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Evaluating the Influence of the Pacific Decadal Oscillation on Biomass Production across the Western US

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Abstract
This project sought to determine the influence of the Pacific Decadal Oscillation (PDO) on biomass production across the western US as estimated by the normalized difference vegetation index (NDVI). To assess this relationship, Moderate Resolution Imaging Spectroradiometer (MODIS) NDVI data were acquired for 2001-2018 and statistics calculated using ArcGIS software. Results showed NDVI measurements have increased slightly over time and exhibit a variable correlation with PDO based on location (R^2 = 0.000 – 0.593). Overall, the correlation generally increases with distance from the pacific coast. The cause of this correlation pattern is not well understood, as the effects that PDO has on climatic conditions are numerous and somewhat unpredictable.

Keywords: *climate, PDO, Biomass, NDVI*

Introduction
The purpose of this project was to address the following questions:

1. Is the duration of the growing season across the western United States increasing over time?
2. Are NDVI measurements within the western United States affected by PDO, and if so, how?

The extent of the project's study area consisted of 11 western states: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. All imagery used in the project were acquired from the MODIS MOD13 project. It is hoped the results of this research will increase understanding of the long-term patterns of biomass production in the western U.S.

Methods
MODIS MOD13 composite vegetation indices, produced across 16-day intervals, were acquired for the time period of 2001-2018. These vegetation indices were produced from daily imagery, from which the pixel having (1) no contamination (e.g., cloud interference), (2) highest NDVI, and (3) closest-to-nadir orientation was used in the 16-day composite (http://modis.gsfc.nasa.gov, n.d.)). NDVI data were clipped to the extent of the 11 state-study area, and median NDVI extracted by mega-regions using the zonal statistics as table tool in ArcGIS Pro. Mega-regions are defined as areas of the United States differentiated by the degree to which they are influenced by various climatic factors *(figure 1).* The U.S. is divided into three mega-regions: Southeastern, Central, and Northwestern (Kurtz, 2015). Median NDVI data were also extracted by individual state (n = 11) using the same zonal statistics as table tool. Finally, median NDVI data were extracted using a 15-column by 20-row grid of polygons that divided the study area into 259 equal parts (polygons were 123 km x 108 km (13,284 km^2) in size). This approach produced three-levels of spatial analysis, mega-region (largest), state, and grid (smallest).

Figure 1: The two mega-regions that exist within the extent of the project's study area—Northwestern (simply labeled Western) and Central. A mega-region is defined as an area of the U.S. that is differentiated by the degree to which it is influenced by various climatic factors.

The resulting zonal statistics tables were exported into Excel workbooks to create graphs and calculate additional statistics describing the trends and patterns of median NDVI measurements. Median NDVI were calculated using all pixel for a given analysis area (mega-region, state, or grid) from the NDVI raster layer(s). This project used the median statistic instead of mean because of the inherent resilience of median to the effect of outlier data. Within each analysis area, median NDVI was summed annually (2001-2018) resulting in a cumulative median NDVI statistic which was used for further analysis.

PDO data were acquired from NOAA's National Centers for Environmental Information. These data represent a single monthly index value describing the pacific decadal oscillation relative to near coast sea-surface temperature (SST), La Nina, and el Nino effects. Median monthly PDO was calculated for each year (2001-2018) and correlated with cumulative median NDVI for each of the three analysis areas (mega-region, state, and grid).

Results and discussion

No correlation was observed between PDO and NDVI at the mega-region scale *(figure 2).* An analysis of NDVI over time showed a positive slope for all states and a wide range of R^2 values *(table 1).* Periodic oscillations in NDVI measurements were also observed *(figure 3).* These oscillations suggest vegetation productivity may be influenced by the PDO. Additionally, higher amplitudes in the oscillations are indicative of a longer growing season, and lower amplitudes indicate a shorter one.

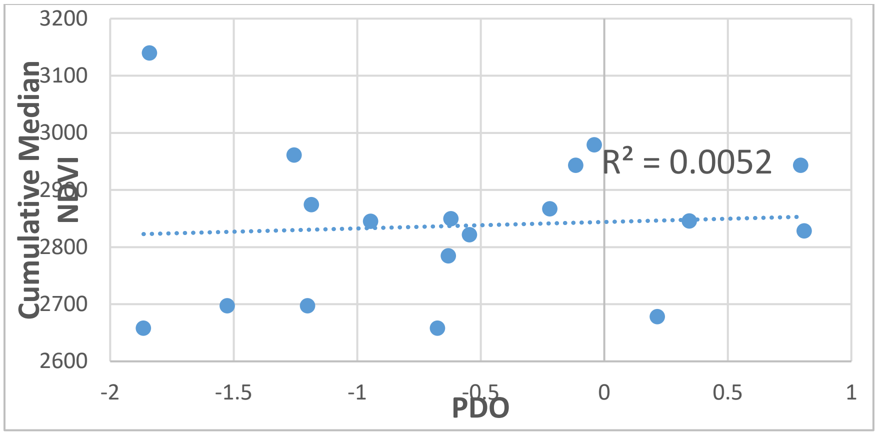

Figure 2: Correlation between median PDO per year and cumulative median NDVI per year across the Northwestern mega-region of the U.S. A mega-region is defined as an area of the U.S. that is differentiated by the degree to which it is influenced by various climatic factors. These data show virtually no correlation with vegetation productivity (NDVI), however.

