White Paper: Assessing the Relationship between Growing Degree Days and Precipitation with cNDVI in the Big Desert, Idaho

Kate Zajanc, Graduate Student, Idaho State University GIS Training and Research Center, 921 S. 8th Ave, stop 8104. Pocatello, Idaho 8320-8104. anthcath@isu.edu.

Keith T. Weber, GISP. GIS Director, Idaho State University GIS Training and Research Center, 921 S. 8th Ave, stop 8104. Pocatello, Idaho 8320-8104. webekeit@isu.edu.

ABSTRACT

Composite Normalized Difference Vegetation Index (cNDVI) data from 1991-2011 was acquired from the Landsat Image Services Archive (LISA) for the Big Desert study area in southeastern Idaho. Growing Degree Day (GDD) and precipitation data for the study area were acquired via the AgriMet weather station in Aberdeen, Idaho for the same time period. These data were used to assess the relationship between these environmental drivers (GDD and precipitation) with mean cNDVI. While both temperature and precipitation are known to be significant drivers of primary productivity in semiarid ecosystems, neither variable demonstrated a strong relationship ($P > 0.05$) with mean cNDVI in this study.

Keywords: composite NDVI; Big Desert, Idaho; Growing Degree Day (GDD); Precipitation; AgriMet; Landsat Image Services Archive (LISA); Growing Season

INTRODUCTION

Semiarid rangelands, which cover approximately 40% of the earth's terrestrial surface, are environments of extremely variable weather conditions and both temperature and precipitation are primary drivers of plant growth in these ecosystems (Chen and Weber, 2012; Weber et al., 2009). A previous study found, for example, that spring precipitation was correlated to summer grass aboveground net primary production (ANPP) in semiarid Patagonian steppe (Jobbagy and Sala, 2000), while another study demonstrated that a specific amount of heat was required for vegetation to develop from one growth stage to another in the semiarid rangelands of Idaho (Nasri and Doescher, 1995).

The progress of a growing season is commonly measured using a calculation known as Growing Degree Days (GDD), also known as a Heat Unit (HU) (AgriMet, 2012; Gibson 2003). It is calculated using an algorithm, accepted in the field of agronomic science, based on the ambient temperature's major influence on plant growth. A plant's growth begins at a given minimum temperature and reaches a plateau at a maximum temperature (Gibson, 2003). The plant's growth rate slows at higher temperatures beyond that maximum. Minimum, optimum, and maximum temperatures vary depending on the individual plant and plant species.

While both temperature and precipitation are known to be principal drivers contributing to plant productivity in semiarid ecosystems, whether or not that relationship would be reflected in composite NDVI (cNDVI) data was the purpose of this study. The Normalized Difference Vegetation Index (NDVI), is one of many vegetation indices that measure vegetative vigor based upon digital brightness values (Campbell and Wynne, 2011). High pixel values (1.0) indicate healthy, green vegetation (Campbell and Wynne, 2011; Jensen, 2007) while low values (-1.0) indicate areas of no photosynthetic activity. NDVI uses the inverse reflectance relationship between the red band and the near-infrared band wherein red light (R) is absorbed by chlorophyll while mesophyll tissue strongly reflects infrared radiation (IR) (Campbell and Wynne, 2011). This results in a high IR/R ratio for actively growing plants. Inversely, bare soil, dead, and stressed vegetation, as well as man-made features and water bodies, do not produce this spectral response. NDVI is an established indicator of plant growth, vegetation cover, biomass production, and plant phenology (Chen and Weber, 2012).

cNDVI, rather than a single measure of NDVI, was used in the study because rangeland ecosystems are predominantly grass and shrub communities which are a spatially heterogeneous and seasonally dynamic land cover (Weber et al., 2009). Therefore, single measures of productivity would likely underestimate the semiarid rangeland's annual productivity. This problem is remedied by using cNDVI as it describes peak photosynthetic activity over a selected time series.

