ANALYSIS OF GROWING SEASON DURATION ACROSS THE WESTERN US

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ABSTRACT

It has been suggested that the length of the growing season may be increasing as a result of climate change. This potential change has been cited as a cause for the increasing frequency of wildfires. To test this hypothesis, this study used 16-day composite normalized difference vegetation index data (NDVI) from the MODIS sensor (MOD13) to characterize the length and onset of the growing season between 2001 and 2019. Actively Growing Vegetation was defined as vegetation exhibiting an NDVI value equal to or in excess of 0.20. Using this threshold value, the onset or beginning of the growing season was determined as the day when $\geq$33% of the study area exhibited actively growing vegetation. Similarly, the growing season was considered to have ended when $\leq$ 33% of the study exhibited actively growing vegetation. The time interval (number of days) between the start and end of the growing season was considered the length of the growing season. These data showed no change in either the length or onset of the growing season. The linear trend in both growing season length and onset over time was stable as evidenced by very small slope values (-0.38 and 0.39, respectively). Future research should strive to expand the length of the dataset to allow a longer period of observations.

KEYWORDS: *biomass, LANDFIRE, NDVI, climate, wildfire*

INTRODUCTION

Over the past few decades, the wildfire season seems to have been growing longer, leading many to abandon the term "fire season" and use the more appropriate term, "fire year". Recent fire years have witnessed more frequent and larger fires (Weber and Yadav 2020). In order for a fire to burn, three criteria must be met: fuel, oxygen, and a source of ignition. Without any one of these three fire triangle components (https://www.nps.gov/articles/wildlandfire-facts-fuel-heat-oxygen.htm) a fire cannot exist. With this understanding, we asked what changed to allow for the current, prolonged fire season/year?

Since the availability of oxygen has been more or less constant over the past centuries, we dismissed this as a driver variable behind this phenomenon. An ignition source that provides sufficient heat to allow a fuel to combust is not readily dismissed. While the prevalence of lightning –the primary ignition source of wildfire-- has likely been relatively constant, the co-occurrence of rainfall along with lightning is not well understood. For example, if a thunderstorm produces both lightning and sufficient precipitation, the likelihood of a wildfire ignition is relatively low compared to a dry-thunderstorm. If dry thunderstorms are more common today than they were just a few decades ago, then a changing ignition regime could help explain the increase in wildfire frequency seen today. In addition, the role of man in both managing the landscape and either accidentally or intentionally starting fires may also help explain the change in fire frequency observed over the past few decades. In essence, an increase in human population increases the probability for human-caused wildfires.

However, even if a change in the ignition regime could be demonstrated, this would not readily explain the increase in fire size currently observed. In a previous paper, we found the mean fire size increased from 1,890 acres between 2001 and 2005 to nearly 5,000 acres between 2015 and 2019 (Weber and Yadav 2020). Thus, the only reasonable explanation for this change points to the final portion of the fire triangle, fuel.

Wildfire fuels include both live and dead biomass that must be dry enough to combust. Weather (precipitation, heat, and humidity) is the key driving factor influencing fuel moisture. In addition, fuels must be continuous to carry a fire across the landscape. Areas of sparse vegetation can and will burn but the likelihood of a fire growing into a 100,000+ acre megafire is extremely low. Thus, fuel load, availability, and continuity are very important components which may be affected by changing climate as well as land management policies and practices (e.g., long-term fire suppression leading to fuel stockpiling).

In many areas, wildfire is not feasible during the colder fall and winter months, or the wet months of early spring. However, if the traditional seasonality changed whereby the period of time were shortened when wildfires are improbable, then the wildfire season would concomitantly lengthen. As a result, there would exist an increased likelihood for more wildfires (i.e., increased fire frequency) simply because the temporal window of opportunity is longer. For the purposes of this study, it is assumed the length of the fire season correlates well with the length of the growing season under the premise that without fuel (a by-product of vegetation production) a wildfire cannot exist. It is not assumed that the length of the fire season is the same as the length of the growing season or that one is simply a subset of the other. This assumption will be revisited later in this paper.

