Initial Analysis of Change in Vegetation Productivity for the Grand Staircase-Escalante National Monument, 1986-2011

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INTRODUCTION

Ongoing global climate change will have strong and varied effects at regional levels, and may include devastating impacts such as intensified forest pest outbreak (Logan et al. 2003) and increased wildfire risk (Westerling et al. 2006) in the western United States. In the Southwest in particular, warming will continue with increasing variability in precipitation and greater intensity of droughts; and land cover, plant species distribution, and plant mortality will be substantially affected (Overpeck et al. 2013). Anthropogenic land use can compound the effects of a changing climate on the primary productivity of a landscape (DeFries et al. 2012), particularly in more vulnerable ecosystems such as riparian areas (Palmer et al. 2008). This presents a formidable challenge to land managers, who must effectively balance selective land uses with ecosystem health to ensure the long-term sustainability of both. Using indicators of rangeland health, such as vegetation productivity, can aid in identifying areas that are more sensitive to disturbances such as climate change or impactful land uses and can provide a foundation for strategic land management that can mitigate further environmental degradation.

Primary productivity of terrestrial vegetation is an important indicator of rangeland health (Hunt et al. 2003) and is influenced by many factors including climate, topography, soils, plant and microbial factors, disturbance, and anthropogenic impacts such as land use (Field et al. 1995). Although vegetation productivity is directly related to photosynthesis and is an important metric of ecosystem dynamics, direct estimates of vegetation productivity are laborious to measure on the ground (Gower et al. 1999). However, with the availability of remotely-sensed data, landscape-level estimates of vegetation productivity are possible, enabling ecologists and land managers to assess trends in ecosystem responses to environmental changes (Pettorelli et al. 2005).

The Grand Staircase-Escalante National Monument (GSENM) in southern Utah will not be exempt from the effects of climate change and, similarly, its land managers are faced with difficult but important decisions on how best to maintain the landscape and its multiple uses. An important national monument due to its rich cultural history and geologic uniqueness (Administration of William J. Clinton 1996), the GSENM is also a hotspot of plant species that are rare or endemic to the Colorado Plateau or to the Monument itself, with the majority of species-rich areas in rare, mesic, or high-elevation habitats that include aspen stands and riparian zones (Stohlgren et al. 2005). We present a 25-year (1986-2011) analysis of productivity across the GSENM to identify those areas where significant losses in productivity have occurred as a first step in assessing climate vulnerability on the Monument. We specifically looked at how this change in vegetation productivity varied by livestock grazing allotment and vegetation type (e.g., pinyon-juniper woodlands) to identify those areas where strategic grazing management will be particularly important.

METHODS

To evaluate the change in vegetation productivity over the 25-year period in the GSENM, we analyzed publicly available vegetation-specific satellite imagery in a Geographic Information System (GIS). Specifically, we used LANDSAT Thematic Mapper (4-5) data available for the years 1986-2011 (obtained from the United States Geological Survey's GloVis data distribution site; glovis.usgs.gov) for the full extent of the GSENM, including a 1-km buffer area outside the boundary to avoid errors associated with edge effects (total study area, 8,337 km^2). This type of satellite data can be used to represent net primary productivity of vegetation through the metric of Normalized Difference Vegetation Index (NDVI), a robust tool for assessing ecological responses to environmental change (Pettorelli et al. 2005).

For the 1986-2011 time period (which encompassed all possible years of available data), one usable (less than 25% cloud cover with highest possible image quality) was obtained each year during the month of October, the month before most livestock graze on the GSENM and during the second vegetation green-up period in the region. Due to limited availability of quality images each month, some years included the next best image, which was selected from between late August and early November. These images were processed for analysis[1] and NDVI was calculated for each year.

To calculate NDVI change over time, we used a difference between a 10-year average of 1986-1995 and of 2002-2011 for our comparison between original (1986 to1995) and current (2002 to 2011) vegetation productivity. A 10-year average was used to help reduce the effect of year-to-year variation and obtain a more robust historical trend.

