Projecting Future Changes in Sagebrush Distribution in the Great Basin

U.S. Geological Survey Great Basin Integrated Landscape Monitoring Project

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Abstract

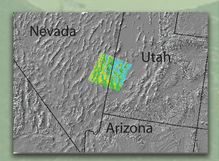
Changes to the Great Basin landscape are due to the effects of numerous drivers including climate change. A pilot study was initiated to evaluate approaches to assess the causative factors for changes in landcover for a 24,000-sq km area surrounding Great Basin National Park. LANDSAT-derived landcover change at ~5 year intervals from 1985-2007 were analyzed to detect transitions in sagebrush communities either to or from cold desert scrub or pinyon-juniper communities. These transitions were then evaluated with regard to the climatic and hydrologic conditions that corresponded to changes in these communities to define "hydroclimatic envelopes" for each community type that could be used to anticipate future changes in vegetation distribution. Downscaled future climate scenarios were then used with a regional hydrologic model to project future hydroclimatic envelopes across the study region for 2000-2100.

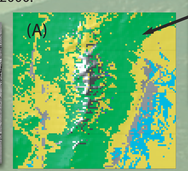
INTRODUCTION

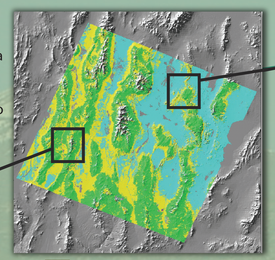
Climate change and observed changes in the spatial distribution of biota has spurred increased interest in understanding the causative factors driving transitions from one landcover type to another in a effort to predict changes in the spatial distribution of important ecosystem components. Ecophysiological and correlative approaches are typically pursued, but as projections of climate change generally only offer precipitation and air temperature parameters, hydrologic response was considered in this study. This pilot study endeavors to illustrate the hydrologic response to climate projections and to establish a hydrologic derivative that correlates well with vegetation distribution on the basis of energy and water demands. This study was initiated to evaluate approaches to assess the causative factors for changes in landcover for a 24,000-sq km area surrounding Great Basin National Park using LANDSAT images of transitions in landcover and focusing on sagebrush and the dominant species to which it transitions. Correlations with the hydrologic derivative "climate water deficit" are analyzed and used to project future distributions of sagebrush.

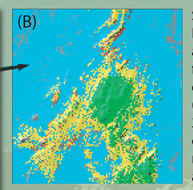
METHODS

The study area is a 24,000-sq km area around Great Basin National Park, on the border between Nevada and Utah. The area was defined on the basis of the extent of a LANDSAT scene, selected and analyzed for 4 5-yr periods from 1985-2007, depicting changes in land cover. (A) shows transitions of SAGE to PJ between 1985 and 1990, whereas (B) shows transitions of SAGE to CDS between 1995 and 2000.









Sagebrush steppe (SAGE), an important ecosystem in the Great Basin, was chosen as the illustrative landcover for analysis, along with the spatially adjacent vegetation to which SAGE is found to transition, pinyon-juniper woodlands (PJ) and cold desert scrub (CDS), respectively.

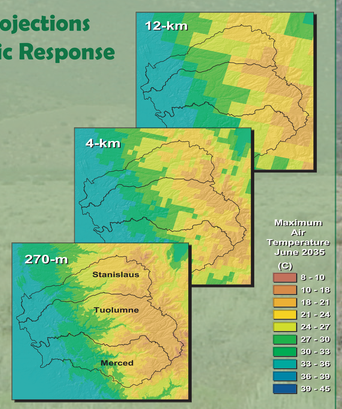
(1) Careful analysis of 5 LANDSAT images (1985, 1990, 1995, 2000, and 2007) were done to compare periods when landcover changes were evident, and were not due to fire or land management treatments. Images were converted to GIS grids at 270-m resolution for further analysis.

(2) The BCM (described below) was run for 1985-2007 and hydrologic parameters were correlated with the presence of each of the 3 vegetation types, as well as conditions that resulted in a transition of SAGE to CDS or PJ. "Hydroclimatic envelopes" were developed that described the conditions (range of CWD, described below) under which each species was found.

(3) The BCM was run for future climate scenario GFDL-A2 and the hydroclimatic envelope for each vegetation type was used to project the spatial distribution of each for two future decades, 2030-2039 and 2090-2099.

