent across the study area. The sampled NDVI values and corresponding dates were exported to a spreadsheet. These data were sorted and separated by GACC, by year, and by month to help quantify NDVI trends over time within each GACC. The NDVI trends were then graphed for comparison.

RESULTS AND DISCUSSION

Statistics describing median NDVI over the last decade reveal variations in NDVI across and within GACCs (Figure 2). The standard deviation of NDVI values within each GACC ranges from +/- 400 to +/- 900 with coefficients of variation ($(\sigma/\mu)*100$) ranging from 35-54%. While the maximum median NDVI values observed within each GACC are similar, the minimum median NDVI values vary greatly. The boxplots also reveal that the minimum and maximum NDVI values of each GACC fall well beyond the whiskers, indicating that our dataset has statistical outliers, albeit real NDVI data. These outliers were mapped to show regions within each GACC where the median NDVI was unusually low or high (Figure 3). The clusters of extremely low NDVI values surround the Great Salt Lake in the Great Basin GACC and other waterbodies throughout each of the GACCs, as well as along barren, high-elevation mountain peaks. Unusually high NDVI values were most commonly clustered around agricultural lands, large cities, and forests. However, these statistics themselves do not tell us about the timing of the differences across years or across growing seasons.

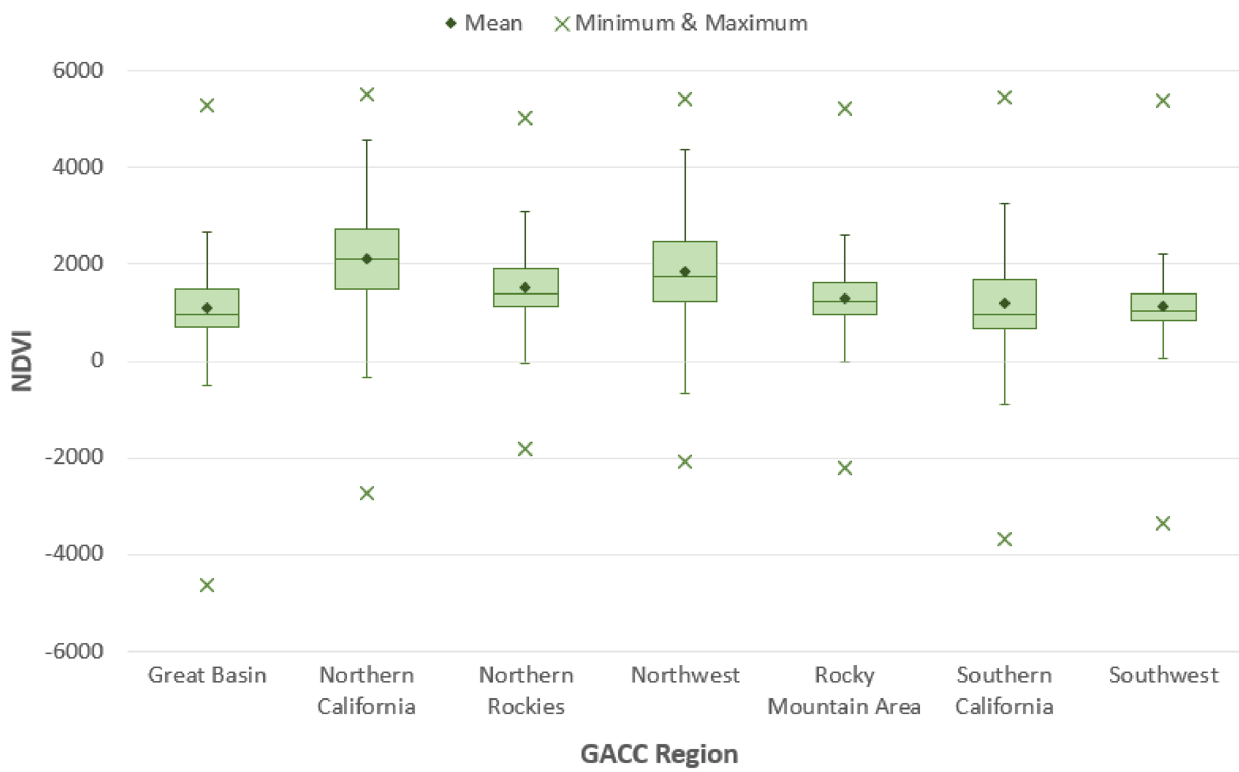

Figure 2. Boxplots describing the minimum, maximum, median, mean, first quartile, third quartile, and outlier statistics of the median NDVI values over the last decade within each of the 7 GACC extents. Zonal statistics were acquired from the scaled NDVI Baseline Median raster layer in which each GACC polygon represents a zone. NDVI values have been scaled by a factor of 10,000 in which NDVI values approaching 10,000 represent healthier, greener, and denser vegetation. NDVI values near 0 represent unhealthy, spare vegetation while NDVI values approaching -10,000 indicate bare surfaces or water-bodies.

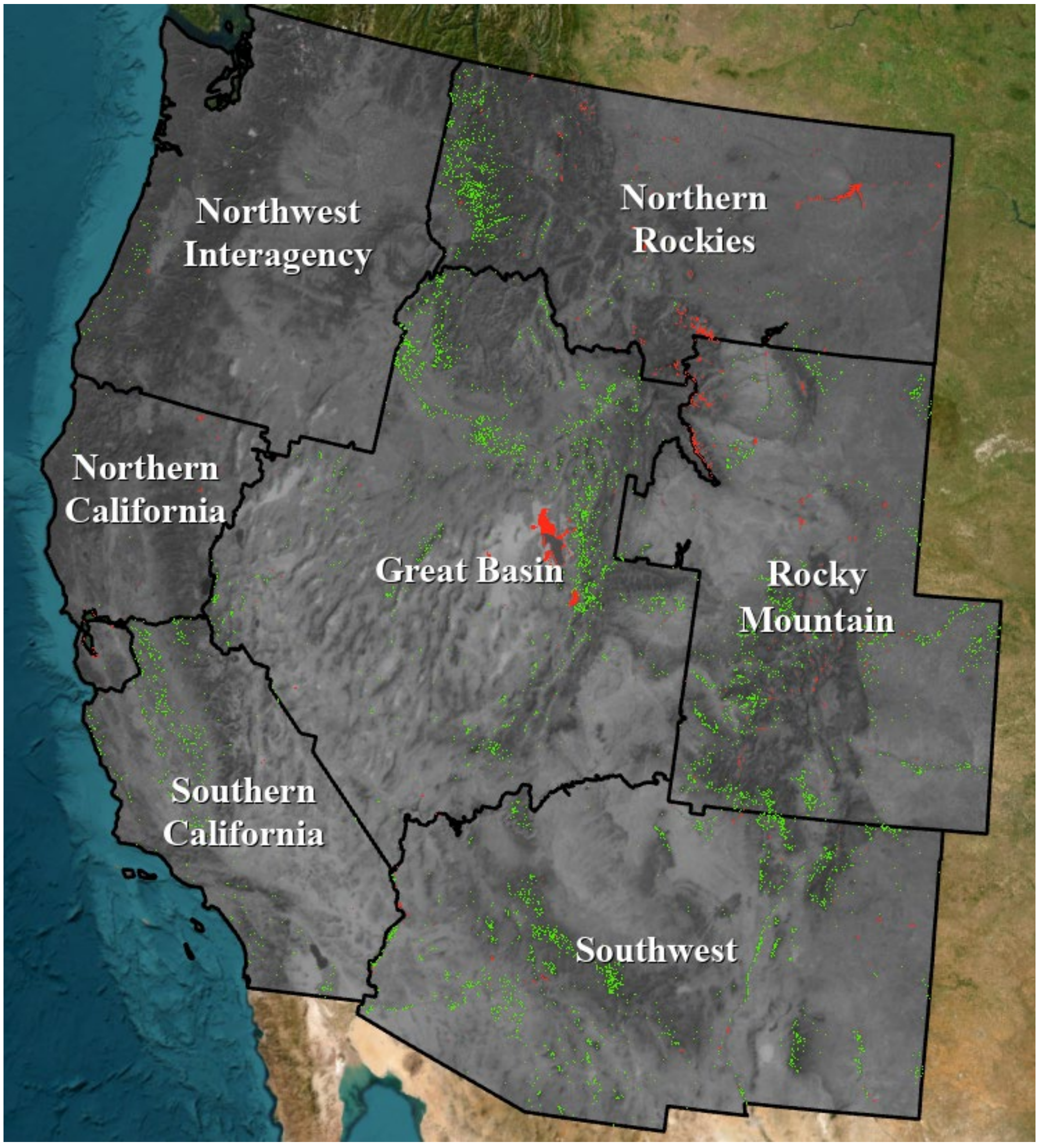

Figure 3. A spatial map of near high outliers (green) and near low outliers (red) within each GACC across the Western US based on statistics calculated from the median NDVI of the last decade.

