# A STUDY OF FUEL MOISTURE AND THE VEGETATION CYCLE OF THE PLANT CHAMISE CHAPARRAL (*ADENOSTOMA FASCICULATUM*) IN CALIFORNIA

Abbigayle Cuomo, Grade 10 and Elizabeth Van Loon, Grade 10, Commack High School, Commack, NY

ABSTRACT

Fuel moisture is a major component to forest fire behavior and is used as an important factor in determining fire danger. The purpose of this study was to investigate the relationship between fuel moisture and the phenological stages throughout the life cycle of the plant Chamise Chaparral (*Adenostoma fasciculatum*), a densely growing coniferous shrub found in chaparral shrublands in California. Fuel moisture from Elk Creek, Sequoia National Park, was compared to data from other sites in California obtained through the National Fuel Moisture Database and old (one or more years old) and new growth (current year's growth) samples were also compared. Phenology refers to the study of the influence of climate on cyclical biological events such as growth or flowering. If during a particular phenological stage the fuel moisture can be determined, the intensity of forest fires during different seasons could be predicted allowing for better fire prevention and firefighting preparation. The results showed that fuel moisture varied based on its location because fuel moisture samples were statistically different among sites. A correlation existed between old and new growth in the new growth stages, meaning that in mid-spring when Chamise begins to grow, the fuel moisture will be higher resulting in less intense forest fires when compared to the rest of the year.

INTRODUCTION

The United States has averaged 4 million acres of land burned due to forest fires each year from 1995 through 2003 and that average has increased by 3 million acres since 2005 until now (www.mnn.com). Before 2000, the total suppression cost of forest fires never reached over 1 billion dollars, but since 2010, the total suppression cost has averaged 1.63 billion dollars per year (http://www.nifc.gov). One of the major contributors to the severity of fires is the reduction of moisture in vegetation (Nelson, 2001). The reduction in moisture content is mainly due to relative humidity (Schroeder, 1970); the lower the relative humidity, the more moisture that can evaporate from vegetation. The amount of moisture in vegetation relative to the dry biomass is called fuel moisture. Fuel moisture is affected by factors such as temperature, wind, humidity,

rainfall and the type of vegetation.  Fire danger can increase greatly if the fuel moisture of the vegetation in the area is low (Dennison, et al., 2003). The purpose of this study was to [1] determine if there is a difference between *old* and *new growth*, in a given area of California [2] compare fuel moisture among various sites in California and [3] determine if there is a relationship between the amount of moisture in vegetation and the phenological phase of the vegetation.

One way fuel moisture affects fire behavior is by reducing fuel consumption or slowing the rate of burning (Nelson, 2001). The rate at which a fire burns can be calculated by dividing the mass of fuel consumed by unit area of ground by the time required to burn the fuel in the unit area (Nelson, 2001). Higher fuel moisture will decrease the rate of fuel consumption, thus decreasing the amount of vegetation burned in a given time.

Forest fires burn in stages. The stages of a forest fire are the events that occur before, during, and after forest fires such as preheating and ignition. One of the first stages of the combustion process is preheating. It is during this process that heat is absorbed by the vegetation and moisture is evaporated into the atmosphere (Nelson, 2001). The greater amount of fuel moisture, the longer the preheating period will be until the temperature for ignition is reached (Nelson, 2001). Ignition is the beginning of the fire, which requires a temperature from 200ºC-300ºC in order to start burning regardless of fuel moisture content. Since the higher fuel moisture causes a longer preheating period, the ignition stage would be prolonged (Albini, et al., 1995).

Another way fuel moisture has an effect on fire behavior is that moisture reduces flame temperature, because the heat that the fire produces has to not only heat the vegetation, but also the moisture contained within the plant (Nelson, 2001). The water vapor in the air also decreases the oxygen available to the flames. The reduction in



1) Preheating: Vegetation reaches specific temperature

2) Fire Ignition: Vegetation reached temperature and fire begins

4) Suppression: Forest fire is suppressed and spread ceases.

3) Consumption: Forest fire begins to spread and bun fuel

temperature usually results in the production of char (partially burned) rather than the production of volatiles (completely burned) (Nelson, 2001).
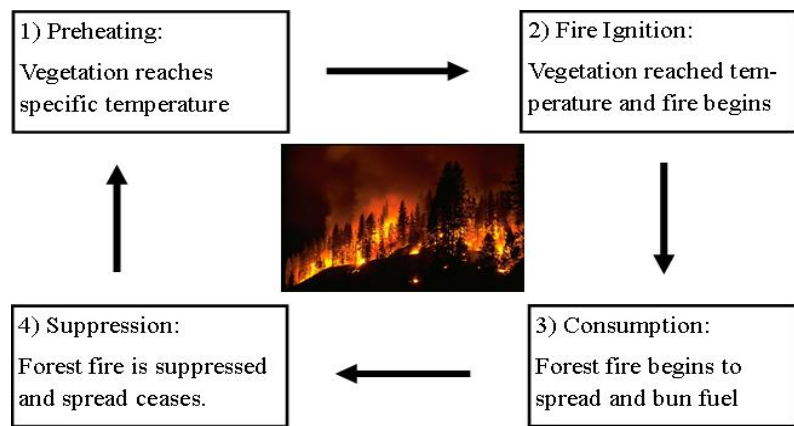
The third effect of fuel moisture on fire behavior is that it lengthens the particle residence time or the time in which the fire remains on a layer of fuel, which is what a fire burns such as vegetation, during combustion (Albini, et al., 1995). Experimental studies have shown that in order for fuel combustion to occur, it needs the heat from radiative energy (difference between energy from sun received by the Earth and the energy radiated back into space) and convective heat transfer (Albini, et al., 1995). Meaning that, heat from solar radiation will contribute to the ignition of a forest fire. Increased fuel moisture will reduce the amount of solar radiation that

reaches the vegetation, which in turn increases the length of time the fire will remain in an area of fuel and reduce the probability of a fire spreading.