Regardless of the underlying cause, this study sought to quantify the length of the growing season and compare the annual growing season duration throughout the new millennia (2001-2019).

METHODS

Study Area

The study area is a region covering approximately 3 million km^2 and 11 western states (Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming) (**Figure 1**). The study area contains numerous vegetation types and ecosystems including conifer, grassland, shrubland, sparsely vegetated, hardwood, and riparian areas. However, conifer, grassland, and shrubland vegetation types make up 78% of the study area (**Figure 2).**

Figure 1. *The study area is a region including 11 states (Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington and Wyoming). The majority of wildfires in the conterminous United States occur in this region.*

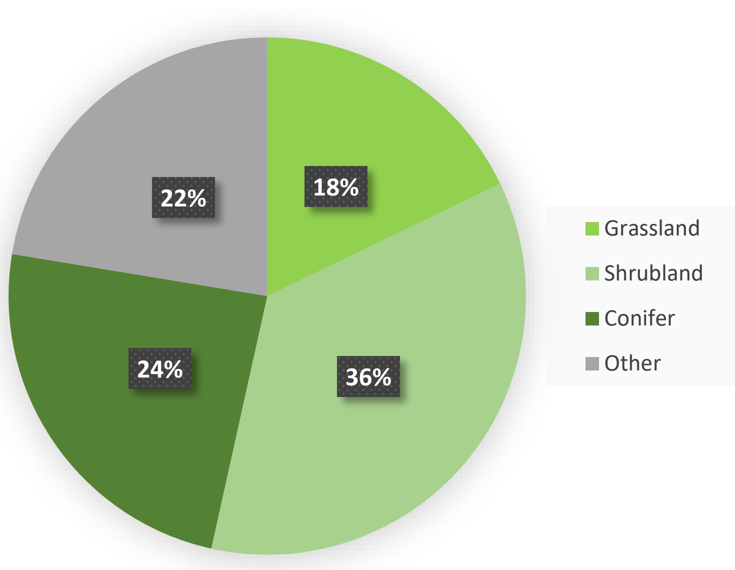

Figure 2 *Percent cover by vegetation type for the study area. Conifer, grassland, and shrubland make up 78% of the land cover.*

Spatial Data
MODIS composite NDVI data (MOD13) were used to estimate vegetation production across the study area. This dataset library contained 23 composite NDVI images annually (2001-2019) and has a 250-meter x 250-meter spatial resolution.

Determining the Length of the Growing Season
A query using the ArcGIS Pro raster calculator was made to identify pixels with NDVI values exceeding 0.2. This value of 0.2 is important because bare soil (areas devoid of vegetation) can exhibit a near infrared (NIR) spectral reflectance somewhat larger than the reflectance from the red band and thereby generate small positive NDVI values of 0.1 and in some cases, approaching 0.2 (Huete et. al, 1999). Thus, a minimum value of 0.2 was used to provide improved confidence of true photosynthetic activity and biomass production (Myneni 1995, Al-doski 2013; Walz and Weber 2021a, b). All pixels that satisfied this criterion were assigned a value of one (1, true). The resulting layers were henceforth referred to as Actively Growing Vegetation (AGV) to distinguish these data from the original NDVI source data. These 23 data layers characterize the spatio-temporal extent or “green wave” and allow for the visualization of the growing season throughout each year.

The onset of the growing season was determined as the day on which a minimum of 1/3rd of the study area exhibited actively growing vegetation. To expound, each AGV layer contained 64,346,876 pixels (7,403 columns by 8,692 rows). One-third of the study area is approximated as 21,234,000 pixels. Since each AGV layer contains Boolean data, when the sum of pixels on a given date equals or exceeds 21,234,000, the growing season and subsequent green wave was considered to have started. This date (in Julian format) was noted for year. Similarly, when the sum of pixels once again dropped below the same threshold value (21,234,000), the growing season was considered to have ended and the Julian date of that occurrence was similarly noted.

The duration of the growing season was calculated by subtracting the Julian start date from the Julian end date (e.g., 337 – 65 = 272 days (2001)). Descriptive statistics were calculated along with XY-scatter plots and trend analyses.

