



Identifying the appropriate spatial and temporal scales to address sustainable management of drylands: a US Tribal lands case study

Washington-Allen, RA¹; White, CD¹; Gilbert, W¹; Emanuel, RE²; Louhaichi, M³

¹ Dept. of Agriculture, Veterinary, and Rangeland Sciences, University of Nevada-Reno, Reno, Nevada, USA; ² Nicholas School of the Environment, Duke University, Durham, North Carolina, USA; ³

International Center for Agricultural Research in the Dry Areas (ICARDA), Tunis, Tunisia ...

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Abstract

There are 234 indigenous tribes within 225,365 km² of tribally managed drylands within the conterminous United States of America (USA). A national report on the carbon dynamics of US Tribal drylands argued that a knowledge gap existed for these dynamics in drylands because data, publications, and research were nonexistent. However, carbon stocks of Tribal lands have been implicitly studied, and a few explicit studies have used poor experimental design to produce questionable results. We explicitly address the carbon dynamics knowledge gap by defining Tribal dryland extent using the aridity index (AI) and a time series of Moderate Resolution Imaging Spectroradiometer (MODIS) 250-m pixel resolution net primary productivity or NPPM250, g C m⁻² yr⁻¹ from 2001 to 2019 of US drylands. We compared the 19-year mean NPP of the rangeland and cropland land uses within the tribal, public, and private land ownerships within their shared ecoregions. We compared the ecological resilience of tribal and non-tribal rangeland's NPP in response to the 2002 global change-type drought. We mapped aridity thresholds associated with land degradation and used the thresholds to identify tribal lands vulnerable to increasing aridity. We conducted these analyses at multiple scales using open-source GIS software, including Google Earth Engine (GEE) and QGIS. We found that Tribal rangeland and cropland land uses had greater productivity than non-tribal drylands. We found that Tribal rangelands had greater ecological resilience in the face of a global change-type drought than non-tribal drylands. However, we also found that with increasing aridity, 86% of the Tribal land area exhibits potential vulnerabilities that include declines in food security, species richness, canopy cover, productivity, and soil fertility. These potential vulnerabilities suggest the need for complementary field and remote sensing studies to determine the integrity of these predictions.

Introduction

Drylands are defined as the 30-year mean aridity index (AI) (1970 – 2000) = mean annual precipitation (MAP) / mean annual potential evapotranspiration (MAPET, Zomer et al. 2022). Carbon dynamics in Drylands are a large source of uncertainty in global carbon budgets that have estimated US dryland carbon sinks at 0.13 Pg C yr⁻¹ (Houghton et al. 1999). Drylands within the conterminous US support 234 federally recognized Tribal Nations, including 25 Tribes that are partially within and 209 that are fully within drylands. Herein, we address two propositions of carbon dynamics in Tribally controlled drylands of the United States:

- Proposition 1 (P1): a key finding of the US Global Change Research Program in the US Second State of Carbon Cycle Report stated that "... scientific data and peer-reviewed publications that pertain to carbon stocks and fluxes on Indigenous (native) lands in North America are virtually nonexistent, which makes establishing accurate baselines for carbon cycle processes problematic." (McCarthy et al. 2018).
- Proposition 2 (P2): A study by Robinson et al. (2019) addressed P1's concerns by comparing the NPP of Tribal, Private, and Public land ownerships within US drylands and concluded that privately owned land was more than twice as productive as Tribal and Public lands and thus the most sustainable type of land ownership. A re-analysis of this study's ecoregion X land ownership stratification found that the productivity of Tribal lands was comparable to privately owned lands and had greater NPP than public lands (Washington-Allen and Emanuel 2020).. However, land ownership is neither a valid experimental unit nor treatment as it lacks uniform and low variance at the landscape spatial scale, and it has no agency. Public lands in US drylands are managed by multiple federal agencies and contain multiple land uses, including cropping, mining, forestry, commercial grazing, and conservation reserves, e.g., national parks. Consequently, the experimental unit should be the intersection of land ownership with individual land-uses, e.g., rangeland and cropland by ecoregions. These experimental units will have low variability and be highly homogenous.

Methods

Comparison of Land Use across Ownerships

We assembled a GIS database of publicly available datasets that included the Protected Areas Database of the U.S. that provides polygons with public, private, and tribal attributes of land ownership. The Global Aridity Index provides aridity index values as means throughout 1970 to 2000. The National Land Cover Database (NLCD) provides land use and land cover across the USA between 2001 and 2016. We addressed P1 by acquiring and intersecting with the previously mentioned GIS datasets, the 250-m pixel resolution Moderate Resolution Imaging Spectroradiometer (MODIS)-derived NPP_{M250} dataset from 2001-2019 (Robinson et al. 2018). This dataset explicitly shows annual carbon uptake from photosynthesis in $g\ C\ m^{-2}\ yr^{-1}$ on Tribal lands at local to global spatial scales.