Using the multidimensional NDVI Baseline dataset, NDVI trends were analyzed and visualized over time. The average annual NDVI was calculated for each year within each GACC to assess how NDVI changes across years (Figure 4). This study found the overall, average NDVI was highest for the Northern California, Northwest, and Northern Rockies GACCs while NDVI generally decreases moving southward and eastward into hotter and more xeric environments. However, the Great Basin, the largest GACC area located in the center of the western US, exhibited the lowest average NDVI values. Comparing this with the EPA's Level 1 Ecoregions map, the Great Basin GACC is classified almost entirely as North American Desert (EPA, 2006). Similarly, the Southwest GACC is also largely classified as North American Desert, but includes a substantial portion of the Temperate Sierra ecoregion. This helps explain why annual NDVI trends are slightly higher in the Southwest GACC compared to the Great Basin GACC. Furthermore, the Great Basin is typified by arid, alkali, salt-laden landscapes which can be expected to have lower NDVI values. The Northern California GACC is the smallest GACC and is almost entirely occupied by the Northwestern Forested Mountain ecological type, which explains why it has consistently higher NDVI values.

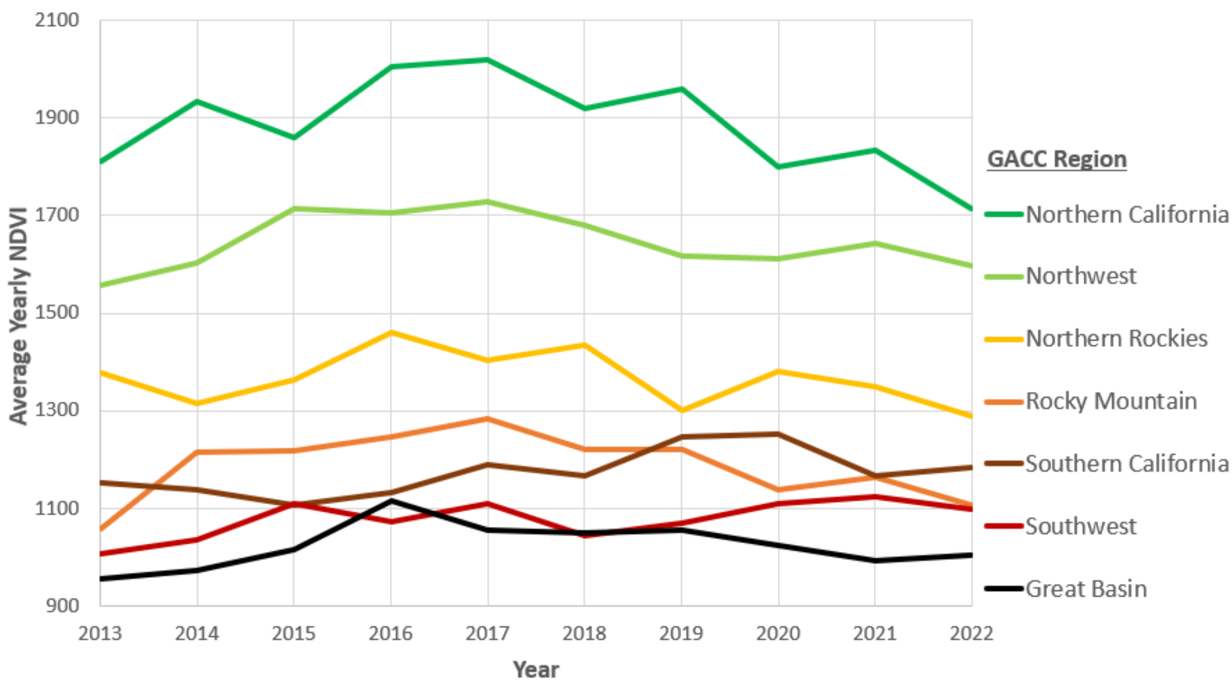

Figure 4. Average annual NDVI trends by GACC from 2013-2022. For each of the 7 GACC extents described in Figure 1, NDVI values and their corresponding dates were randomly extracted from the multidimensional NDVI Baseline and then averaged for each year. NDVI values have been scaled by a factor of 10,000 in which higher values represent healthier, greener, and denser vegetation on average throughout a year. Long-term trends in NDVI across regions are useful in assessing the effects of climate change, fire, land use, and urbanization.

Overall, there does not appear to be drastic changes in NDVI throughout the last decade in any of the GACC regions (Table 1). While there is certainly variability across years, the overall trends appear relatively stable. Linear regression trend lines were fit to these data and for those GACCs with higher annual NDVI trends, a slight decrease is observed over time, but the relationship is fairly weak ($R^2 < 0.15$). Linear regression trend lines for the Southern California and Southwest GACCs are the only two indicating a slight increase in NDVI. These GACCs also exhibit the highest r-squared values (0.359 and 0.409, respectively). Still, the realationship between NDVI and time is not strong and no long-term trend should be inferred without further reseach and analysis.