RESULTS AND DISCUSSION
Three interesting data points were found in the calculation of the growing season (**Table 1**). The first was in 2004 where, by definition, the growing season did not end before the end of the calendar year. However, by January 1st of 2005, the end of growing season threshold was met and the Julian end date is given as day 366. The second year of interest was 2015 which had the longest growing season on record (336 days). Lastly, 2016 was interesting as the onset of the growing season exhibited a very sudden increase in AGV where Julian day 81 (March 22nd) showed 31% of the study area in active growth and Julian day 97 (the next data layer available in the 16-day composite series) recorded nearly 50% of the study area in active growth.

The mean length of the growing season was 268 days while the median was 256 days. These values are similar (+/- 5%) and in reality, may not show any difference at all. Recall, the source data for these determinations was the 16-day composite MODIS NDVI dataset. The fact the difference between the mean and median is only 12 days suggests no difference actually exists. To test this, the series number (1-23) was substituted for the Julian date and descriptive statistics were calculated once again for the duration of the growing season. The result showed a mean of 16.8 and median of 16. This confirms the initial inference but also suggests that some years exhibited anomalously longer growing seasons. With a limited sample size of only 19 years, more data is required to make a more definitive statement about these data.

Table 1*. The start and end of each growing season was identified as that day where the number of actively growing vegetation pixels (defined as having an NDVI > 0.20) met or exceeded 33% of the study area.*

Year	Start of Growing Season		End of Growing Season		Growing
	Date (Julian)	Value (Σ pixels)	Date (Julian)	Value (Σ pixel)	Season (days)
2001	65	21,758,631	337	16,598,865	272
2002	97	25,150,781	353	17,722,456	256
2003	65	22,687,149	321	20,674,675	256
2004	81	25,762,958	366	16,007,475	285
2005	17	24,120,979	337	18,085,117	320
2006	81	21,567,128	353	17,230,429	272
2007	65	24,601,975	337	19,649,159	272
2008	97	23,480,176	353	10,416,683	256
2009	81	21,574,928	337	19,852,430	256
2010	81	23,442,873	321	17,827,577	240
2011	97	24,776,736	337	18,572,785	240
2012	81	25,031,026	353	12,602,105	272
2013	81	23,406,427	337	17,286,154	256
2014	65	25,108,255	353	20,351,214	288
2015	17	23,839,441	353	13,171,387	336
2016	97	32,068,530	337	18,827,391	240
2017	65	23,474,360	353	19,343,351	288
2018	81	21,594,875	337	18,894,162	256
2019	97	29,642,474	337	18,174,070	240

These data were graphed using an XY scatter plot where time (year) was given on the X-axis and the length of the growing season (number of days) was given on the Y-axis (**Figure 3**). A trend line was added along with the R-squared value ($R^2 = 0.007$) for the relationship between year and length of growing season ($P = 0.73$). From these data it can be seen that while the length of the growing season varies, no discernible trend is apparent throughout nearly 20 years of observations. Indeed, the slope of the trend line (-0.389) suggests a slight decline in the length of the growing season. However, a more meaningful trend might be apparent if the dataset used in this study extended further back in history.

