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Assessing growth response to climate in a Great Basin big sagebrush (*Artemisia tridentata*) plant community

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ABSTRACT

The response of dominant plant species to climate is vital to our understanding of ecosystem function and viability. We compared annual growth ring indices of a dominant Great Basin shrub (*Artemisia tridentata*) growing in the semiarid desert of northern Nevada, USA to historical climate records to identify and determine the extent specific climatic variables have on wood growth. Growth ring indices had a strong, positive correlation with total hydrologic-year precipitation (Oct–Sep; $r = 0.82$, $p < 0.001$) measured at the nearest meteorological station with the months of January, March, April, and June being the most highly correlated to ring growth ($r = 0.48$, 0.36, 0.47, and 0.41, respectively; $p < 0.05$). Mean maximum growing season temperatures were found to be negatively correlated to growth during the months of April, May, June, and October of the previous year ($r = -0.40$, -0.37, -0.50, and -0.30, respectively; $p < 0.001$). Multiple regression analysis determined hydrologic year precipitation and maximum growing season temperature to be the best predictors of ring growth (adj. $r^2 = 0.72$, $p < 0.001$). May NDVI (Normalized Difference Vegetation Index) values were adequate predictors of annual ring growth ($r^2 = 0.48$, $p < 0.01$), and ring growth patterns of big sagebrush were consistent with those of other species in the greater region demonstrating the utility of the shrub for climate studies.

1. Introduction

Studies of the ecological impacts of current climate change are numerous (Walther et al., 2002; Pereira et al., 2010; Bellard et al., 2012; Grimm et al., 2013) and ongoing. Information on future impacts is of great interest as this knowledge will influence mitigation efforts and policy. The southwestern United States could see a 2.5 °F–5.5 °F temperature rise within the next 30 years followed by a potential 5.5 °F–9.5 °F increase in the subsequent 20 years (Garfin et al., 2014). Precipitation changes are more uncertain and variable within the region with models predicting a general decreasing pattern of rainfall averages along a north-south gradient (Seager et al., 2007; Kunkel et al., 2013). Coupled together, these projections can help to more accurately predict potential ecosystem response.

Sagebrush (*Artemisia tridentata* ssp.) are ubiquitous throughout the Great Basin (Connelly et al., 2011; Welch, 2005), and the habitats they support may be affected by future climate change. It is possible the direction of these effects, positive or negative, and the extent to which they may occur may differ between sagebrush species as each exists within certain elevational margins experiencing different environmental demands. For example, ecosystem warming has been shown to benefit mountain sagebrush (ssp. *vaseyana*) growth (Perfors et al., 2003), but this positive effect may not be shared across species growing under other climate regimes. Basin big sagebrush (ssp. *tridentata*) typically occupies low-elevation valleys and foothills (Welch, 2005) in the southernmost range of the species, and future sagebrush distribution at this range may experience substantial declines in response to more arid conditions (Schlaepfer et al., 2012).

Proxy records, such as tree rings, provide a link between plant productivity and historical climate (Fritts, 1976; Speer, 2010; Griffin et al., 2011; Salzer et al., 2013). However, most ring studies in the intermountain western U.S. are relegated to mountainous terrains, and the information gleaned from indigenous trees may not be representative of the adjacent, lower elevation environments. Big sagebrush is one of the few shrubs to produce a well-defined, annual growth ring pattern (Diettert, 1938; Biondi et al., 2007). Early studies successfully linked sagebrush annual wood growth to regional precipitation (Ferguson and Humphrey, 1959; Ferguson, 1964), but few have utilized the shrub to examine this relationship at finer resolutions where the impacts of climate change are most relevant (Cawker, 1980; Perfors et al., 2003; Poore et al., 2009).

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Remote sensing has assumed an important role in the global monitoring of shifts in plant distribution, cover, and phenology potentially attributable to climate change (Yang et al., 2013; Kennedy et al., 2014; Pettorelli et al., 2014). Relationships between Normalized Difference Vegetation Index (NDVI) values derived from satellite imagery and plant growth rings have helped describe how plant productivity has varied with respect to past climate (Wang et al., 2004; Liang et al., 2005; Lopatin et al., 2006; Forbes et al., 2010), and this information would be valuable in predicting and monitoring plant response to future climate shifts. Previous studies have used NVDI to examine plant water use and physiology in sagebrush-dominated plant communities (Baghzouz et al., 2010; Devitt et al., 2010), but a direct link to sagebrush productivity has not been made.

The goals of this study were to examine the growth response of big sagebrush to short-term climate variation, demonstrate the utility of big sagebrush growth rings as indicators of past climate, and determine if satellite-derived vegetation index data (NDVI) have an empirical relationship with sagebrush growth rings. A combination of correlation and regression analysis was used to examine the effects of precipitation and temperature on radial stem growth. Based on previous study of plant water use in the study area of Spring Valley, NV (Devitt et al., 2010), we hypothesized that mean winter season precipitation would show the greatest correlation with sagebrush ring widths. Correlation analysis between monthly averages of climate variables and ring widths was done to examine relationships on a finer temporal scale as the effects of climate change may not be constant throughout the growth year. We also hypothesized a regression model incorporating both mean winter season precipitation and mean maximum growing season temperatures would be able to account for the largest amount of variation in annual sagebrush ring widths compared to other combinations of annual and seasonal measures of precipitation and temperature. The utility of big sagebrush rings as a climate proxy was shown by comparing the constructed sagebrush ring chronology with those of other studies utilizing tree species more prevalent in the tree ring literature. Further regression analysis was used to examine the empirical relationship between remotely-sensed NDVI and sagebrush growth as this relationship could be used to estimate future sagebrush production.