Table 1: Slope and R^2 values of cumulative median NDVI per year for all 11 western states contained in the study area.

State	Slope	R^2
Arizona	39.74	0.01
California	205.28	0.09
Colorado	340.61	0.24
Idaho	483.96	0.39
Montana	420.57	0.34
Nevada	268.26	0.25
New Mexico	152.51	0.05
Oregon	765.98	0.75
Utah	353.68	0.31
Washington	583.15	0.34
Wyoming	325.55	0.26

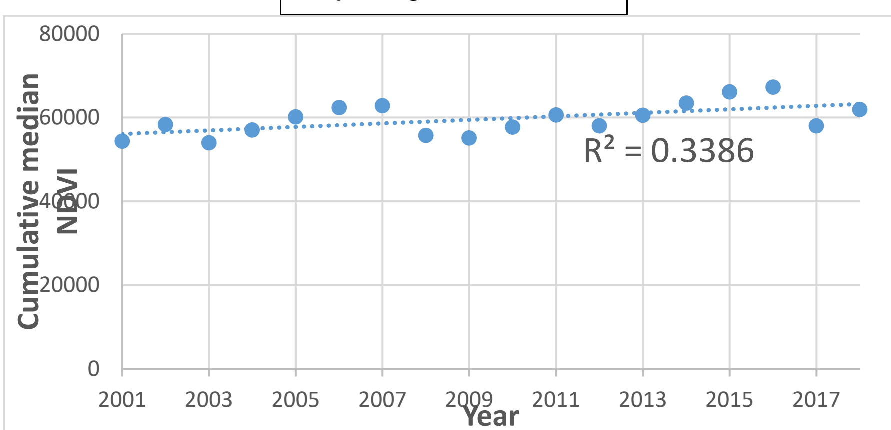

Figure 3: Cumulative median NDVI per year in Montana exhibiting a trend that increases slightly with time. An approximate 8-year oscillation pattern can also be observed. All other states within the western U.S. show similar oscillations, although Montana's was one of the most prominent examples.

When PDO values were compared to NDVI by state, a definite pattern emerged showing a correlation with PDO that increased with distance from the pacific coast *(figure 4).* The cause of this pattern is not well understood at this time.