Because changes in vegetation productivity are not homogeneous across the landscape, we stratified our analysis by current vegetation type using publicly available satellite data of vegetation cover type from LANDFIRE (2010; www.landfire.gov) and a simplified version of the Society of American Foresters and Society for Range Management (SAF_SRM) vegetation classification[2]. We also summarized our results by grazing allotment to identify any particular allotments where vegetation productivity may have changed more dramatically than others.

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[1] *LANDSAT scenes were obtained for the entire GSENM and, for the infrared and near infrared bands of this imagery, each scene was converted to the LANDSAT TM7 digital number equivalent, then converted to a radiance metric, then to a reflectance metric (where positive reflectances were enforced) before NDVI was calculated from the two bands, following the process outlined in the tutorial by Firl and Carter (2011).*

[2] *The following descriptions indicate how the original SAF_SRM classification was consolidated: Aspen (SAF217: Aspen); Deciduous Shrubland or Chaparral (SRM421: Chokecherry-Serviceberry-Rose, SRM 413: Gambel Oak, SRM415: Curlleaf Mountain-Mahogany, SAF241: Western Live Oak); Desert Scrub or Shrubland (SRM501: Saltbush-Greasewood, SRM212:Blackbush, SRM414: Salt Desert Shrub, SRM605: Sandsage Prairie); Developed (LF20: Developed, LF80: Agriculture); Grassland (SRM502: Grama-Galleta, SRM410: Alpine Rangeland, SRM505: Grama-Tobosa Shrub); Introduced Riparian Vegetation (LF58: Introduced Riparian Vegetation); Introduced Upland Vegetation (LF54: Introduced Upland Vegetation - Herbaceous); Mixed Conifer (SAF210: Interior Douglas Fir, SAF206: Engelmann Spruce-Subalpine Fir, SAF237: Interior Ponderosa Pine, SAF219: Limber Pine, SAF211: White Fir); Pinyon-Juniper Woodland (SRM504/412: Pinyon-Juniper Woodland); Riparian (SRM 422: Riparian, SRM203: Riparian Woodland, SAF235: Cottonwood-Willow, SRM418: Bigtooth Maple); Sagebrush (SRM405: Black Sagebrush, SRM403: Wyoming Big Sagebrush, SRM402: Mountain Big Sagebrush, SRM314: Big Sagebrush-Bluebunch Wheatgrass);and Sparse (LF33: Sparsely vegetated, non-vegetated, no dominant lifeform).*

RESULTS

Average change in vegetation productivity, as displayed by the change in NDVI, showed both increases (green areas) and decreases (brown areas) across the GSENM, with some areas having negligible change (yellow areas; FIGURE 1).

Using the most recent (2010) vegetation cover from LANDFIRE and the consolidated SAF_SRM vegetation classification (FIGURE 2), we found that the majority vegetation type for each allotment was either a majority of pinyon-juniper woodland (60 allotments), sparse vegetation (18 allotments), desert scrub and shrubland (17 allotments), sagebrush (7 allotments), or riparian (1 allotment). Stratifying by vegetation type and calculating the overall relative change as a percent of the original (1986-1995 average) NDVI image values, we found that vegetation productivity increased overall for introduced riparian vegetation, introduced upland vegetation, deciduous shrubland or chaparral, and aspen woodland vegetation types (FIGURE 3). The remaining vegetation types – sagebrush, riparian, pinyon-juniper woodland, mixed conifer, grassland, developed, desert scrub or shrubland, and sparse – decreased during the study period, with areas currently classified as mixed conifer, pinyon-juniper woodland, or grassland having the highest overall decrease (FIGURE 3). Notably, all vegetation types comprising more than 1% of the study area, with the exception of the introduced riparian vegetation, decreased in productivity.