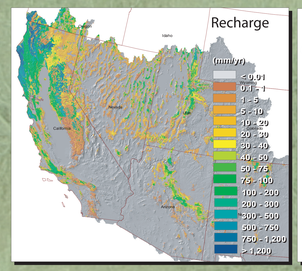
Downscaling Climate Projections and Modeling Hydrologic Response

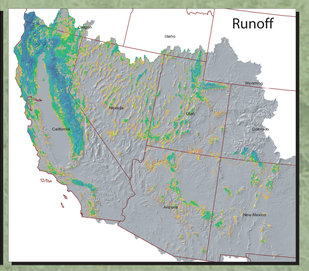
Global climate model data are downscaled from 2.5 degree resolution (~275-km) to 1/8 degree (12-km) using a constructed analogues method by Hidalgo et al. (2007). The 12-km data are further downscaled to 4-km using a gradient-inverse-distance-squared (GIDS) method. These data are transformed statistically to ensure that the climate model and historical data have similar statistical properties: the mean and standard deviation of the 1950-2000 period were used for corrections. These data are further downscaled to 270-m using GIDS for model application in the Basin Characterization Model.



Basin Characterization Model (BCM)

The BCM (Flint and Flint, 2007) is a regional, monthly, grid-based, water-balance calculation, run in FORTRAN, that uses an hourly potential evapotranspiration (PET) model that relies on solar radiation modeled using topographic shading, cloudiness, and vegetation density. Recharge and runoff are calculated on the basis of snow accumulation and melt, soil and bedrock properties and precipitation and air temperature inputs.

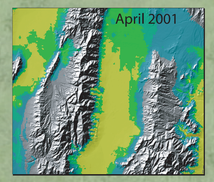


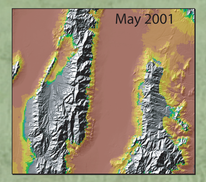


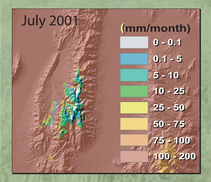
Hydrologic Drivers of Landscape Change

Calculation of Climatic Water Deficit

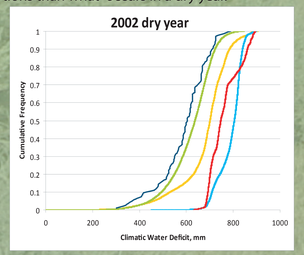
Climatic water deficit (CWD) is evaporative demand not met by available water (W), a measure of how much more water could have been evaporated or transpired from a site covered by a standard crop, had that water been available (Stephenson, 1990). Potential evapotranspiration (PET) is evaporative demand, and W is defined as the total amount of water reaching the soil, minus the change in soil water storage. W is equal to actual evapotranspiration (AET) minus surplus water, which is unavailable to plants, therefore CWD is calculated as PET - AET. Monthly AET is calculated by the Basin Characterization Model as precipitation + last month's snowpack + last month's soil water storage - soil water storage - sublimation - snowpack. This parameter is biologically meaningful and well correlated with the distribution of vegetation types, which exhibit these qualities over several orders of magnitude of spatial scale (Stephenson, 1998).

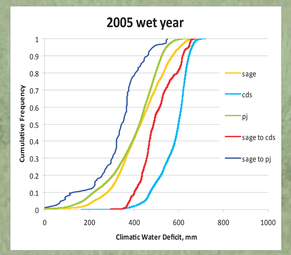




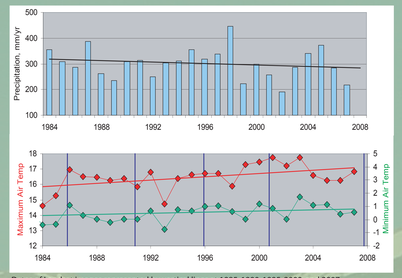


The CWD for all 270-m pixels for each vegetation type and transition were identified and illustrate the CWD under which each type is found, as well as the conditions that lead to a transition to another type. For example, the SAGE is found in CWD conditions drier than PJ and wetter than CDS and will transition to one or the other depending on the conditions. In a wet year (2005), SAGE transitioning to PJ occurs at a much drier condition relative to the SAGE conditions than what occurs in a dry year.



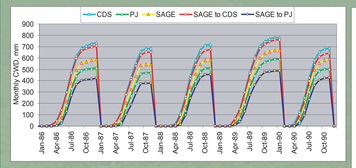


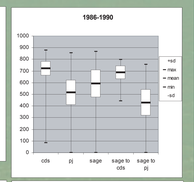
RESULTS OF CURRENT CONDITIONS

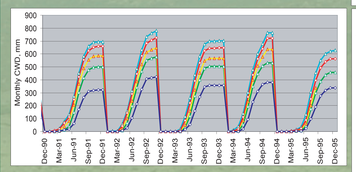


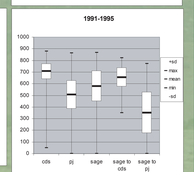
Dates of Landsat images represented by vertical lines at 1985, 1990, 1995, 2000, and 2007

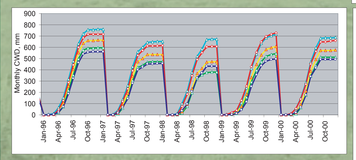
Precipitation over the study period 1985-2007 generally declined and air temperature increased, with a wet period reflected in the 1995-2000 LANDSAT time frame and a dry period reflected in the 2000-2007 LANDSAT time frame. Hydrologic conditions are represented below for the 4 time periods as monthly CWD for the 3 vegetation types and the transitions from SAGE to CDS and SAGE to PJ. Corresponding statistics are shown.