In this study, data was used from a widely dispersed and densely populated plant found in California, called Chamise Chaparral (*Adenostoma fasciculatum*). Chamise is a dense coniferous shrub that covers 7,300,000 acres of California and is part of the rose family (Keeley, 1985). Chamise is a good indicator of seasonal changes and fuel moisture because it covers a large area of mountain slopes in central and southern California (McPherson, 1969) and fires associated with this species occur frequently. Chamise is a highly flammable plant because it has a low moisture content. Fires are very common among Chamise plants, especially during the summer months and during droughts (Keeley, 1985).

The prediction of how a fire will spread if Chamise Chaparral is burning is limited because current fire spread models were not designed for this type of live fuel and there is a limited amount of experimental data to develop and test with these models (Weise, et al., 2005). Since fire spread cannot be predicted while Chamise Chaparral is burning, fire managers, who are conducting controlled burns, typically begin a forest fire in the spring months when the fuel moisture is significantly higher compared to the other months in the year (Weise, et al. 2005).

Vegetation phenology, the study of reoccurring vegetation cycles and their connection to the environment, plays an important role on Earth, especially when it comes to global environmental climate change, water resources and atmospheric chemistry (White, et al., 1997). Some key phenological phases include; greenup, the beginning of photosynthetic activity; maturity, when the maximum growth is completed; and dormancy, when physiological activity nears zero (Zhang, 2003). If the amount of fuel moisture differs during different stages of a plant's phenology then the intensity of a fire during certain times of the year may be predicted, and therefore allows for more preparation for the suppression of fires. However, there are other factors that may affect how forest fires burn such as if there was a drought, wind, and the amount of vegetation in the area.

There have not been extensive studies done for California on the relationship between fuel moisture and phenology. A study was done with species of plants in the Mediterranean area and how seasonal weather variations and phenology affect fuel moisture content and ignitability of Mediterranean plant species (Pellizzaro, 2007).The study was done in North/North-Western Sardinia, Italy. The plants were found to be moderately flammable in the spring, when the plants were re-sprouting and flowering (Pellizzaro, 2007).

Fuel moisture and phenology data for this research were obtained from undigitized data charts in logbooks in PDF format from Sequoia and Kings Canyon National Park. The data was collected from 2001-2014 and had not previously been analyzed. We digitized and analyzed the data using Excel spreadsheets. We hypothesized that there would be a difference between *old* and *new growth* samples and fuel moisture would not vary upon its location. We also hypothesized that a relationship would exist between fuel moisture and phenology.

MATERIALS AND METHODS

*Data Collection*

Fuel moisture and phenology data were obtained in PDF format from a fire ecologist at Sequoia and Kings Canyon National Parks (Fig. 1). The data was collected for 14 years from the Elk Creek area (39.36˚N, 122.32˚W). The data was digitized into Microsoft Excel spreadsheets (Fig. 2). Separate sections for *old growth* and *new growth* were created and gross wet weight, gross dry weight, can weight, dry weight, weight loss, and percent moisture were transferred as they were written on the PDF files. The data was then placed into one larger table with all of the same information for data analysis. Weather and phenology data were also digitized into Microsoft Excel Sheets (Fig. 3).

Other fuel moisture data from different national parks in California were obtained through the National Fuel Moisture Database (NFMD) (www.wfas.net/), (Fig. 4). This data was then entered into a separate spreadsheet from the fuel moisture data in Microsoft Excel.

Table 1. Example of fuel moisture organized into charts based on phenological stage. Different colors represent different years.

| ripe | | | | | |
|------|------|------|------|------|------|
| Old 1 | Old 2 | Old 3 | New 1 | New 2 | New 3 |
| 68.3 | 57.1 | 67.6 | 74.4 | 68.6 | 69.8 |
| 45.6 | 49.1 | 55.6 | 63.6 | 55.3 | 61.5 |
| 47.8 | 53.6 | 44.8 | 56.0 | 53.8 | 52.1 |
| 47.4 | 50.0 | 53.3 | 56.1 | 50.0 | 57.4 |
| 55.0 | 41.9 | 48.7 | 54.3 | 53.6 | 52.3 |
| 50.0 | 50.0 | 50.0 | 52.0 | 58.3 | 48.0 |
| 70.2 | 47.4 | 56.8 | 74.2 | 71.4 | 61.1 |
| 56.0 | 53.6 | 60.0 | 64.4 | 66.7 | 62.5 |
| 52.3 | 50.0 | 54.1 | 61.3 | 67.4 | 75.0 |
| 52.9 | 51.1 | 53.3 | 63.4 | 66.0 | 67.7 |
| 44.4 | 46.7 | 49.2 | 66.7 | 62.0 | 64.0 |
| 80.0 | 87.1 | 61.5 | 78.0 | 100.0 | 93.1 |
| 58.8 | 70.6 | 55.6 | 80.0 | 88.6 | 65.1 |
| 62.1 | 54.5 | 57.1 | 63.0 | 75.0 | 64.9 |
| 52.6 | 56.0 | 61.9 | 76.5 | 59.3 | 72.2 |
| 80.0 | 88.9 | 90.5 | 108.7 | 114.3 | 123.1 |
| 61.0 | 62.0 | 50.0 | 67.0 | 67.0 | 65.0 |
| 61.0 | 56.0 | 62.0 | 58.0 | 60.0 | 55.0 |
| 50.0 | 60.0 | 42.0 | 46.0 | 52.0 | 50.0 |