We also stratified by allotment to see if any trends in change in vegetation productivity would be present. We found that 80 out of 103 allotments showed an overall decrease in vegetation productivity. Of these 103, we looked at the 25 largest allotments (by calculated area) in greater detail (FIGURE 4) and calculated the total change as a percent of the original (1986 to 1995) value. Of the 103 allotments, the largest decrease was found in the Sink Holes allotment (-5.33%) and the largest increase was found in the Long Canyon Stock Driveway allotment (3.87%). The average change for all allotments was -0.83% (standard deviation ±0.02).

DISCUSSION

While we did not explicitly model relationships between vegetation productivity and livestock grazing or climate variables (e.g., historic precipitation and temperature records), we were able to demonstrate several trends in the change of plant productivity over the 25-year period.

Our analysis of change in vegetation productivity by vegetation cover type demonstrated a decrease in overall greenness in some types but an overall increase in others. Our basic analysis was not designed to determine changes in vegetation cover type and related LANDFIRE expected vegetation type data is not updated frequently enough to track changes in vegetation type during the study period. Vegetation cover types may have also changed since 1986 – for example, areas currently classified as pinyon-juniper woodlands may have been grassland regions in previous decades. This does not directly impact our results, which measured a relative change in vegetation greenness whose value does not change as a result of a change in vegetation classification. However, understanding shifts in vegetation type can aid in characterizing the management implications associated with demonstrated increases or decreases in vegetation productivity. As cover type is another important indicator of rangeland health (Hunt et al. 2003), exploration of these shifts during recent decades could be a useful expansion of this initial assessment.

Despite the lack of information on change in vegetation cover type, most of the vegetation classifications were determined to be declining in productivity, including pinyon-juniper woodland, desert scrub or shrubland, and sparsely vegetated areas which covered a majority of the GSENM area assessed (approximately 33%, 26%, and 20%, respectively; Figure 3). The exceptions to this trend were areas classified as introduced riparian vegetation, introduced upland vegetation, deciduous shrubland or chaparral, and aspen woodland. Of these areas that increased in vegetation productivity, three represented less than 1% (83 km^2) of the total area studied.

Increases in deciduous shrubland or chaparral and in aspen woodland vegetation types were incongruous with the other native vegetation types which demonstrated a decrease in productivity over the study period. Aspen woodlands are considered to be declining in much of the American West and hotspots of rapid mortality events have been documented (Oukrop et al. 2011). The increase in productivity depicted in these results could suggest a shifting phenology in seasonal aspen green-up such that green-up may have occurred earlier and earlier over the study period (i.e., occurring earlier during the fall months rather than winter months). A more in-depth analysis of intraannual NDVI changes consisting of multiple images per year could help tease apart possible causation factors (Oukrop et al. 2011) while an assessment of change in land cover type could provide more information on overall aspen cover dynamics.

Although we were not able to explicitly evaluate the effect of phenological shifts on our results, the general trends of decreasing native vegetation productivity and increasing introduced vegetation productivity are considerable concerns for managers. Riparian areas in this region have been documented to be increasingly occupied by invasive species such as Russian olive (*Elaeagnus angustifolia*), which is a dominant woody plant invader along rivers, including in areas in the GSENM (Jarnevich and Reynolds 2011). Russian olive or other riparian invasive expansion may have contributed to the increase in introduced riparian vegetation productivity. This is a cause for concern to land managers working to mitigate invasive species in the GSENM, as riparian areas may be more vulnerable (Palmer et al. 2008), particularly to livestock grazing impacts (Fleischner 1994), in the face of climate change.

CONCLUSIONS

We detected both increases and decreases in vegetation productivity across the GSENM, but our initial findings suggest that there has been an overall decrease in vegetation productivity in 80 of 103 allotments and 8 of 12 vegetation types from 1986 to 2011.