We addressed P2 by following a recommendation by (McCarthy et al. 2018) to conduct estimates of carbon cycle impacts on tribal lands by comparing **with practices on similar non-tribal lands, i.e., we stratified land ownership by ecoregions and land use**. We followed the procedures by Robinson et al. (2019), but rather than comparing land ownerships, we compared the NPP of the rangeland and cropland land uses within the three land ownerships using the National Land Cover Database's (NLCD) discrete time series. We show the result for the rangelands land use that composed 40 of 55 shared ecoregions (Fig. 1). The cropland's land use was composed of 33 of 56 shared ecoregions.

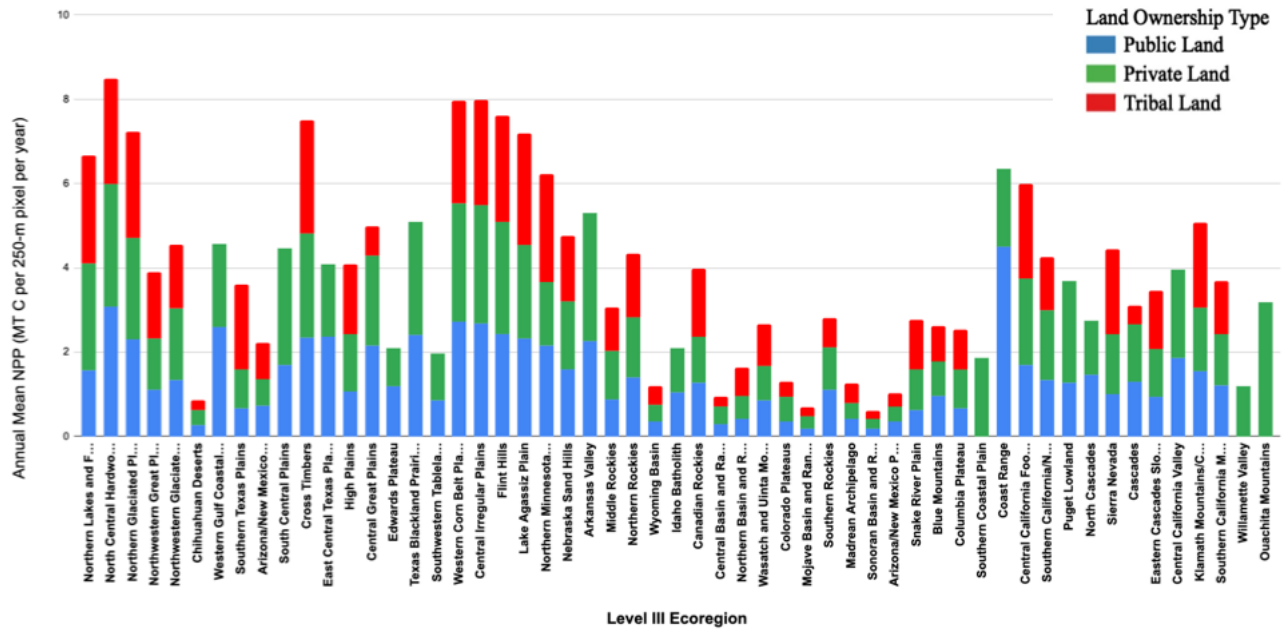


Figure 1. Comparison of NPP for three land ownerships that were stratified by EPA ecoregions and treated by the rangeland land use., i.e., grazing by commercial livestock.

Ecological Resilience

Ecological resilience is the pace, pattern, and recovery of an ecosystem in response to disturbance(s). It can be quantified in terms of amplitude, which is the threshold or magnitude of change in an ecosystem attribute, e.g., NPP over time in response to a disturbance, using a remotely sensed vegetation index change detection method. For example, in equation (1) below we calculate amplitude (the subscript A) using the 2001 MODIS NPP_{M250} versus the 2002 MODIS NPP_{M250} (the subscript D):

$$|\Delta NPP_{ijA}| = NPP_{ijR} (2001) - NPP_{ijD} (2002) + c \tag{1}$$

The 2002 US drought was labeled a global change-type drought, because it led to major tree die-offs across the southwestern US (Breshears et al. 2005). The 2001 and subsequent scenes are the year before a disturbance or the reference year (the subscript R), and c is the error of uncertainty in the registration of scenes. The results of this change detection are that critical vegetation resources that “do not change” or are “increasing” in the face of drought or other disturbances are located and identified, i.e., the ecologically resilient resources are spatially identified (Washington-Allen et al. 2008).

Vulnerability to increasing Aridity

Berdugo et al. (2020) studied the response of 21 variables to increasing aridity and identified three aridity thresholds (1 – AI) that delineated four system states or phases of decline, including a state we designated “no abrupt changes” (1 – AI < 0.54), a “vegetation decline phase” (aridity threshold: 1 – AI > 0.54) that included two correlated declining variables: the NDVI and photosynthetic activity, the “soil disruption phase” (1 – AI > 0.69) that comprised 12 declining soil attributes such as soil fertility and structure, and a “systemic breakdown phase” (1 – AI > 0.83) that included declines in 7 associated variables including an increase in the variability of rainfall and a reduction in plant cover that leads to increased soil albedo and leaf stress. We assessed the mean AI’s contemporary spatial distribution for these 4 aridity states within U.S. Tribal drylands for 30 years (1970 – 2000) using the time series developed by Zomer et al. (2022),. We used the ‘landscapemetrics’ package in R to determine the patch area of the four aridity states within U.S. Tribal drylands (Hesselbarth et al. 2019, Fig. 2).