Fig.1. Original data from Sequoia and Kings Canyon National Park National Park

| Location: Elk Creek | | Topographic Features | | Moisture Determination Record | | | |
|---|---|---|---|---|---|---|---|
| Area: Ash Mountain | | Aspect | S SE | Date | Time in Oven | Date | Time out of Oven |
| Type: Live | | Elevational | 2100 | 5/17/2005 | 1215 | 5/18/2005 | 1840 |
| Year: 2005 | | Shading | 0 | 5/31/2005 | 1530 | 6/2/2005 | 1245 |
| | | Slope | 17 | 6/15/2005 | 1450 | 6/17/2005 | 1430 |
| | | Upper 1/3 | | 7/1/2005 | 1640 | 7/3/2005 | 1045 |
| | | Middle 1/3 | | 7/15/2005 | 1630 | 7/16/2005 | 1845 |
| | | Lower 1/3 | x | 8/5/2005 | 1100 | 8/6/2005 | 1105 |
| | | Ridgetop | | 8/17/2005 | 1430 | 8/18/2005 | 1500 |
| | | Saddle | | 8/31/2005 | 1600 | N/A | N/A |
| | | Valley | | 10/2/2005 | 1125 | 10/3/2005 | 1230 |
| | | Canyon | | | | | |

| Collection Record | | Old Growth 1 | | | | | |
|---|---|---|---|---|---|---|---|
| Date | Time | Gross Wet Weight | Gross Dry Weight | Can Weight | Dry Weight | Weight Loss | % Moisture |
| 5/17/2005 | 1130 | 129.0 | 119.0 | 104.0 | 15.0 | 10.0 | 66.7 |
| 5/31/2005 | 1500 | 144.0 | 127.0 | 104.0 | 23.0 | 17.0 | 73.9 |
| 6/15/2005 | 1415 | 164.0 | 135.0 | 104.0 | 31.0 | 29.0 | 93.5 |
| 7/1/2005 | 1620 | 155.0 | 123.0 | 104.0 | 19.0 | 32.0 | 168.4 |
| 7/15/2005 | 1545 | 183.0 | 148.0 | 103.0 | 45.0 | 35.0 | 77.8 |
| 8/5/2005 | 1020 | 156.0 | N/A | N/A | N/A | 156.0 | N/A |
| 8/17/2005 | 1345 | 160.0 | 137.0 | 103.0 | 34.0 | 23.0 | 67.6 |
| 8/31/2005 | 1530 | 140.0 | 126.0 | 104.0 | 22.0 | 14.0 | 63.6 |
| 10/2/2005 | 1045 | 159.0 | 140.0 | 104.0 | 36.0 | 19.0 | 52.8 |

Fig.2. Data from Sequoia and Kings Canyon National Park digitized into Microsoft

| Date | Dry Bulb | Wet Bulb | Relative Humidity (%) | % Cloud Cover | Wind Speed (mph) | Wind Direction | 10 Hr Stick (if known) | New Growth | Flowering | Fruit |
|---|---|---|---|---|---|---|---|---|---|---|
| 5/17/2005 | 66 | 58 | 63 | 5 | 1 to 2 (8) | SW | N/A | N/A | N/A | N/A |
| 5/31/2005 | 86 | 70 | 46 | 0 | 3 to 5 | ups | 8.5 | N/A | N/A | N/A |
| 6/15/2005 | 91 | 67 | 34 | 0 | 5 | 3 | 7 | N/A | N/A | none |
| 7/1/2005 | 99 | 71 | 26 | 2 | 2 to 6 | SW | 4 | done | ended | N/A |
| 7/15/2005 | 83 | 72 | 60 | 75 | 0 to 2 | up caynon | 5 | N/A | ending | none |
| 8/5/2005 | 93 | 61 | 14 | 20 | 3 | SW | 58 | N/A | N/A | N/A |
| 8/17/2005 | 97 | 72 | 30 | 35 | 2 | ups | 6 | N/A | N/A | N/A |
| 8/31/2005 | 96 | 67 | 22 | 0 | 2 to 5 | SW | 4.25 | N/A | N/A | N/A |
| 10/2/2005 | 75 | 61 | N/A | 0 | 1 to 3 | SW | 4 | N/A | N/A | N/A |

Fig.3. Weather and phenology data from Sequoia and Kings Canyon National Park digitized into Excel