The direct cause of this decrease is difficult to determine in our initial analysis as it is likely the product of complex interactions between biotic and abiotic factors. However, our analysis does suggest that in allotments where vegetation productivity has decreased overall land managers should take steps to reduce disturbance, such as livestock grazing, which could compound this response. Livestock grazing is a widespread influence on native ecosystems in the American West. While this influence varies by range management practice and ecosystem type, numerous studies have identified ecological impacts such as altered vegetation diversity, especially in riparian habitats (as summarized by Fleischner 1994), and disrupted cryptobiotic (biological) soil crusts, which has been linked to nonnative species spread (Stohlgren et al. 2001, Guenther et al. 2004). These have the potential to exacerbate current and anticipated climate change impacts on the landscape.

Although land managers in GSENM are faced with the challenge of climate change impacts and other compounding disturbances, they are also presented with an opportunity to balance selective land uses that could otherwise compound climate change effects. The trends in average change in vegetation productivity explored here suggest that there are areas within the Monument that are vulnerable to disturbance. These trends encourage future strategic decisions about livestock management that will reduce the exploitation of this vulnerability and the intensification of anticipated detrimental effects of climate change.

LITERATURE CITED

Administration of William J. Clinton 1996. Proclamation 6920 - Establishment of the Grand Staircase-Escalante National Monument, September 18, 1996. United States Government, Washington, D.C., USA.

DeFries, R.S., C.B. Field, I. Fung, G.J. Collatz, and L. Bounoua. 2012. Combining satellite data and biogeochemical models to estimate global effects of human-induced land cover change on carbon emissions and primary productivity. Global Biogeochemical Cycles 13:803-815.

Field, C.B, J.T. Randerson, and C.M. Malmström. 1995. Global net primary production: combining ecology and remote sensing. Remote Sensing of Environment 51:74-88.

Firl, G.J., and L. Carter. 2011. Lesson 10: Calculating Vegetation Indices from Landsat 5 TM and Landsat 7 TM+ Data. Colorado State University Tutorial. Online: http://ibis.colostate.edu/WebContent/WS/ColoradoView/TutorialsDownloads/CO_RS_Tutorial10.pdf. Accessed January 10, 2014.

Fleischner, T.L. 1994. Ecological costs of livestock grazing in western North America. Conservation Biology 8:1523-1739.

Gower, S.T., C.J.Kucharik, and J.M. Norman. 1999. Direct and Indirect Estimation of Leaf Area Index, f_{APAR}, and Net Primary Production of Terrestrial Ecosystems. Remote Sensing of Environment 70:29-51.

Guenther, D., T.J. Stohlgren, and P. Evangelista. 2004. A comparison of a near-relict site and a grazed site in a pinyon-juniper community in the Grand Staircase-Escalante National Monument, Utah. *In* The Colorado Plateau: Cultural, Biological, and Physical Research, C. van Riper III and K.L. Cole, editors. The University of Arizona Press, USA.

Hunt, E.R., J.E. Everitt, J.C. Ritchie, M.S. Moran, D.T. Booth, G.L. Anderson, P.E. Clark, and M.S. Seyfried. 2003. Applications and research using remote sensing for rangeland management. Photogrammetric Engineering and Remote Sensing 69: 675-693

Jarnevich, C.S., and L.V. Reynolds. 2011. Challenges of predicting the potential distribution of a slow-spreading invader: a habitat suitability map for an invasive riparian tree. Biological Invasions 13:153-163.

Logan, J.A., J. Régnière, and James A. Powell 2003. Assessing the impacts of global warming on forest pest dynamics. Frontiers in Ecology and the Environment 1:130–137.