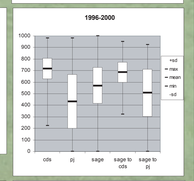


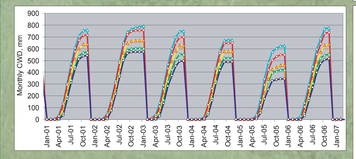


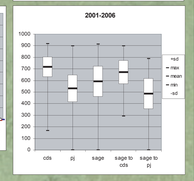












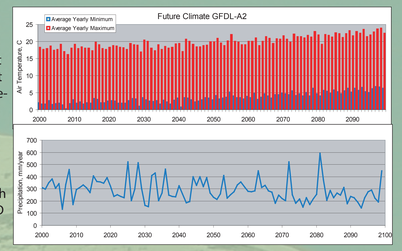
Climatic Water Deficit, mm/year

	1986-1990	1990-1995	1995-2000	2001-2006	mean
CDS	721	706	716	715	**714**
number of cells	*98,462*	*97,275*	*97,666*	*97,632*	
PJ	516	505	432	532	**496**
number of cells	*95,998*	*96,748*	*96,611*	*98,078*	
SAGE	591	579	569	591	**583**
number of cells	*84,879*	*85,228*	*85,628*	*84,727*	
SAGE to CDS	686	655	684	670	**674**
number of cells	*37*	*149*	*404*	*1,502*	
SAGE to PJ	429	351	506	485	**443**
number of cells	*130*	*86*	*262*	*82*	

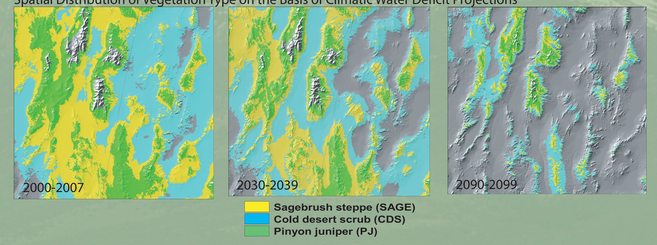
RESULTS OF FUTURE PROJECTIONS

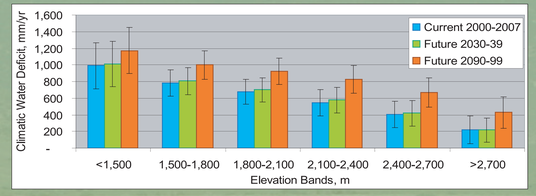
Air temperature increases throughout the next century with an approximate increase of about 5 degrees in both maximum and minimum. Precipitation slightly declines, but most notably there are multi-year droughts in the 70's and mid-80's through the 90's.

The spatial distribution of vegetation type on the basis of projections of CWD are shown, with a large decline in all vegetation types. The CWD moves upslope, but as air temperature and freezing are not considered, the distribution is over-estimated.



Spatial Distribution of Vegetation Type on the Basis of Climatic Water Deficit Projections





Increases in climatic water deficit are evident for each future time period for all elevation bands. However, the percentage of increase projected for the higher elevations indicate a much more definitive loss of habitat for the vegetation types occupying the higher elevations, such as the pinyon-juniper woodlands. As this analysis did not consider minimum air temperature, which may be an inhibiting factor for invasions of vegetation at the higher elevations, the apparent movement upslope of all 3 vegetation types is undoubtedly overestimated, and thus total distribution is overestimated.

SUMMARY and CONCLUSIONS

A pilot project was undertaken to evaluate the use of Landsat images to identify transitions among vegetation communities in the Great Basin and to establish "hydroclimatic envelopes" that could be used to predict the potential future distribution of vegetation with a changing climate. Sagebrush steppe was analyzed to determine the hydrologic response derivatives that were correlated to it's spatial distribution and transition to cold desert scrub or pinyon-juniper woodlands.

Climatic water deficit (CWD) was determined to be a relevant and correlated driver in the Great Basin for these dominant vegetation types, and is useful for the projection of future distribution, rather than the climate parameters that are available from global climate projections. Downscaling of future climate projections to ecologially relevant scales, in this case 270-m, and translation to hydrologic derivatives via a regional water-balance model were necessary for the analysis.

Results of future projections using the GFDL-A2 scenaio indicate an increase in CWD at all elevations and throughout the current distribution of all three vegetation types of interest, sage, cold desert scrub and pinyon-juniper woodlands. The projected changes over the next century resulted in the movement of acceptable CWD upslope and the projection of greatly diminished areal extent of all three vegetation types.

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