Parkhill, California
39.7224°N, -121.4966°W

FH-7, California
39.6156°N, -122.1745°W

Elk Mountain, California
39.4250°N, -122.9772°W

Smith Ranch, California
36.3825°N, -120.8558°W

Irish Hills, California
35.2378°N, -120.7805°W

Marshall Grade, California
38.8317°N, -121.0092°W

Tonzi Road, California
38.5908°N, -120.9336°W

El Portal, California
37.6753°N, -119.7879°W

Elk Creek, California
36.4914°N, -118.8253°W

Jake Flat, California
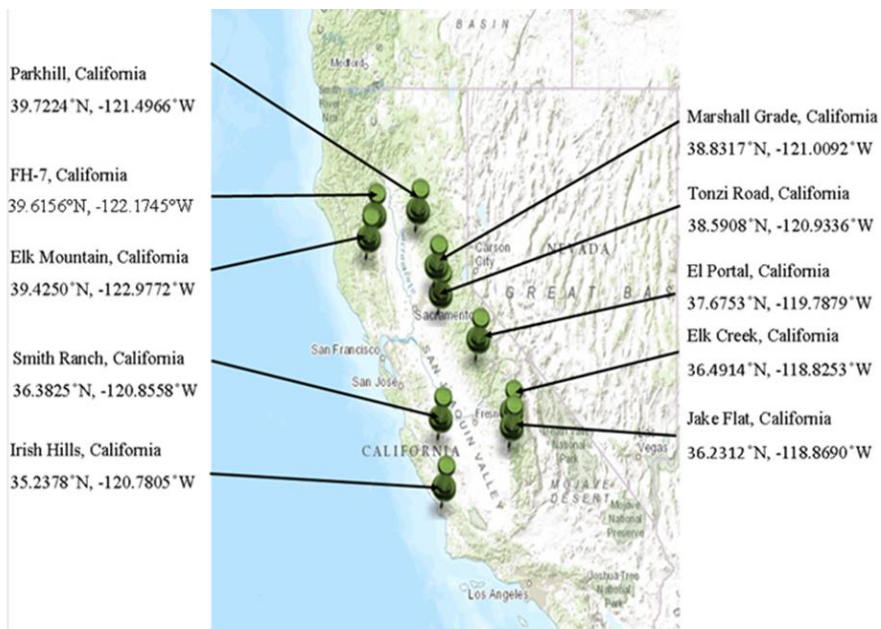36.2312°N, -118.8690°W

Figure 4. Map of the data locations used from California obtained from the National Fuel Moisture Database

*Data Analysis*

*Old Growth Fuel Moisture vs. New Growth Fuel Moisture*

After the Sequoia and Kings National Park data (2001-2014) was entered into Microsoft Excel, the fuel moisture was calculated by:
1) "Gross Dry Weight" – "Can Weight"* = "Dry Weight"
2) "Gross Wet Weight" – "Gross Dry Weight" = "Weight Loss"
3) ("Weight Loss" / "Dry Weight") x 100 = "% Moisture"

*Can Weight= the weight of the plastic container into which the live vegetation is placed during sampling in the field.

When all of the fuel moisture percentages were determined, the fuel moisture was categorized by phenology. Since the fuel moisture and phenology data were separated on the data charts, the phenology was transferred and matched by date to the corresponding fuel moisture percentage. When all of the phenological descriptions are paired with its appropriate fuel moisture by date, the data was organized into broader categories by phenology (Table 1). Three main stages of phenology are new growth, which is sub-divided into starting (the plant has just begun to grow), continuing (the plant is growing leaves, etc.), complete (all growth has come to a stop), and none (there is no new growth). The next stage is flowering, which is sub-divided into starting (flowers are beginning to grow), peaking (the flowers are done/almost done growing), drying (beginning stages of the flowers' decline), none (no flowers are present), and declining (the flowers are dying). The last stage of phenology is fruit, which is sub-divided into starting (growth of fruit has started), ripe (the fruit has peaked), fallen (fruit is falling off the plant), and none (no fruit is present).

A One-way Analysis of Variance [ANOVA] test was used to test the null hypothesis that the samples within a particular stage came from populations with the same mean value. If the data among the samples within a stage were not statistically different then the data was grouped and an unpaired Student t-test was used to test the null hypothesis that the *old growth* compared to the *new growth* within the phenological stages was not statistically different.

*A Comparison of fuel moisture among sites in California*

Fuel moisture data was obtained from various sites throughout California that were selected from the National Fuel Moisture Database (www.wfas.net/). The data was compared among all of the sites. The fuel moisture data for each site went from 2002 to 2014.
The mean and standard error were calculated for the months with the highest fuel moisture (March, April, and May) and lowest fuel moisture (August, September, and October). Using this data, two graphs were made for the highest fuel moisture months for *old* and *new growth*.

Additional graphs were created for the lowest fuel moisture months. Error bars represented the standard error on the graphs (Fig. 6-9).

Paired Student t-tests were used for each combination of locations in California (Table 2).

Table 2. P-values for all comparisons of sites in California for *old growth*; Yellow=p-values < 0.05