Oukrop, C.M., D.M. Evans, D.L. Bartos, D.R. Ramsey, and R.J. Ryel. 2011. Moderate-scale mapping methods of aspen stand types: a case study for Cedar Mountain in southern Utah. General Technical Report RMRS-GTR-259. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Overpeck, J., G. Garfin, A. Jardine, D. E. Busch, D. Cayan, M. Dettinger, E. Fleishman, A. Gershunov, G. MacDonald, K. T. Redmond, W. R. Travis, and B. Udall. 2013. “Summary for Decision Makers.” In Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 1–20. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

Palmer, M.A., D.P. Lettenmaier, N. LeRoy Poff, S.L. Postel, B. Richter, and R. Warner. 2008. Climate change and river ecosystems: protection and adaptation options. Environmental Management 44:1053-1068.

Pettorelli, N., J.O. Vik, A. Mysterud, J.M. Gaillard, C. Tucker, and N.C. Stenseth. 2005. Using the satellite-derived NDVI to assess ecological responses to environmental change. Trends in Ecology and Evolution 20:503-510.

Stohlgren, T.J., D.A. Guenther, P.H. Evangelista, and N. Alley. 2005. Patterns of plant species richness, rarity, endemism, and uniqueness in an arid landscape. Ecological Applications 15:715–725.

Stohlgren, T.J., Y. Otsuki, C.A. Villa, M. Lee, and J. Belnap. 2001. Patterns of plant invasions: a case example in native species hotspots and rare habitats. Biological invasions 3-37-50.

Westerling, A.L., H.G. Hildago, D.R. Cayan, and T.W. Swetnam. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science 313:940-943.

