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Predicting forage production into the future

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Abstract

Patterns of forage production on California annual rangelands influences an array of critical ecosystem services and functions across almost 50% of the land area in California, including livestock production, soil carbon sequestration, and wildlife habitat, among others. Growth of annual grasses and forbs that make up this forage base are particularly sensitivity to changes in amount and timing of precipitation and seasonal variation in temperature. Thus, forage production on California rangelands is expected to change significantly with future changes in climate. We created a model to quantify how climate changes might impact timing and amount of forage production in the mid-century, as well as spatial differences across the state.

The broad objectives of this project are to quantify how future changes in temperature and precipitation may alter the timing and amount of forage production on California annual rangelands and evaluate how the changes may vary either spatially (e.g. by major land resource area or ecoregion) or vary as a function of historical climatic conditions (e.g. to sites with lower historical precipitation vs. higher historical precipitation). We have integrated three main sources of data, historical weather data for California, a 30m data product that takes a partitioned 16-day Net Primary Productivity (NPP) dataset and uses an equation based on mean annual temperature to separate belowground from aboveground NPP and is available through the Rangeland Analysis Platform, and projections of future climate. The model was created using back-casting to obtain a statistically significant model. Model(s) will be used to predict future changes in NPP in both timing and amount. Models can then be used by land managers to make decisions on how to best prepare for future scenarios under different Representative Concentration Pathways (RCPs) to determine impacts to forage production, wildlife, and carbon sequestration.

Introduction

Climate change and the impacts to NPP have been a concern for many. In California, with predominately annual rangelands relying on annual precipitation to determine NPP, and therefore a forage base for livestock production as well as wildlife habitat and ecosystem services, predictions of an overall warmer and drier climate as we approach 2100 has many concerned. Researchers are attempting to quantify the impact climate changes will have on NPP, and then extrapolate impacts to managing resources to maintain many ecosystem services. The assumption is that as the temperatures warm and precipitation reduces, NPP will also decrease, resulting in reduction of livestock grazing. We took our teams expertise in forage production (NPP), modelling and GIS to create a model to predict NPP through the end of this century and into the beginning of the next.

Methods

Before we could start to predict forage production, we first needed to define out study area, focusing on grasslands in California. We used freely available data sources for all our efforts. Grassland cover as defined by the California Department of Forestry and Fire Protection's Fire and Resource Assessment Program (FRAP) (CalFire, 2024) was the basis of our data, with the exception of irrigated pastures (Liu et al,. 2021) and unvegetated areas (Felton et al., 2021). Pixels with more than 50% grassland cover were included. Climate data utilized included daily precipitation, daily soil moisture (within the top 10cm layer), minimum temperature, and maximum temperature from the CalAdapt python package for the historical climate period (1950 to 2005). We then converted annual datasets to water years (October 1 to September 30). We defined the start of the growing season based on accumulated precipitation exceeds 25mm (Chaplin-Kramer and George 2013). For the annual rangelands, we also needed to determine the end of the growing season. To do this, we defined the end of the growing season for each pixel using the maximum separation method applied to the top-level soil moisture curve during the water year. This is a phenological algorithm that identifies the two points of greatest change in a given seasonal curve. We utilized only the second point of change to indicate the point in the water year in which soil moisture was depleting. The algorithm is described in Descals et al. (2021). The primary predictor input into our model is the total sum of heat units during our defined growing season for each pixel and each year in the historical period (1950-2005) that we calculated. We were then able to back cast with actual forage production data to ensure a good fit of the model before forecasting. To improve results, the state was broken into fifteen ecoregions: Central California Coast, Central Valley Coast Ranges, Northern Great Valley, Southern Great Valley, Klamath Mountains, Modoc Plateau, Mojave Desert, Northern California Coast, Norther California Coast Ranges, Northern California Interior Coast Ranges, Sierra Nevada, Sierra Nevada Foothills, Southern California Coast, Southern California Mountains and Valleys, and the Southern Cascades. These ecoregions captured seasonal variations in precipitation and temperature and improved the model's ability to predict NPP.