| Locations | El Portal | Elk Creek | Elk Mountain | FH-7 | Irish Hills | Jake Flat | Marshall Grade | Parkhill | Smith Ranch | Tonzi Road |
|---|---|---|---|---|---|---|---|---|---|---|
| El Portal | | 0.31 | 0.17 | 0.41 | 0.24 | 0.05 | 0.46 | 0.03 | 0.00 | 0.07 |
| Elk Creek | 0.31 | | 0.14 | 0.54 | 0.91 | 0.02 | 0.21 | 0.59 | 0.11 | 0.45 |
| Elk Mountain | 0.17 | 0.14 | | 0.04 | 0.04 | 0.00 | 0.01 | 0.93 | 0.97 | 0.03 |
| FH-7 | 0.41 | 0.54 | 0.04 | | 0.67 | 0.02 | 0.12 | 0.02 | 0.09 | 0.17 |
| Irish Hills | 0.24 | 0.91 | 0.04 | 0.67 | | 0.02 | 0.05 | 0.02 | 0.08 | 0.07 |
| Jake Flat | 0.05 | 0.02 | 0.00 | 0.02 | 0.02 | | 0.35 | 0.00 | 0.00 | 0.61 |
| Marshall Grade | 0.46 | 0.21 | 0.01 | 0.12 | 0.05 | 0.35 | | 0.00 | 0.00 | 0.78 |
| Parkhill | 0.03 | 0.59 | 0.93 | 0.02 | 0.02 | 0.00 | 0.00 | | 0.85 | 0.01 |
| Smith Ranch | 0.00 | 0.11 | 0.97 | 0.09 | 0.08 | 0.00 | 0.00 | 0.85 | | 0.00 |
| Tonzi Road | 0.07 | 0.45 | 0.03 | 0.17 | 0.07 | 0.61 | 0.78 | 0.01 | 0.00 | |

*Relationship between Fuel Moisture and Phenology*

The same fuel moisture tables used for comparing the *old* and *new growth* samples were used for this analysis. For each subdivisions of the phenology (continuing, complete, etc.) the average was taken for the *old growth* and *new growth*. Each phenology subdivision is listed in Table 3.

The numbers that represented the phenology were the x-values on the graph. The y-values were the means of the fuel moistures for the three samples in each phenological stage. To analyze the data, scatter plots were created and the correlation coefficient was determined to see if there was a relationship between fuel moisture and phenology (Fig. 10-12).

Table 3. Each phenology stage and its subdivision.

| New growth | Fruit | Flowering |
|---|---|---|
| Starting | Presenting | Starting |
| Continuing | Ripe | Peaking |
| Complete | Fallen | Drying |
| None | None | None |
| | | Declining |

RESULTS

*Old Growth Fuel Moisture vs. New Growth Fuel Moisture*

The ANOVA tests indicated that there was no statistically significant difference among the three samples for the stages: new growth, flowering and fruit (Table 4). Therefore, we were confident about grouping the data for the comparison of *old* and *new growth* for the subdivisions.

Table 4 shows that in all cases, except for the "none' phenology for both new growth and flowering, there was a significant difference between *old growth* and *new growth* fuel moisture. Figure 5 shows the means of *old* and *new growth* for the flowering stages.

Table 4. ANOVA test probabilities for each fuel type in the three phenological stages. Also shown are the t-test probabilities between *old* and *new growth*.

| | | ANOVA | | T Test | |
|---|---|---|---|---|---|
| Phenology | | Old | New | Old vs. New | |
| New Growth | Continuing | 0.39 | 0.74 | 6.6E-12 | * |
| | Complete | 0.44 | 0.39 | 0.03 | * |
| | None | 0.12 | 0.53 | 0.39 | |
| | Starting | 0.95 | 0.65 | 0.0002 | * |
| Flowering | Starting | 0.97 | 0.92 | 3.2E-14 | * |
| | Peaking | 0.85 | 0.88 | 1.9E-13 | * |
| | Drying | 0.92 | 0.99 | 3.4E-07 | * |
| | None | 0.28 | 0.78 | 0.43 | |
| | Declining | 0.53 | 0.69 | 0.03 | * |
| Fruit | Presenting | 0.52 | 0.47 | 2.7E-09 | * |
| | Ripe | 0.95 | 0.94 | 0.0002 | * |
| | Fallen | 0.81 | 0.65 | 0.004 | * |
| | None | 0.46 | 0.68 | 2.6E-14 | * |

*data is statistically significant ($p<.05$)
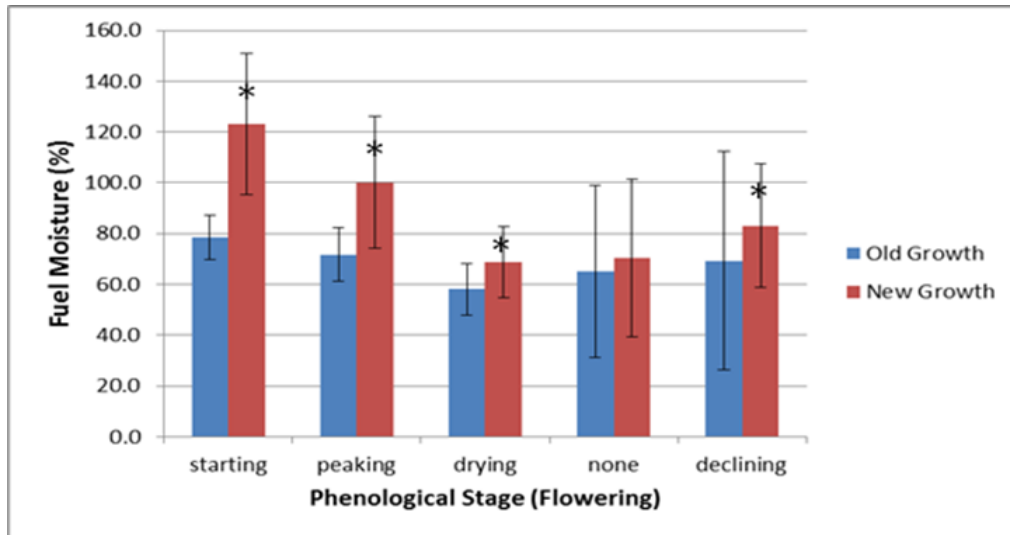


Figure 5. Example of a graph of means of *old* and *new growth* with standard error bars. * = Statistical difference between *old* and *new growth*, (p-value ≤ 0.05%)

*A Comparison of Elk Creek fuel moisture to other sites in California*

The graph for the spring months of *new growth* indicated that Marshall Grade had the highest mean fuel moisture and Elk Mountain had the lowest (Fig 6).