FIGURES

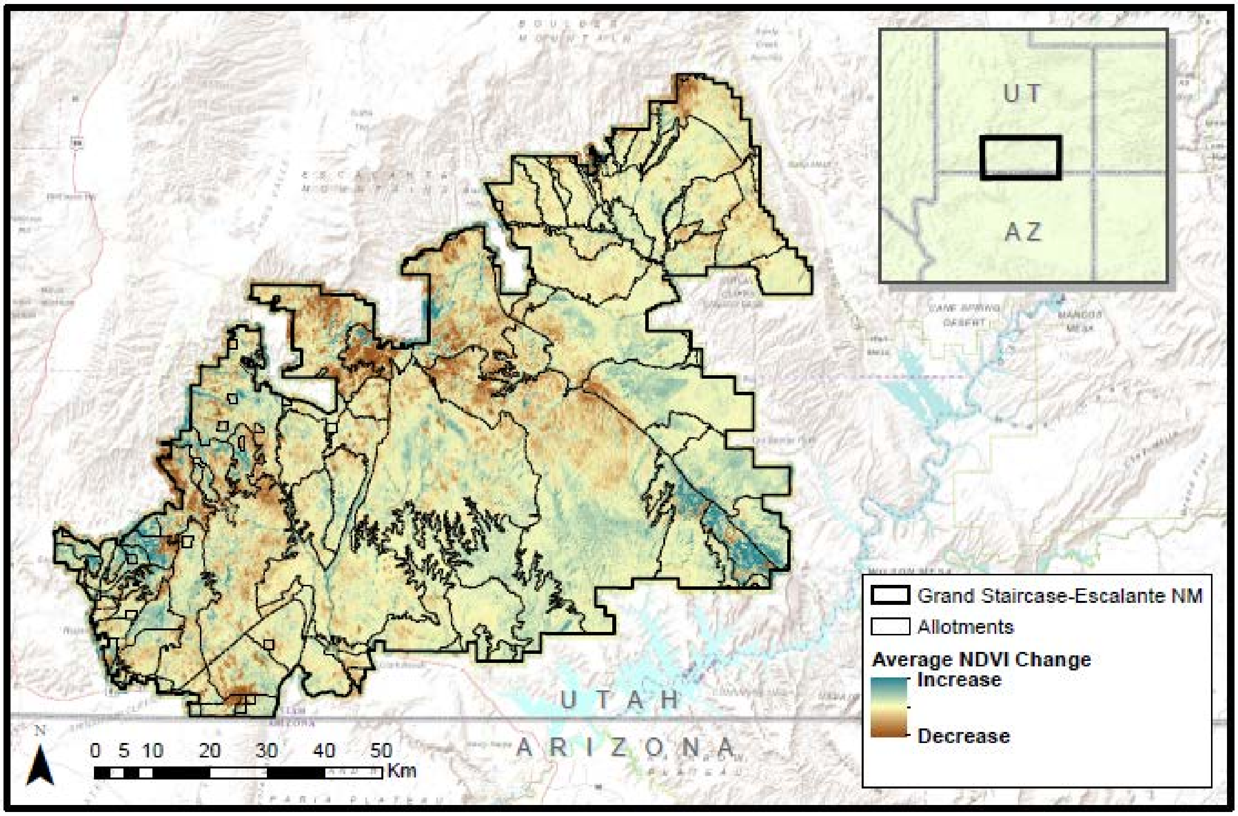

FIGURE 1 – Average change in Normalized Difference Vegetation Index (NDVI), a surrogate for vegetation productivity, from 1986-2011. Change is based on the difference between 10-year averages (1986-1995 and 1992-2011), and green values show an increase in productivity over this period while brown values show a decrease in productivity over this period.