MATERIALS AND METHODS

Study Area

The Big Desert, located approximately 71 km northwest of Pocatello, Idaho, was used as the study area (Figure 1). The approximate center of the study area is 43°15' 18.317" N, 113°4' 39.778" W. The area is a semiarid sagebrush-steppe ecosystem with a high proportion of bare ground ($\bar{x}$ bare ground ~ 17%) (Chen et al. 2012). Its habitat type is classified as Wyoming big sagebrush/blue bunch wheatgrass (Chen et al., 2011). A large part of the Big Desert is managed as grazing allotments by the USDI BLM, and approximately 40% of the Big Desert was burned in the Crystal Fire of 2006.

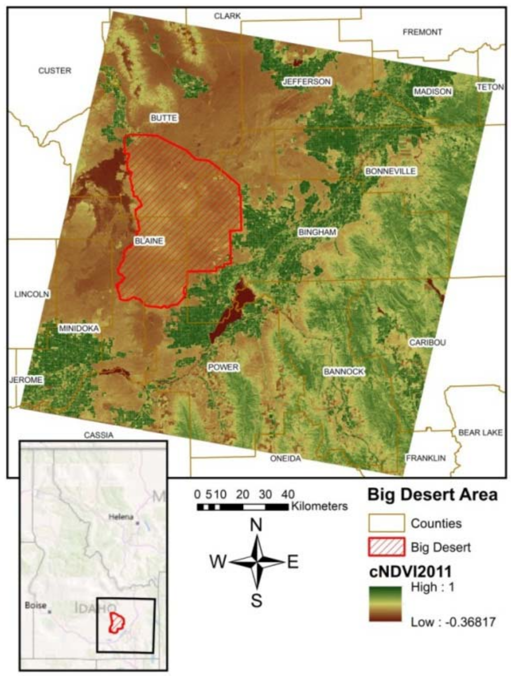

Figure 1. Location and general characteristics of the Big Desert study area in southeastern Idaho, USA. The cNDVI is LISA Imagery of the Big Desert area of Idaho, from Landsat 5 TM path 39 row 30.

The AgriMet Weather Station Network

The GDD and precipitation data for the study were acquired via the AgriMet weather station in Aberdeen, Idaho (AgriMet 2012). The 70 satellite-based, automated agricultural weather stations that make up the AgriMet network are located in irrigated agricultural areas throughout the Pacific Northwest. The network is maintained by the Bureau of Reclamation, wherein, real-time data is transmitted from the stations (Figure 2), once per hour, to the bureau's receiver site in Boise, Idaho via Geostationary Operational Environmental Satellites (GOES-8 and GOES-9) and DOMSAT satellites.

The weather stations serve to further many aspects of agricultural monitoring and research including crop water use modeling, frost monitoring, and integrated pest and fertility management. The three stations at Aberdeen, Kettle Butte, and Monteview, Idaho also provide the data necessary to model evapotranspiration. The types of data collected at the Aberdeen Idaho Weather Station include air temperature, precipitation, solar radiation, soil temperature—at 5.08 cm, 10.16 cm, 20.32 cm, 50.8 cm, and 101.6 cm depths, dew point, relative humidity, wind direction, peak wind gust, and average wind speed. The data pertinent to this study was GDD and Accumulated Water Year Precipitation.

The Growing Degree Day Algorithm

The algorithm used by AgriMet for computing GDD is: GDD = (Maximum Air Temperature + Minimum Air Temperature) / 2 - Base Temperature (10˚C). Because a plant's growth begins at a minimum temperature, the minimum air temperature is set at 10˚ C. Likewise, because temperatures above 30˚C can be stressful to plant growth, the maximum air temperature is set to 30˚C. For example, if the maximum air temperature for a day is 37˚C and the minimum air temperature is 0˚C, the values are adjusted to 30˚C and 10˚C as they are outside of the upper and lower limits.

Figure 2. The Aberdeen, Idaho AgriMet Station (ABEI) located at: 42° 57' 12" N, 112° 49' 36" W. Elevation: 1.34 km, Installation Date: 3/20/91.

Precipitation

A previous study of the Big Desert study area reported annual precipitation (including snow) as 23 cm with 40% of the precipitation falling from April through June (Chen et al., 2011). In this study, mean precipitation was compiled for the growing season (April 1-September 30), and, over the last 21 years, was found to average 11.06 cm annually.