Similar to the spring months, Marshall Grade had one of the highest mean fuel moistures along with Irish Hills and Tonzi Road for fall months of *new growth*, while Smith Ranch had the lowest (Fig 7).

Graphs were also made for *old growth* for the fall and spring months. Marshall Grade still had one of the higher mean fuel moisture, but Tonzi Road had the highest. Similar to the spring months for *new growth*, Elk Mountain had the lowest mean fuel moisture for *old growth* (Fig 8).
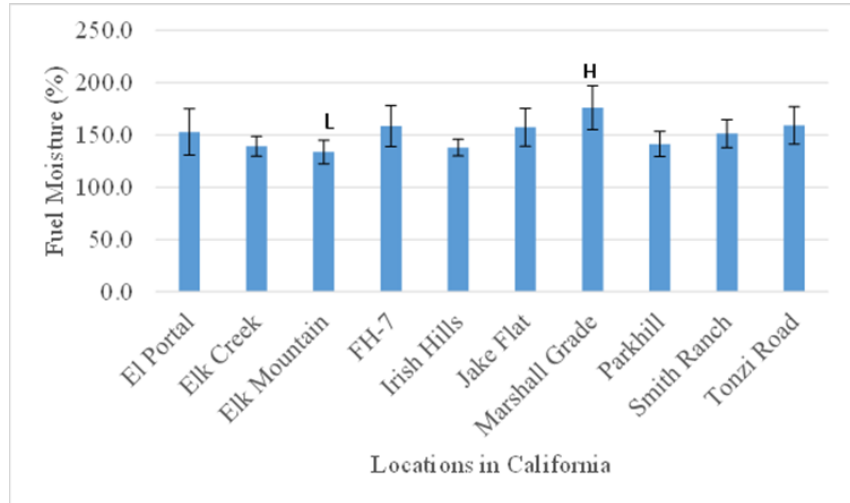


Figure 6. *New growth* means for March, April and May; H=Highest, L=Lowest

The mean for Marshall Grade decreased, and it is not one of the higher means consistent with data in Figures 6, 7 and 8. During the fall months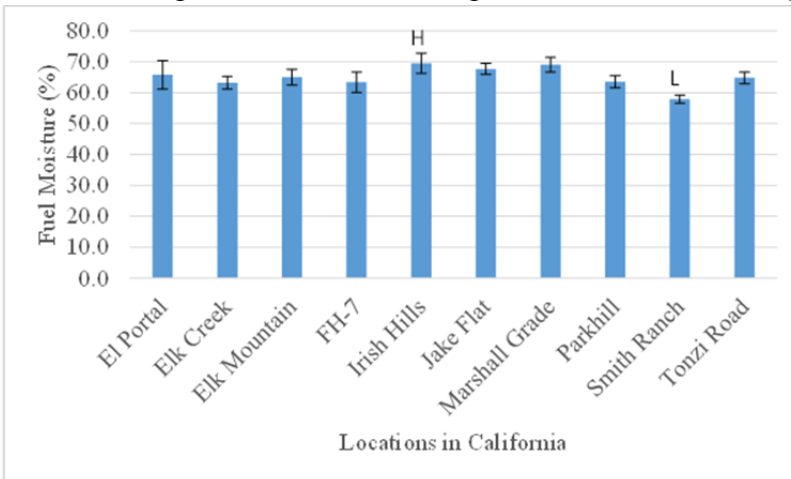 for *old growth*, Jake Flat and FH-7 had the highest mean fuel moisture. Smith Ranch had the lowest, comparable to the fall for *new growth* (Fig 9).

Paired Student t-tests were done to test the null hypothesis that the fuel moisture of different locations for both *old* and *new growth* was statistically different.

Table 2 indicated that for 28 out of the 46 possible combinations, there was no statistical difference between the two locations. Every location had at least one difference with another. The location that had the lowest amount of statistical differences with any other was Elk Creek, with only one instance with Jake Flat. Jake Flat and Parkhill had the most differences compared to any other location for *old growth* as shown in Table 2.



Figure 7. *New growth* means for August, September and October; H=Highest, L=Lowest

Table 5 shows that out of the 46 combinations of locations, 33 of them were statistically different. The only location that was statistically the same to every other location was Irish Hills. For *new growth*, Marshall Grade, Parkhill, Smith Ranch and Tonzi Road had the most differences with other locations.

*Relationship between*
*Fuel Moisture and Phenology*

The means of all of the samples were graphed along with their corresponding phenological stage based on Table 3.