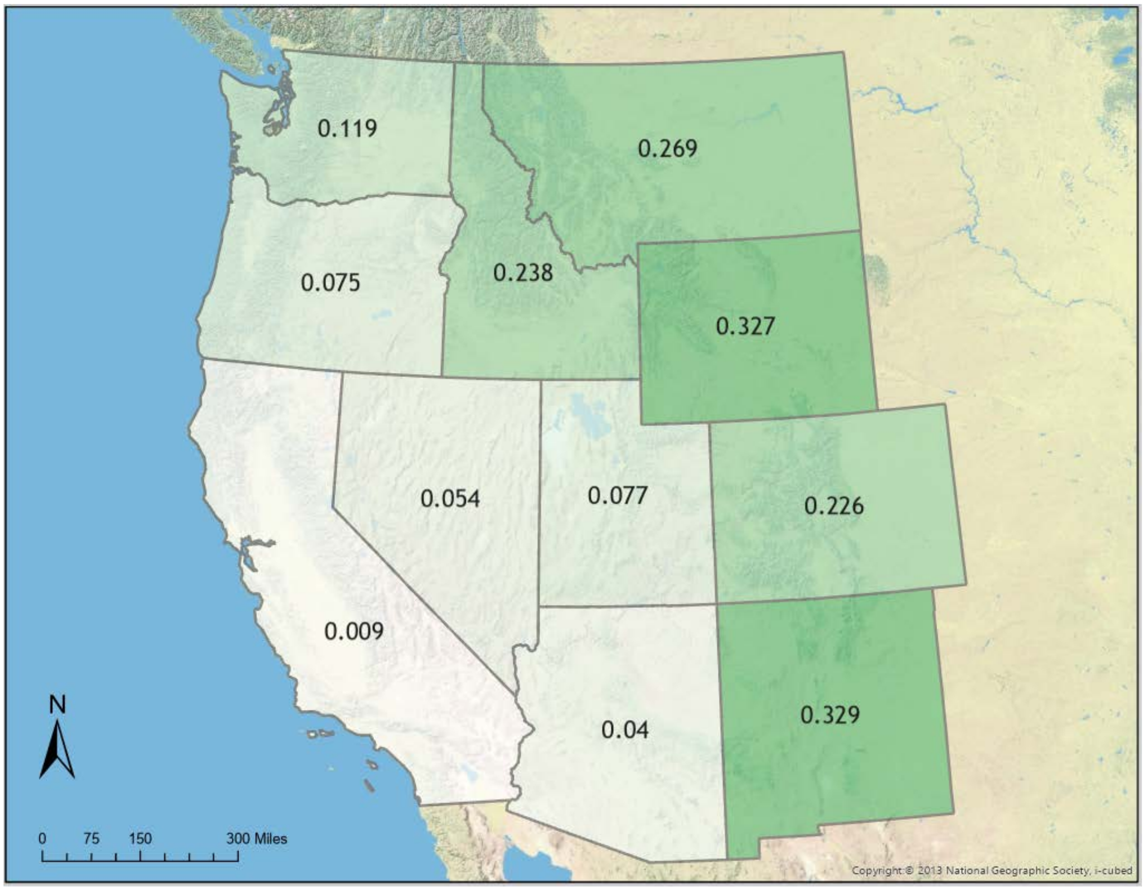

Figure 4: Correlation between median PDO per year and cumulative median NDVI per year, categorized by state. Darker colors represent a higher correlation, and lighter colors represent a lower correlation. Correlation values (R^2) values are displayed within each state.

The correlation pattern observed in the state-scale analysis (figure 4) was further investigated using a polygon grid analysis *(figure 5).* From these results, it can be seen that PDO correlations with NDVI area highest in the southeastern corner of the study area (i.e., New Mexico).

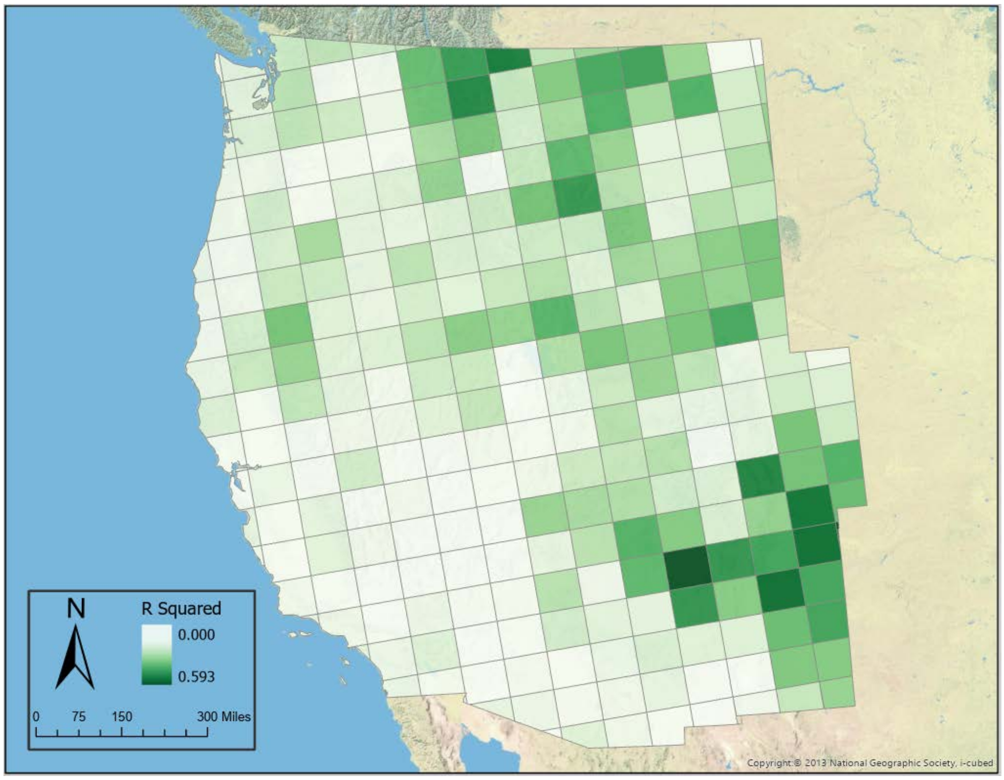

Figure 5: Correlation between median PDO per year and cumulative median NDVI per year in the western U.S., categorized using a 259-polygon grid. Darker colors represent a higher correlation, and lighter colors represent a lower correlation (R^2 = 0.000 – 0.593).

Conclusions

NDVI measurements increased slightly between 2001-2018 for every state in this study, but the increase was not substantial. Oscillation patterns observed in NDVI measurements across the western United States showed a variable correlation (R^2 = 0.000 – 0.593) with standardized PDO values. This correlation increased with distance from the Pacific coast, and was most pronounced in the southeastern corner of the project's study area. Since PDO can create a variety of climatic abnormalities that are not always consistent with one another (such as rainfall anomalies vs. temperature anomalies), it is difficult to comprehensively explain the correlation patterns observed in this study. Additional research is needed to better understand the observed phenomena.

References

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