The Landsat Image Services Archive (LISA)

The cNDVI data used in the project was obtained by using the Landsat Image Services Archive (LISA)**.** LISA data were derived from Landsat 5 TM imagery (path 39 and row 30) and compiled into cNDVI scenes for all growing seasons (April 1-September 30) from 1982 to 2011(Weber et al., 2011).. The portion of imagery used in the study (Landsat 5 TM path 39 row 30) is the Big Desert study area of

Idaho (Figure 1), considered to be one of the last remaining areas of sagebrush-steppe habitat for sagebrush-obligate species such as the Greater Sage Grouse.

Data Analysis

GDD and accumulated daily precipitation, for each growing season (April 1-September 30) throughout the study period (1991 to 2011), were acquired from the Aberdeen, Idaho AgriMet weather station. The total for each year was calculated, and a 21-year mean and standard deviation were also determined for both GDD and the accumulated annual precipitation. Each year was then classified as "warmer" or "colder" than the 21-year mean GDD and as either "wetter" or "drier" than the 21-year mean precipitation value. Next, these categories were combined to classify each growing season as either "warmer and wetter", "warmer and drier", "cooler and wetter", or "cooler and drier" relative to the 21-year average.

A polygon layer describing the Big Desert study area was used to extract cNDVI values from the LISA imagery using the zonal statistics tool in ArcGIS 10.0. Mean cNDVI was assigned to the corresponding growing season and categories as described above. Single-factor ANOVA was used to determine if mean cNDVI differed ($P < 0.05$) relative to GDD and/or precipitation categories.

RESULTS AND DISCUSSION

GDD data for the study period (1991-2011) resulted in a 21-year mean of 2243.4. The highest value of GDD for the study period was in 1994 (2497.5) and the lowest in 1993 (1892.1). The standard deviation was 156.1 (Figure 3). Precipitation data for the same period had a mean value of 11.06 cm and a standard deviation of 5.06. The highest value was 19.79 cm in 1993 and the lowest value was 3.88 cm in 1992 (Figure 4).

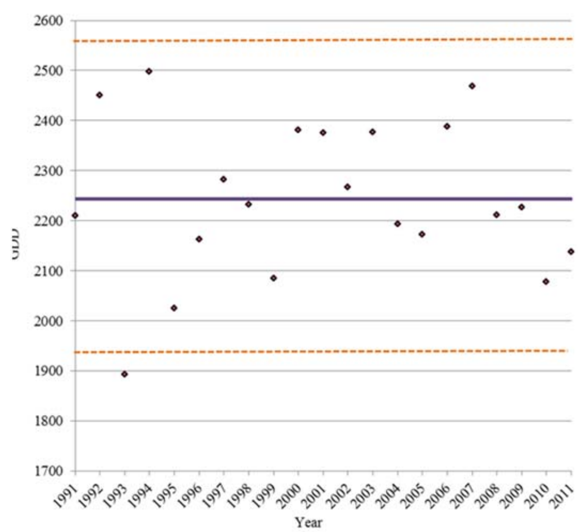

Figure 3. Total annual GDD (April 1-Sept 30) by year for the 21-year period 1991-2011. Mean GDD for the 21-year period is indicated by the solid line (mean=2243) and variance among years by the dashed lines (mean + 2 std. dev. =2556 and mean – 2 std. dev. = 1931).

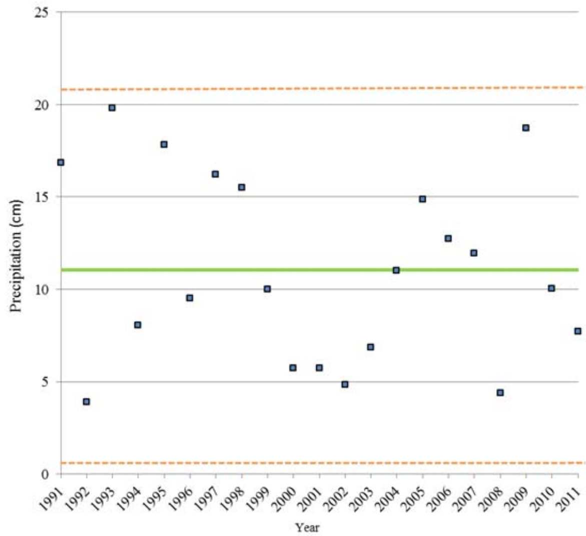

Figure 4. Total accumulated annual precipitation, in centimeters, from April 1-Sept 30, for the 21-year study period (1991-2011). Mean accumulated daily precipitation for the entire 21-year period is indicated by the solid line (mean=11.06 cm) and variance among years by the dashed lines (mean + 2 std. dev. = 21.18 cm and mean – 2 std. dev. = 0.94 cm).