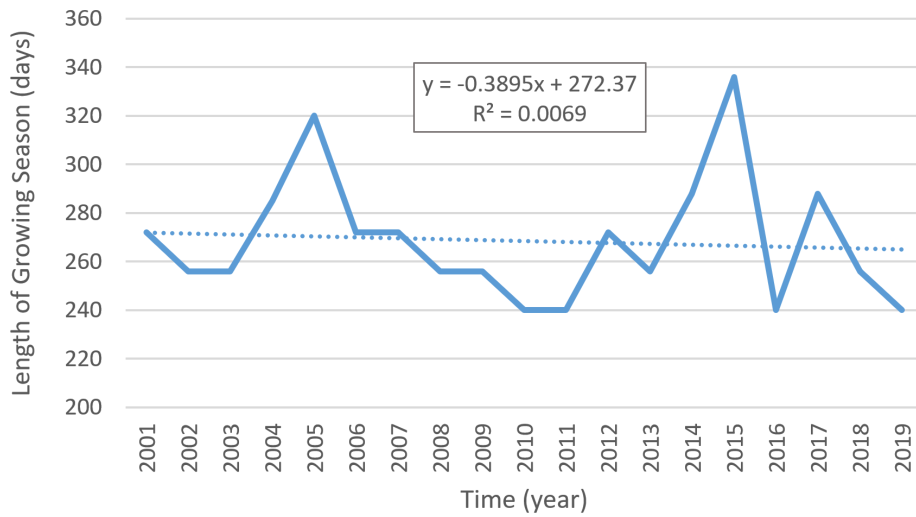

Figure 3. *Variation in length of growing season over time.*

A relatively popular discussion regarding growing season is the hypothesis that while the growing season may not have changed in length or duration, it has instead shifted so that the growing season begins earlier. This was tested using the start of growing season data given in table 1, and graphed for visualization in **figure 4**. Once again, over the nearly 20 years of data included in this study, no statistical difference was observed in start of growing season (R^2 = 0.009). Furthermore, the slope of the trend line (0.393) indicates only a slight positive change over time, suggesting –if anything—that the growing season is beginning later.

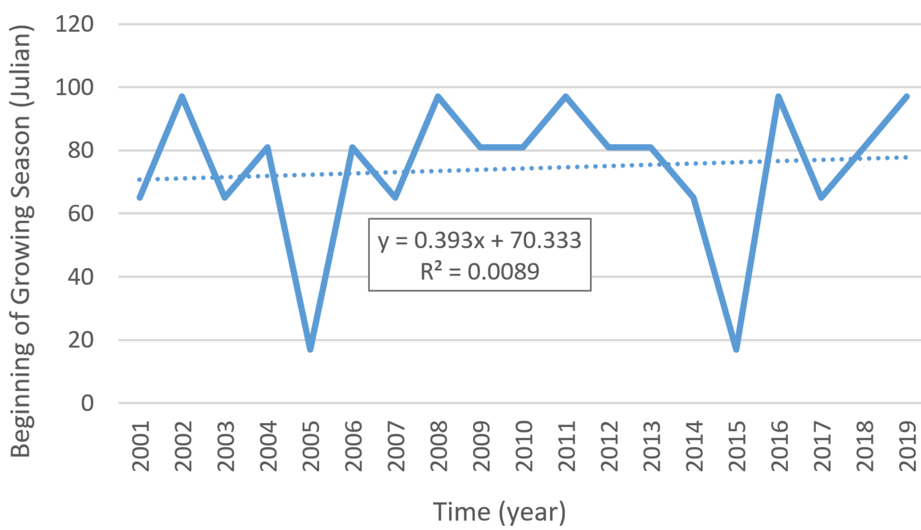

Figure 4. *Variation in the onset of the growing season over time.*

CONCLUSIONS

This study used 16-day composite normalized difference vegetation index data (NDVI) from the MODIS sensor (MOD13) to characterize the length and onset of the growing season between 2001 and 2019. Actively Growing Vegetation was defined as vegetation exhibiting an NDVI value equal to or in excess of 0.20. Using this threshold value, the onset or beginning of the growing season was determined as the day when $\geq$33% of the study area exhibited actively growing vegetation. Similarly, the growing season was considered to have ended when ≤ 33% of the study exhibited actively growing vegetation. The time interval (number of days) between the start and end of the growing season was considered the length of the growing season.

Using these data, no change was observed in either the length or onset of the growing season across the study area. Rather, the trend in both growing season length and onset appears to be quite stable. Future research should strive to expand the length of the dataset by perhaps using the Landsat archive which could allow observations back to the 1970's or 1980's. A limiting factor however is the volume of these data and the differences between the Landsat sensor over time. While the authors sought to use observations of vegetation across the study area, an alternative approach would be the use of precipitation, temperature, and perhaps growing degree days data to address this same question. The latter approach would allow for a much longer temporal record but would also require careful validation to identify actively growing vegetation.

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