2. Methods

2.1. Study area

Spring Valley is located within the eastern extent of the Great Basin Desert. It is bounded by the Schell and Snake mountain ranges (west and east, respectively) in east-central Nevada and is immediately west of the Great Basin National Park near the Utah-Nevada border. The climate is semi-arid with hot summers and cold winters, and precipitation is highly variable throughout the year with most rainfall occurring during the warmer growing season months (between March and September) (Devitt et al., 2010). Precipitation during the coolest months (October through February) falls largely as snow. Vegetative cover and composition is highly heterogeneous with the two dominant species being sagebrush (*Artemisia tridentata*) and greasewood (*Sarcobatus vermiculatus*). Sagebrush is most dominant in the southern half of the valley where both pure and mixed-shrub stands exist with some combination of greasewood, rabbitbrush (*Crysothammus viscidiflorus*) and shadscale (*Atriplex confertifolia*) present.

2.2. Field methods

118 sagebrush stem cross-sections were collected during nine trips between February and July of 2011 in Spring Valley, NV. The 36 sampling sites were chosen by scouting from the field vehicle for the presence of plants of suitable size for ring analysis. Individual plants were not randomly selected within each plot as many of the sagebrush had splitting stems that would be difficult for tree ring dating. Plants possessing a single-stem morphology were collected using a pruning saw on the main stem at soil level. Sites were located in the elevation range of 1681–1856 m. Care was taken to avoid sites where plants might have possible access to shallow groundwater, sites containing signs of heavy disturbance, or sites that could potentially receive enhanced precipitation runoff. Plant community composition at each site ranged from homogenous sagebrush stands to sagebrush-dominated, mixed-shrub communities. Three to five sagebrush stems were collected at each sampling site with each plant being located within an arbitrary $30 \times 30\,m^2$ plot, corresponding to the area of an individual Landsat image pixel. A minimum distance of 3 km between sites was maintained to avoid clumping. GPS coordinates (Garmin 400 t) of each site were recorded to the nearest 3 m to relate each site location with its respective pixel in a satellite image scene.

2.3. Data acquisition

All historical precipitation and temperature data were downloaded from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) land-based station data archives (http://www.ncdc.noaa.gov/data-access/land-based-station-data). Data from climate monitoring stations in or near Ely, Lund, Pioche, and the Great Basin National Park were collected. Data from these stations spanned between 1938 and 2010. Climate data from within Spring Valley were also collected (Shoshone station), but these data were more abbreviated (1989–2007). Precipitation data were downloaded as monthly totals from all stations. Regional ring records from other studies were downloaded from the NCDC NOAA International Tree-Ring database (http://www.ncdc.noaa.gov/paleo/treering.html) to compare sagebrush growth patterns with those of other species. These records were limited to studies with growth records overlapping those of the plants collected for this study. All studies meeting that criterion from within central-eastern Nevada were used and more distant study sites were included for contrasting comparisons.

NDVI values corresponding to each sagebrush sampling site were extracted from Landsat 5 TM scenes acquired during the growing season months (March-September) of 1986–2010. All images were downloaded from the USGS Earth Resources Observation and Science Center (EROS) via the Global Visualization (GLOVIS) tool (http://glovis.usgs.gov/) and processed using the image processing software, ENvironment for Visualizing Images (ENVI; Exelis Visual Information Solutions, Boulder, CO, USA). As many cloud-free scenes were collected for each year as possible with a maximum of two scenes per month, but due to the satellite's 16-day orbit and random cloud cover, some months were represented by only one image or were missing images entirely. The images acquired during the years of 1995 and 1998 were especially problematic as they were exceptionally wet years with extensive cloud cover through much of the growing season.

Image analysis included radiometric calibration, conversion to reflectance values and calculation of NDVI. Downloaded images were previously terrain corrected and georectified by EROS. After radiometric calibration was performed using the ENVI Landsat calibration algorithm (based on Chandler et al., 2009), field spectra, corresponding to light, medium, and dark targets, were used to atmospherically correct and normalize reflectance data using the empirical line method (Farrand et al., 1994; Smith and Milton, 1999). Field spectra acquired with a FieldSpec Pro (Analytical Spectral Devices, Inc., Boulder, CO, USA) with 1 nm spectral resolution were converted to Landsat TM bandwidths using the ENVI Spectral Library Resampling tool, which employs a Gaussian model based on the TM band wavelength and full-width at half maximum (FWHM) sensitivity of the Landsat TM detector for the conversion. The resulting converted field reflectance spectra and corresponding average Landsat TM pixel radiances for each ground target location were used to develop regression equations for the empirical line atmospheric correction. NDVI was calculated for each sagebrush sampling site from each available Landsat image using the following equation (Rouse et al., 1974):