ANOVA results testing mean cNDVI with classification of GDD conditions relative to the 21-year mean (i.e.,“warmer” or “colder”) were not significant (P = 0.35).. A similar test of mean cNDVI and classified precipitation conditions (i.e., “wetter” or “drier”) yielded similar results (P = 0.38). A third test, combining relative environmental condition categories (i.e., “warmer and wetter”, “warmer and drier”, “cooler and wetter”, or “cooler and drier” [table 1]) again producded similar results (P = 0.71).

Table 1. Classification of growing seasons as “warmer and wetter”, “warmer and drier”, “colder and wetter”, or “colder and drier” relative to the 21-year mean and corresponding mean cNDVI across the Big Desert study area[1].

Warmer/Wetter	Warmer/Drier	Colder/Wetter	Colder/Drier
0.214 (1997)	0.234 (1992)	0.152 (1991)	0.241 (1996)
0.207 (2006)	0.157105 (1994)	0.205 (1993)	0.250 (1999)
0.196 (2007)	0.194 (2000)	0.281 (1995)	0.204 (2008)
	0.188 (2001)	0.231 (1998)	0.126 (2010)
	0.189 (2002)	0.317 (2005)	0.226 (2011)

0.209 (2003) 0.171 (2009)

1. Data for 2004 was included in the used in all GDD analysis, but was not used in precipitation analyses as the the annual accumulated precipitation was equal to the 21-year mean precipitation.

None of the environmental condition variables demonstrated a strong relationship with mean cNDVI for the study area, resulting in a mean P-value of 0.48. Similarly, a linear regression was performed to investigate the relationship of annual GDD (X-axis, independent variable) to mean annual cNDVI (Y-axis, dependent variable). This resulted in an R^2 value of 0.58 whereas a second regression using annual precipitation and mean annual cNDVI resulted in an R^2 value of 0.02 (Figures 5 and 6).

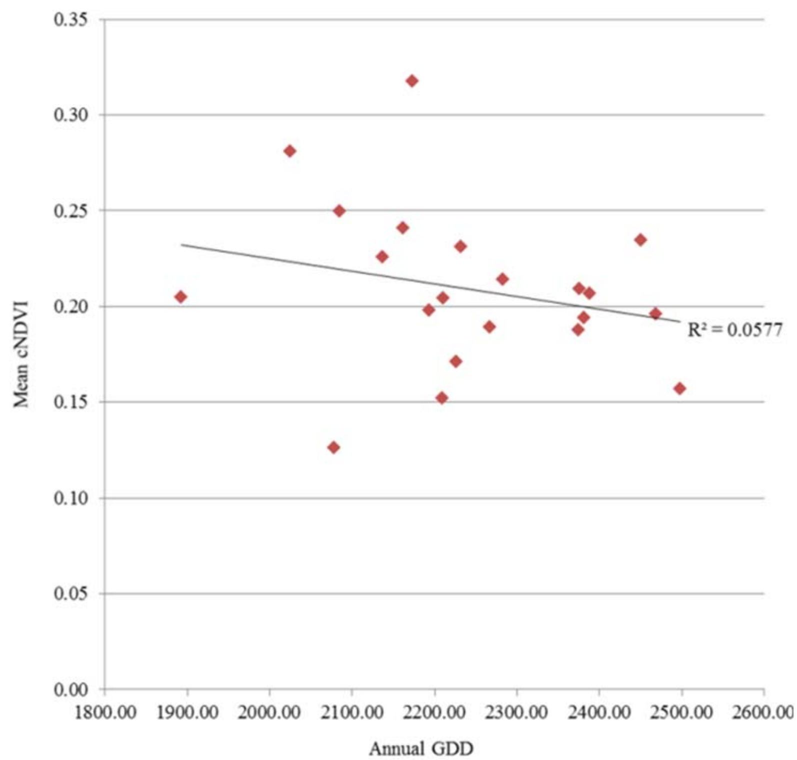

Figure 5. Linear regression analysis for annual GDD in relation to mean cNDVI results in R^2=0.0577 showing only a 5% correlation between annual GDD and mean cNDVI.