Table 1. The slopes of linear regression trendlines and corresponding R^2 values of average annual NDVI for each GACC.

GACC	Slope of trendline	R^2
Northern California	-12.6	0.152
Northwest	-1.2	0.004
Northern Rockies	-5.5	0.087
Rocky Mountain	-2.8	0.015
Southern California	9.3	0.359
Southwest	8.1	0.409
Great Basin	2.7	0.030

The multidimensional NDVI Baseline can be used to determine the average NDVI for each month and compare growing season trends across GACCs (Figure 5). Generally, NDVI values tended to be highest in June and July, except for the Southwest GACC where the timing of the average NDVI peak was delayed into August and September. The North American monsoon may be a possible driver behind this, especially considering the Southwest GACC consists of Arizona and New Mexico only. Both of these states are heavily impacted by the monsoon event (Adams & Comrie, 1997). As expected, NDVI values tended to be lowest during April and May, except for the Southern California GACC which had unusually high NDVI values in April and May relative to June, July, August, and September. Southern California is the only GACC in which NDVI values were higher in spring than they were in late summer. Additionally, the Northern Rockies, Northwest, and Rocky Mountain GACCs exhibited the greatest variability in NDVI across the growing season. This high degree of variability may be explained by harsher winters and a higher range in elevation within these regions, resulting in lower initial NDVI values which then rapidly increase throughout the early summer with the continued release of snowmelt and warmer temperatures. As water resources dwindle through the late summer months and temperatures continue to increase, NDVI values begin to decline steeply in these GACCs. NDVI trends in GACCs such as Northern California, Southern California, and the Southwest are more consistent throughout the growing season which indicates plant growth does not exhibit the seasonality as markedly as in other GACCs.