Figure 10 indicates that the fuel moisture for "starting" phenology in new growth is higher than that of all other



Figure 8. *Old growth* means for March, April, and May; H=Highest, L=Lowest

subdivisions, with greater differences between the "starting" subdivision and "complete" and "none" subdivisions. The lowest fuel moisture by phenological subdivision of *old growth* was
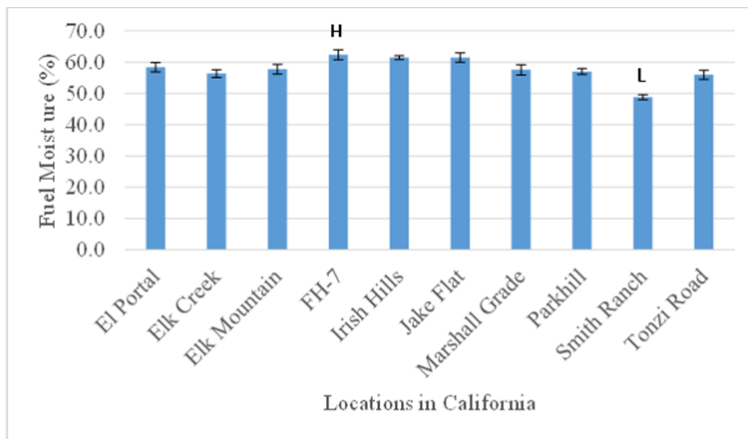


Figure 9. *Old growth* means for August, September and October; H=Highest, L=Lowest

"complete" and for *new growth* the lowest was "none".

The phenological subdivision of "presenting" has the highest mean fuel moisture for both the *old* and *new growth* graphs for fruit. In both graphs "none" has the second greatest fuel moisture percentage and the fuel moisture increases greatly when the "fallen" stage has ended.

"Fallen" has the lowest fuel moisture in both graphs and the fuel moisture decreases from "ripe" when it's changing into the "fallen" stage as seen in Figure 11.
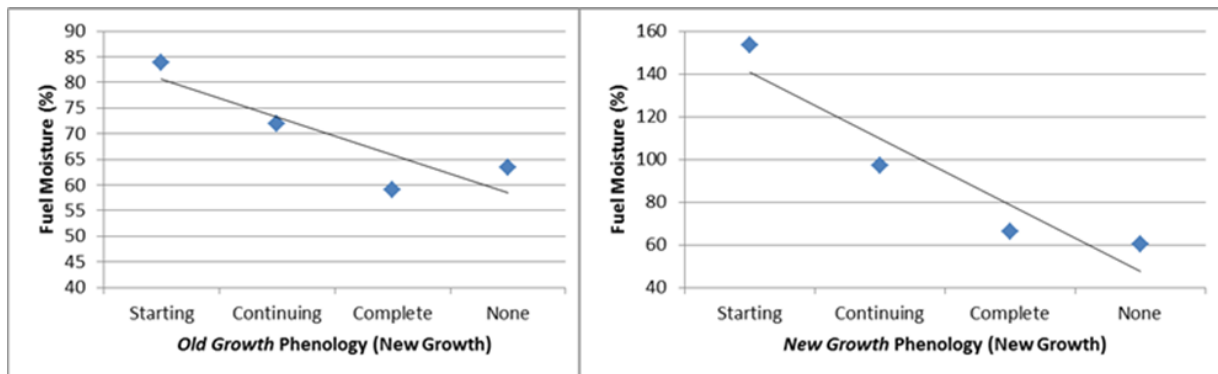


Figure 10. Relationship between the mean fuel moisture mean to the phenological subdivisions of new growth. Fuel mean moisture= Average amount of water in vegetation. Phenological stage= stage in life cycle of Chamise
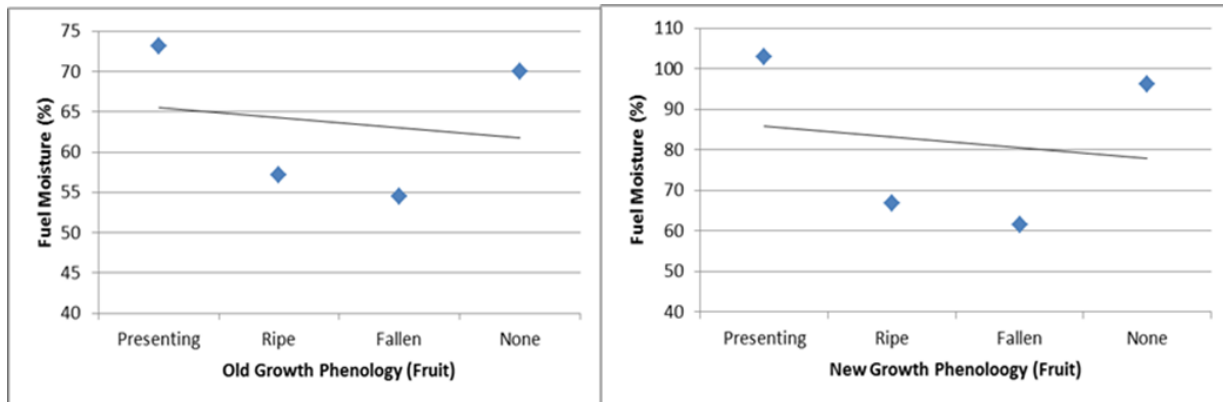
Figure 11. Relationship between the fuel moisture mean to the phenological stages of fruit. Fuel mean moisture = Average amount of water in vegetation. Phenological stage= stage in life cycle of Chamise