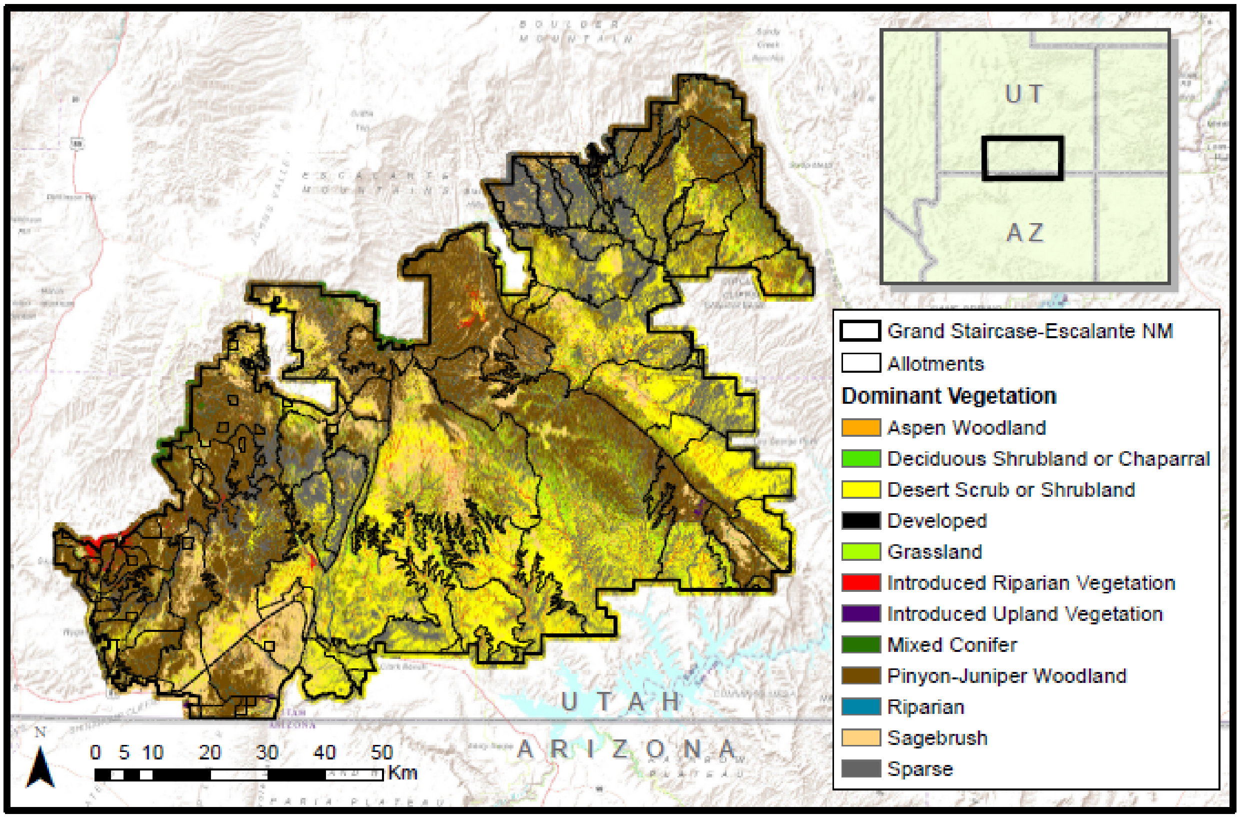

FIGURE 2 – Dominant vegetation types for the Grand Staircase-Escalante National Monument, based on a consolidated vegetation classification from Society of American Foresters (SAF) and Society for Range Management (SRM) available from the LANDFIRE data depository for the most recent year of 2010. Each allotment was either a majority of pinyon-juniper woodland, sparse vegetation, desert scrub and shrubland, sagebrush, or riparian vegetation.

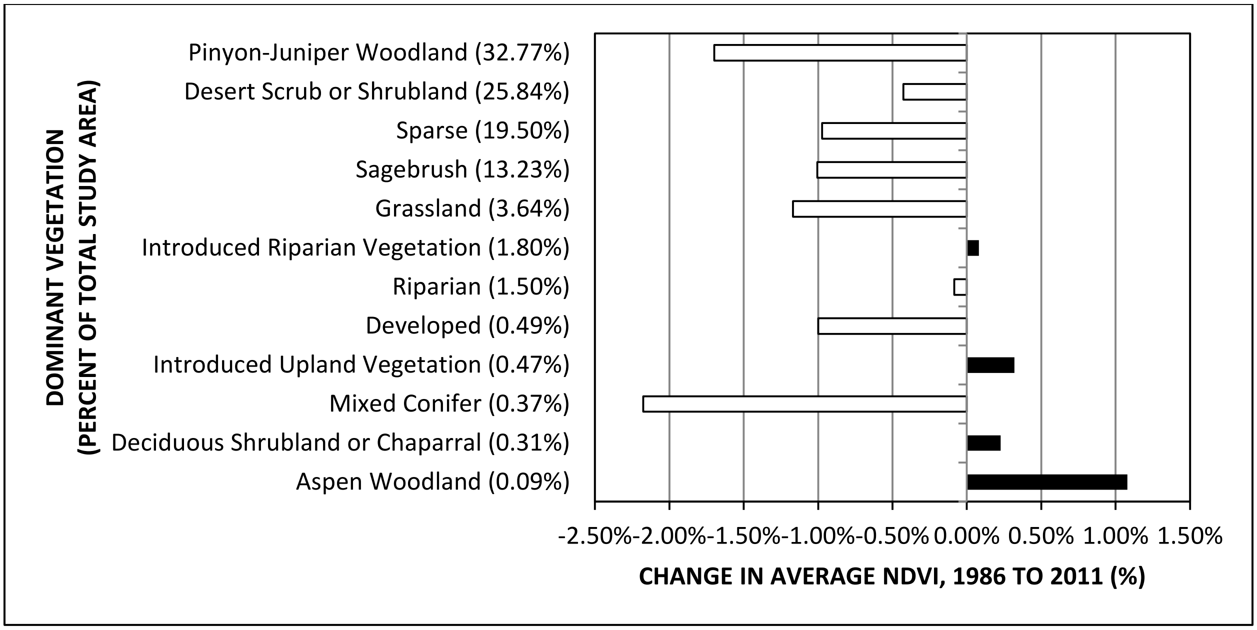

FIGURE 3 – Average change in Normalized Difference Vegetation Index (NDVI; a surrogate for vegetation productivity) from 1986 to 2011 based on the difference between 10-year averages (1986-1995 and 1992-2011) and averaged across each vegetation type. Results are listed by percent of total study area represented by that vegetation type, ordered from largest to smallest. Vegetation types were classified based on a consolidated vegetation classification from Society of American Foresters (SAF) and Society for Range Management (SRM) available from the LANDFIRE data depository for the most recent year of 2010. Average change in NDVI is represented as relative to the original, i.e., as a percent to the 1985 to 1995 10-year average value.