Results

Back casting proved the model's fit in predicting NPP (Figure 1) when predicted NPP was plotted against actual NPP (R^2 equals 0.724). It should be noted that outliers in production at either end did not produce a perfect fit model, and why our R^2 is not higher. The model tends to overpredict NPP at the lower end, and underpredict NPP at the upper end with the strongest correlation from 1,000 kg/ha to 4,000 kg/ha. Extremes on either end did not have enough sample size to provide enough data to accurately predict with the model. We then examined all the variables that were potentially available for the model and looked at the Random Forest Feature Importance of each to see what was driving the overall model. Distance to the ocean and elevation were the two most important features in the model, accounting for approximately 40% of the model (Figure 2).

As the distance from the ocean increased, NPP dropped, as expected. Looking at forecasting NPP by ecoregion, the model's prediction varies across ecoregions, with the southern California Coast predicted to decrease in NPP while the Northern Great Valley as well as other ecoregions will increase in NPP.

Discussion [Conclusions/Implications]

If our current trajectory for climate does not change, the current Representative Concentration Pathway (RCP 8.5) will result in a mix of decreased NPP especially in the southern coastal area of California, but also increases in NPP, in both north and south Great Valley and the adjoining Central Valley Coast Range. The predicted variation in NPP across the state will require managers to shift their management practices. For part of the state, that means increasing management potentially through grazing, to manage NPP. Also of note, the model is not predicting any large swings in NPP across the state between now and 2100, but there are predicted swings at 30-year intervals that could impact management over the next 75 years. Managers will need to continue to implement all drought management tools they have developed over the years and be prepared for the next downward trend in NPP.

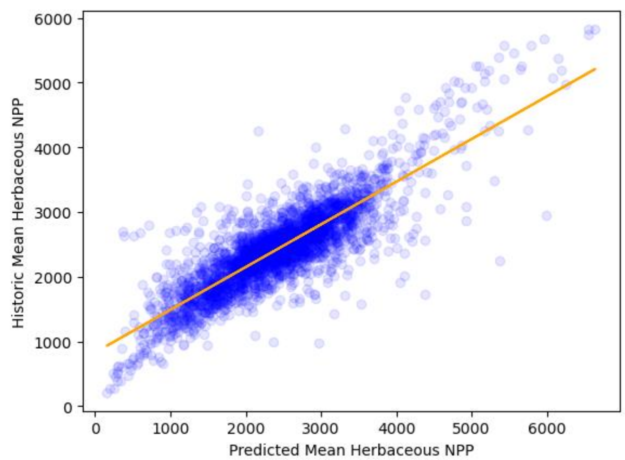

Figure 1. Model prediction of NPP plotted against actual NPP

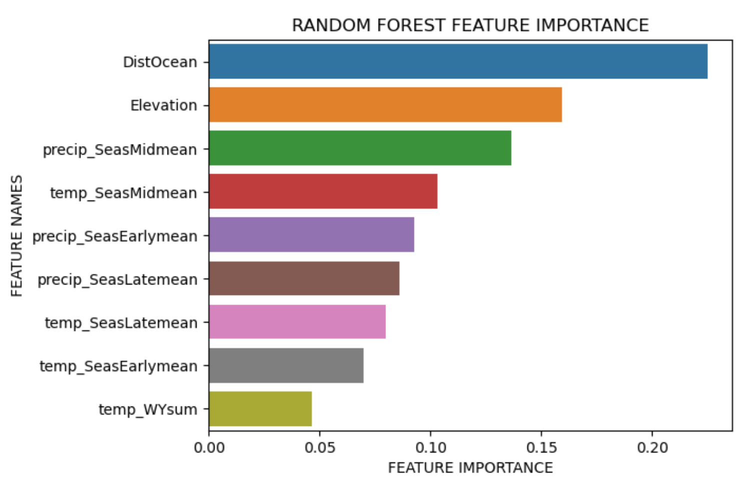

Figure 2. Random Forest Feature Importance of the overall model.

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