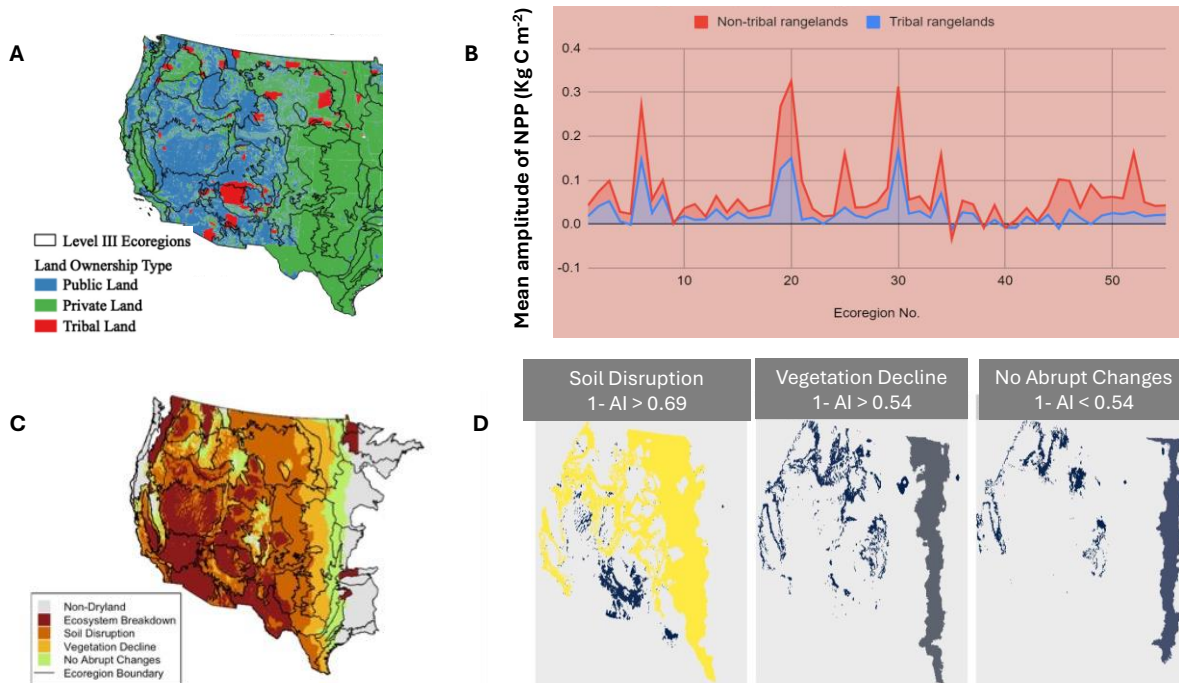


Figure 2. Comparison of the ecological resilience of tribal rangelds (in the red, A) to non-tribal rangelds (green and blue, A) where lower mean amplitude NPP values from 2001 to 2019 indicate greater resilience of tribal lands relative to the 2002 global change type drought (B). Application of the aridity thresholds to current conditions suggests the potential level of vulnerability of tribal land to increasing aridity (C). Green areas in C are stable, with the majority of tribal lands in drylands, spatially trending towards "systemic breakdown" of 18% of the tribal lands (C).

Results

Comparison of Land Use across Ownerships

We found that the rangeland land use for the 234 Tribes in Drylands had greater productivity in 21 of the 40 shared ecoregions compared to public (4/40), and private (15/40) lands (Fig. 1). We found that the cropland land use had greater productivity in the shared ecoregions (15/33) than public (7/33) and private (11/33) lands.

Ecological Resilience

In the face of the 2002 climate-change drought, Tribal rangelds had greater ecological resilience, when quantified as amplitude, than non-tribal rangelds, i.e., public and private lands (Fig. 2B).

Vulnerability to increasing Aridity

We determined that 1,467,862 ha (14%) of Tribal lands were in the "no abrupt changes" phase (green in Fig. 2C and D), 2,950,288 ha (29%) were in the vegetation decline state (Fig. 2D), 4,020,931 ha (39%) were in the 'soil disruption' state (Fig. 2D), and 1,796,894 ha of tribal lands (18%) were in the highest vulnerability category of "ecosystem breakdown" (Figure 2C).

Conclusions/Implications

We found that across the majority of the shared ecoregions, Tribal rangeland, and cropland land uses had higher productivity than Public and Private drylands and that this productivity made the rangelds more ecologically resilient in the face of a global change-type drought. However, in the face of increasing aridity, 86% of the Tribal land area potentially exhibits threats to livestock and human nutrition and food security, including sharp declines in species richness, canopy cover, productivity, soil fertility, and increases in woody encroachment, and albedo.

These potential vulnerabilities suggest the need for complementary field and remote sensing studies to determine the integrity of these predictions.

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