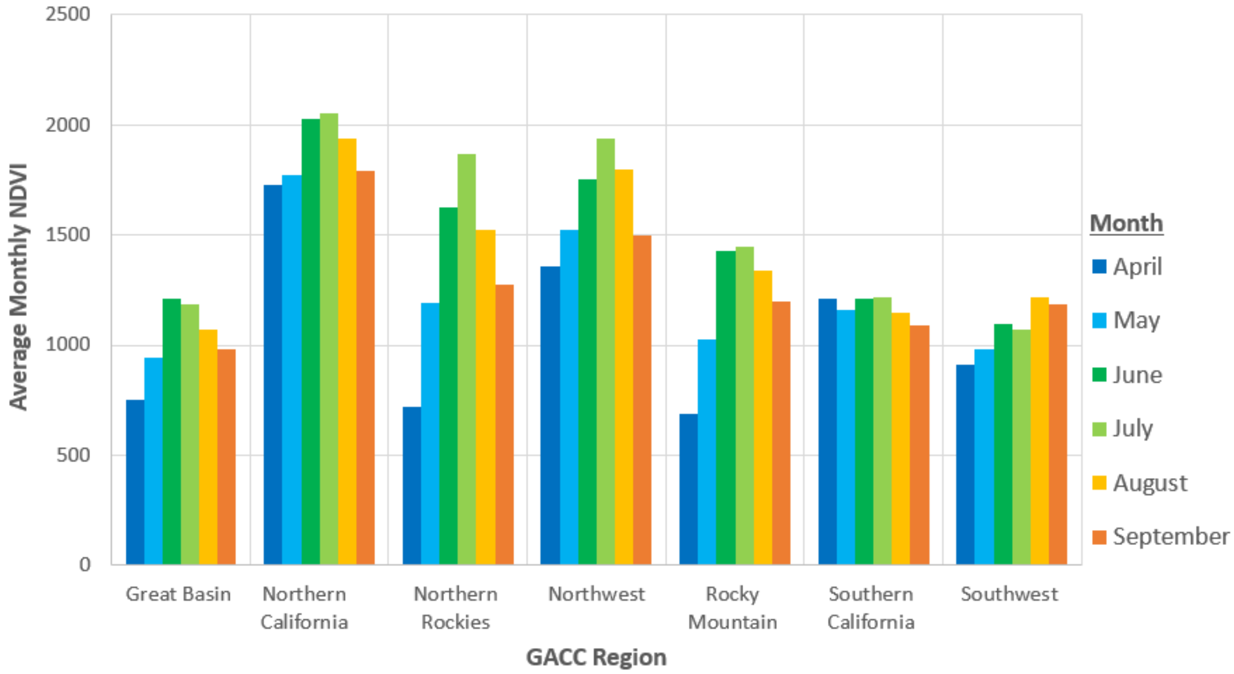

Figure 5. Average monthly NDVI values within each of the 7 GACCs, averaged for each month from 2013-2022. Blues represent late spring, greens represent early summer, and oranges represent late summer. NDVI values and their corresponding dates were randomly extracted from the multidimensional NDVI Baseline and then averaged for each month using monthly data spanning from 2013-2022. NDVI values have been scaled by a factor of 10,000 in which higher values represent healthier, greener, and denser vegetation on average for that month throughout the last decade. Long-term trends in NDVI across regions and months are useful in assessing the effects and timing of climate change, fire, land use, and urbanization.

CONCLUSIONS

The results of this NDVI analysis are fairly well correlated to the EPA's Level 1 ecological zones (EPA, 2006). GACC regions that contain a greater proportion of the North American Desert ecological zone have lower NDVI values whereas GACC regions consisting mostly of the Northwestern Forested Mountains ecological zone exhibit higher NDVI values. Semi-arid and temperate ecological zones such as Mediterranean California, Temperate Sierras, and Southern Semi-arid Highlands commonly occur alongside deserts and appear to increase NDVI values of otherwise arid GACCs. Considering the ecoregions may also help interpret monthly NDVI trends across a growing season. This is because the phenology of plant greenup and senescense is largely driven by specific ecological responses to environmental conditions and changes in those conditions.

Generally, the annual trends in NDVI appear to be relatively stable throughout the last decade. However, a decade may not be long enough to sufficiently capture the effects of climate change, changing fire regimes, land use change, and urbanization on vegetative health.

Federal agencies responsible for post-wildfire management are tasked with returning burned areas to their natural, pre-fire conditions, in which the landscape is suitably restored with the native species that existed before the disturbance. NDVI trends can help land managers realistically understand pre-fire vegetation conditions and identify when a post-fire recovery goal has been achieved. The results of this study suggest post-wildfire vegetation recovery should not be considered comparable across GACCs and therefore, management plans need to reflect this reality. For example, restored fire areas in the Great Basin GACC should not be expected to reach the same NDVI values as recovered fire areas in Northern California.

Monitoring and comparing NDVI values across space and time using an appropriate landscape scale is useful in assessing post-fire conditions and recovery. Despite limitations regarding the resolution of satellite imagery and its inability to record understory growth, there are numerous instances where NDVI data from satellite imagery can be very useful metrics to assess vegetation growth and post-fire recovery (Telesca & Lasaponara, 2006), especially when coupled with field observations. Additional research to assess the duration of recovery within GACCs or ecological zones is merited to more fully understand and better manage these ecosystems.

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