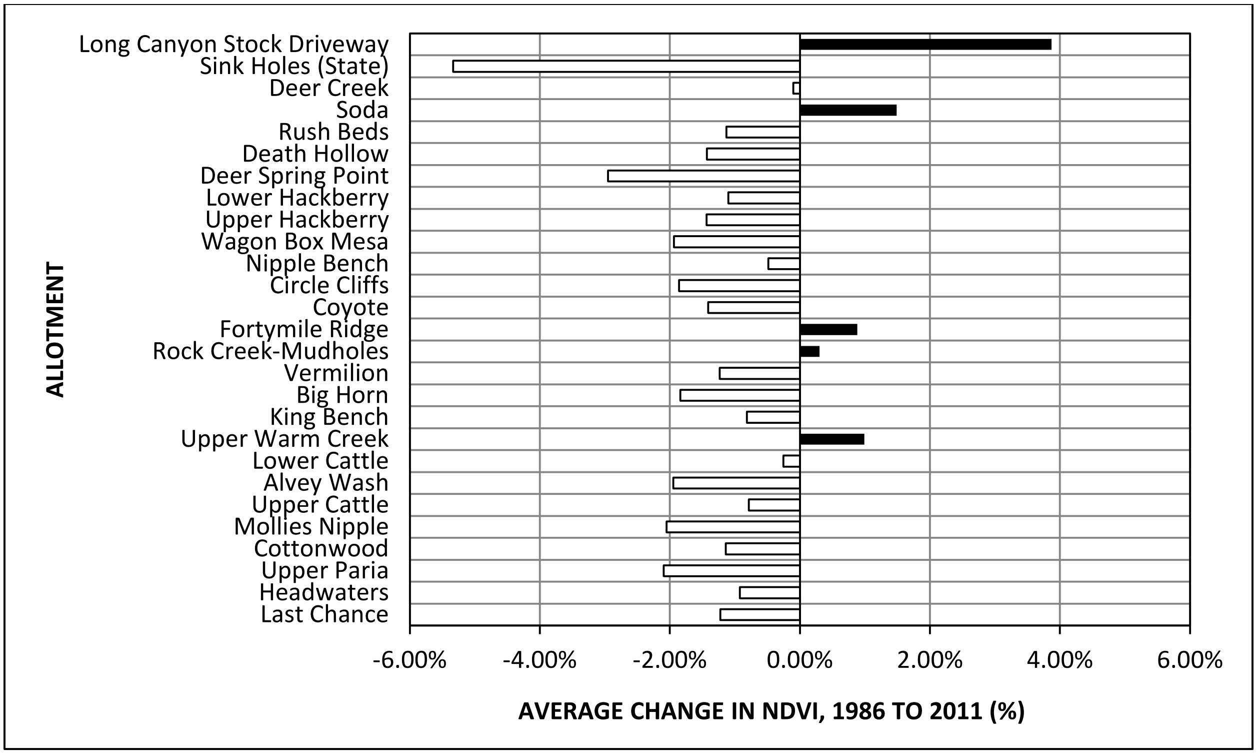

FIGURE 4 – Average change in Normalized Difference Vegetation Index (NDVI); a surrogate for vegetation productivity) from 1986 to 2011, based on the difference between 10-year averages (1986-1995 and 1992-2011) and averaged across each allotment. Only the 25 (out of 103) allotments with the largest areas are displayed in this figure along with the two allotments with the largest decrease and largest increase in NDVI. Allotments are ordered first by largest increase [Long Canyon Stock Driveway], then by largest decrease [Sink Holes State], and then by smallest to largest area.