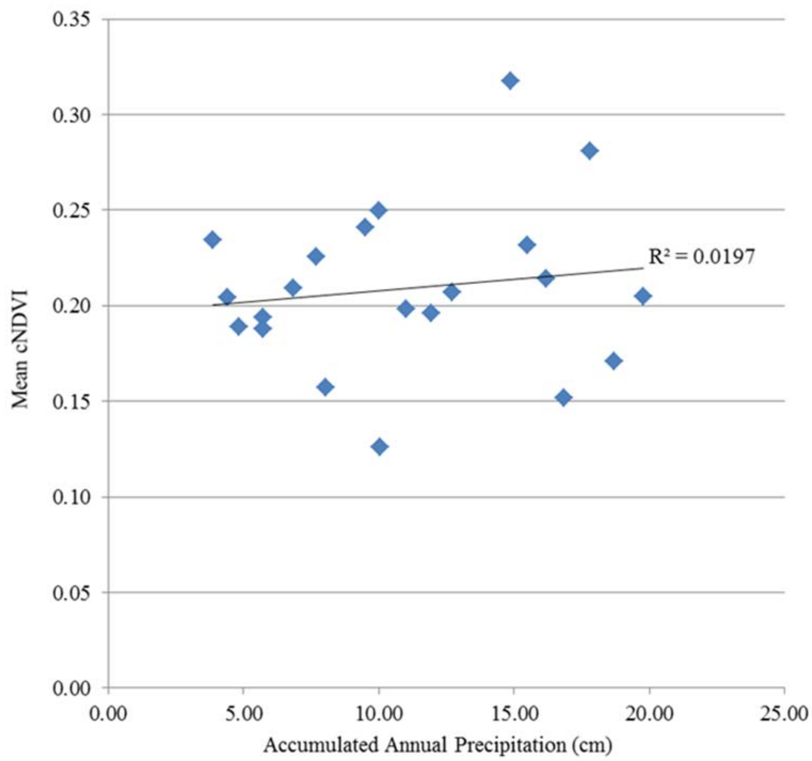

Figure 6. Linear regression analysis for accumulated annual precipitation in relation to mean cNDVI results in R^2=0.0197showing only a 1% correlation between accumulated annual precipitation and mean cNDVI.

Since neither temperature nor precipitation demonstrated a strong relationship ($P > 0.05$) with mean cNDVI in this study, previous studies may provide some explanation. A study by Wang et al. (2003) found a positive correlation between temperature and NDVI in the early and later portions of the growing season; however, temperature was negatively correlated with NDVI during the *middle* of the growing season. Du Plessis (1999) also points out that much variability can be due to region- and site-specific conditions, for example soil and vegetation types. The current study compiled GDD data by growing season and did not divide the years intra-seasonally.

In examining the relationship between precipitation and NDVI, Malo and Nicholson (1990) found a strong linear relationship between NDVI and rainfall *specifically* when rainfall accumulations were between 15 cm and 100 cm. The precipitation data's highest value in this study was 19.79 cm (1993) with a 21-year mode of 5.72 cm (Figure 4), significantly less than the previous study's 15-100 cm. Moreover, Davenport and Nicholson (1993) found a log-linear relationship between NDVI and precipitation when annual precipitation was below 100 cm and monthly precipitation did not exceed 20 cm. Further, in a study similar to this, Chen and Weber's (2012) results indicated that NDVI values observed in June and July had strong correlation with accumulated precipitation ($R^2 > 0.75$), but NDVI values observed in

May, August, and September were only *moderately* related with accumulated precipitation ($R^2 \geq 0.45$). As with GDD, this current study compiled precipitation data by year and did not divide intra-annually.