"Starting" had the highest mean fuel moisture and "drying" had the lowest mean for flowering. As the "peaking" stage arrived, the fuel moisture decreased more in the *new growth* graph than the *old growth* graph. Also the increase in fuel moisture from "drying" to the "none" stage increased much more in *old growth* graph than in the *new growth* (Fig 12). Correlation coefficient values were calculated (Table 6);
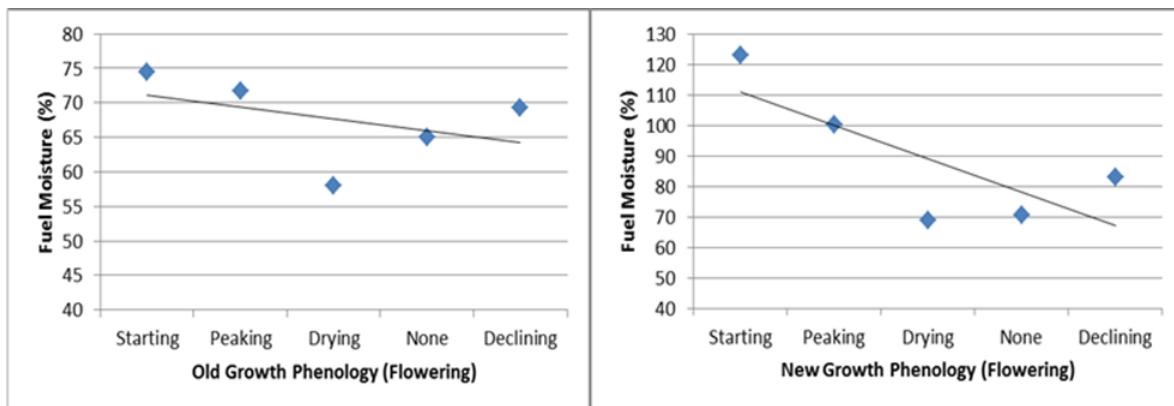


Figure 12 Relationship between the fuel moisture mean to the phenological stage for flowering. Fuel mean moisture = Average amount of water in vegetation. Phenological stage= stage in life cycle of Chamise

Two of the stronger correlations are between the *old growth* and *new growth* fuel moisture and phenology for the new growth stages. A weak correlation was seen between *new growth* fuel moisture and its phenology in the flowering subdivision; however the *old growth* for flowering did not show any correlation. The *old/new growth* fuel moistures had no correlation with the phenology in the fruit subdivision as well.

Table 6. Correlation coefficient values for the relationship between phenology and fuel moisture.

|  | Old | New |
|---|---|---|
| New Growth | -0.874 | -0.940 |
| Fruit | -0.172 | -0.161 |
| Flowering | -0.416 | -0.762 |

DISCUSSION

One of the primary goals of this study was to determine if there was a relationship between fuel moisture and phenology. If a relationship did exist between the two, then forest fires would occur at varying intensities as vegetation goes through different stages of its life. If the fire intensity of a potential fire could be predicted using the phenology of vegetation, then more preparation could be made in anticipation of a fire, because the speed at which fires spread could be predicted. Based on our results, fuel moisture had a strong correlation with the *old* and *new growth* of the new growth stages and a weaker correlation for the *new growth* of the flowering stage. This means that when Chamise Chaparral starts growing in early to mid-spring, the fuel moisture will be higher than at other points during the year. During this time, the intensity of forest fires will be less than they would be during the rest of the year. Chamise generally blooms from late spring to early summer in both a diverse vegetative environment and a Chamise only environment (Stohlgren, et. al., 1984). However, when in a diverse environment, Chamise is still the dominant plant. During this time, the fuel moisture decreases, so the intensity of forest fires will increase due to the lack of moisture. This study corroborates Pellizzaro's (2007) study involving Mediterranean plants. Because there have not been extensive studies done in California on the relationship between fuel moisture and phenology, future research could entail studying the same relationship with other species found in California.

Our original hypothesis was that the fuel moisture of Chamise Chaparral would not vary relative to its location. However, the data showed that the fuel moisture was different throughout the sites we observed in California. The only instance when there was no difference in fuel moisture based on location was the *new growth* in Irish Hills. For *old growth*, Elk Creek had the fewest number of differences in fuel moisture compared to other locations. The only location where there was a difference was at Jake Flat, which happened to be the location geographically closest to Elk Creek. Although our graphs show overlapping error bars, this could be due to difficulty in obtaining a consistent sample size for the different areas. We further hypothesized that rainfall, relative humidity and elevation could be key factors for the difference in fuel moisture. More field research would be required to test that hypothesis.

Another aspect of this study was to determine if the fuel moisture of *old* and *new growth* samples were the same or different. To do this we needed to see if the samples themselves (*old/new*) were the same. Since they were comparable, the samples were juxtaposed. From our data, it was obvious that *new growth* moisture was always higher than the *old growth*. Because they are different and the *new growth* was higher than the *old,* fires could potentially burn Chamise at different rates since the plant itself has different fuel moistures.

Our results support that during different seasons of the year, forest fires will burn at different intensities. These intensities can be predicted based on the phenological stage of Chamise Chaparral and that the fuel moisture for Chamise varies by location. Data for fuel moisture has been used in making strategic decisions when it comes to igniting prescribed forest fires and has been used ever since the 1940s in order to calculate fire danger (Weise, et al. 1998).

Results from this study can potentially be used to help determine the intensity of forest fires, as fuel moisture continues to be an important part of determining fire danger, not only in California but in other parts of the United States and many other countries. This can be used as a baseline for understanding how a changing climate would affect vegetation as well as potential changes in fires and their effects.

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