CONCLUSIONS

While both temperature and precipitation are known to be significant drivers of primary productivity in semiarid ecosystems, it appears that many factors can potentially influence that relationship with cNDVI. Semiarid rangelands are environments of extremely variable weather conditions where the plant life is spatially heterogeneous and seasonally dynamic. Although a plant's growth begins at a given minimum temperature and reaches a plateau at a maximum temperature, these temperatures vary depending on the individual plant and plant species.

Furthermore, although using cNDVI should remedy the problem of productivity underestimation, the semiarid sagebrush-steppe ecosystem, with its high proportion of bare ground, as well as possibly stressed vegetation, may not produce the expected spectral response. Lastly, strong linear relationships between NDVI and rainfall have been found but at much higher accumulation levels than those in this study's dataset.

LITERATURE CITED

AgriMet, 2012. http://www.usbr.gov/pn/agrimet/index.html (accessed 6/16/12).

Campbell, J.B. and R.H. Wynne, 2011. *Introduction to Remote Sensing, Fifth Edition*. New York: The Guilford Press. Pages 483-485.

Chen, F. and K.T. Weber, 2012. *Assessing Impact of Seasonal Precipitation and Temperature on Vegetation Dynamics in Semiarid Rangelands.* Pages 1-14.

Chen, F., K.T. Weber, J. Anderson, and B. Gokhale, 2011. *Comparison of MODIS fPAR Products with Landsat-5 TM Derived fPAR over Semiarid Rangelands of Idaho*. Pages 69-88 in K. T. Weber and K. Davis (Eds.), Final Report: Assessing Post-Fire Recovery of Sagebrush-Steppe Rangelands in Southeastern Idaho (NNX08AO90G). 252 pp.

Chen, F., K.T. Weber, and J.L. Schnase, 2012. *Assessing the Success of Post-Fire Reseeding in Semiarid Rangelands using Terra MODIS*. Pages 1-22.

Davenport, M. L., and S. E. Nicholson. 1993. On the relation between rainfall and the Normalized Difference Vegetation Index for diverse vegetation types in East Africa. *International Journal of Remote Sensing* 14, 2369-2389.

Du Plessis, W. P. 1999. Linear regression relationships between NDVI, vegetation and rainfall in Etosha National Park, Namibia. *Journal of Arid Environments* 42, 235-260.

Gibson, L. R., 2003. *Agronomy 212 - Grain and Forage Crops*, Iowa State University. http://www.agron.iastate.edu/courses/agron212/Calculations/GDD.htm (accessed 7/29/12).

Jensen, J.R., 2007. *Remote Sensing of the Environment: An Earth Resource Perspective, Second Edition*. New Jersey: Person Prentice Hall. Pages 382-386.

Jobbágy, E. G., and O. E. Sala. 2000. Controls of grass and shrub aboveground production in the Patagonian steppe. *Ecological Applications* 10, 541-549.

Malo, A. R., and S. E. Nicholson. 1990. A study of rainfall and vegetation dynamics in the African Sahel using normalized difference vegetation index. *Journal of Arid Environments* 19, 1-24.

Nasri, M., and P. S. Doescher. 1995. Effect of temperature on growth of cheatgrass and Idaho fescue. *Journal of Range Management* 48, 406-409.

Wang, J., Rich, P. M., and K. P. Price. 2003. Temporal responses of NDVI to precipitation and temperature in the central Great Plains, USA. *International Journal of Remote Sensing* 24, 2345-2364.

Weber, K.T., P. Gessler, and Nancy Glenn, 2011. *The Landsat Image Service Archive (LISA) Project*, GIS Training and Research Center at Idaho State University. URL = http://giscenter.isu.edu/research/Techpg/lisa/index.htm (accessed 7/23/12).

Weber, K. T., F. Chen, B. Gokhale, C. G. Bueno, and C. L. Alados. 2009. *Application of Composite-NDVI in Semiarid Rangelands*. Pages 71-84 in K.T. Weber and K. Davis (Eds.), Final Report: Comparing Effects of Management Practices on Rangeland Health with Geospatial Technologies (NNX06AE47G). 168 pp.