Ecological catastrophes: threshold responses to climate, soil, and land use drivers of the Dust Bowl

Stacey L. Peters Scroggs[1], Debra P.C. Peters[2] Kris M. Havstad[2], Curtis Monger[3], Dana M. Blumenthal[4], Justin D. Derner[5], Scott L. Kronberg[6], Brian K. Northup[7], Gregory S. Okin[8], Matt A. Sanderson[9] and Jean Steiner[7]

(1) Jornada Basin LTER, New Mexico Stste University, Las Cruces, NM, (2) Jornada Basin LTER and Jornada Experimental Range, USDA Agricultural Research Service, Las Cruces, NM, (3) Plant and Environmental Sciences, New Mexico State University, Las Cruces, NM, (4) USDA-ARS, Fort Collins, CO, (5) USDA ARS, High Plains Grasslands Research Station, Cheyenne, WY, (6) USDA, ARS, Northern Great Plains Research Laboratory, Mandan, ND, (7) Grazinglands Research Laboratory, USDA-ARS, El Reno, OK, (8) Department of Geography, UCLA, Los Angeles, CA, (9) Northern Great Plains Research Laboratory, USDA-ARS, Mandan, ND

(contact: stpeters@nmsu.edu)

Introduction and hypotheses

The Dust Bowl was one of the world's largest environmental disasters, yet it is among the least well-studied for landscape- to regional-scale ecological impacts. In the 1930s, much of the central grasslands region (CGR) of North America experienced a multi-year drought. Combined with spatially-extensive cultivation and overgrazing, the drought led to broad-scale plant mortality, massive dust storms, and decreases in continental-scale air quality. These impacts were collectively called the "Dust Bowl". Although regional accounts exist, most studies focus on effects of abandoned agricultural land in a relatively small area centered on the panhandle of Oklahoma (Fig. 1: purple circle). However, these impacts were also documented on intact grasslands throughout the Great Plains. A recent synthesis of these data show spatial variation across the region: high grass mortality occurred throughout the western and central Great Plains (Fig. 1 black dots, pink areas) whereas only reductions in grass cover primarily occurred in the east (Fig 1: blue dots). A 145-km transition zone was found in the tallgrass prairie between high plant mortality near Crete, NE compared with cover loss without mortality near Glenwood, IA (Fig. 1: yellow line). Understanding the drivers of this variation in grass response is important to predicting dynamics of this region under future long-term drought and occurrence of dust storms.

Our goal was to determine the environmental variables correlated with this dramatic change in vegetation in response to the 1930s drought along a short spatial gradient.

We hypothesized that spatial variation in grass response during the drought (1930-1935) can be explained by one or more of the following environmental variables:

- annual precipitation
- annual average maximum or minimum air temperature
- soil texture (% sand, silt, clay)
- two variables that integrate climate and soils
  - Palmer Drought Severity Index (PDSI)
  - soil water available to plants

Because the vegetation data were collected between 1930-1935, we focused on climate data from those years as well as long-term trends.

Dust storm in Stratford, TX April 18, 1935 (NOAA George E. Marsh Album)

Dust storm in the Midwestern United States on April14, 1935, also known as Black Sunday. (Kansas Historical Society)

Haboob in Phoenix July 2012 (Andrew Pielage)

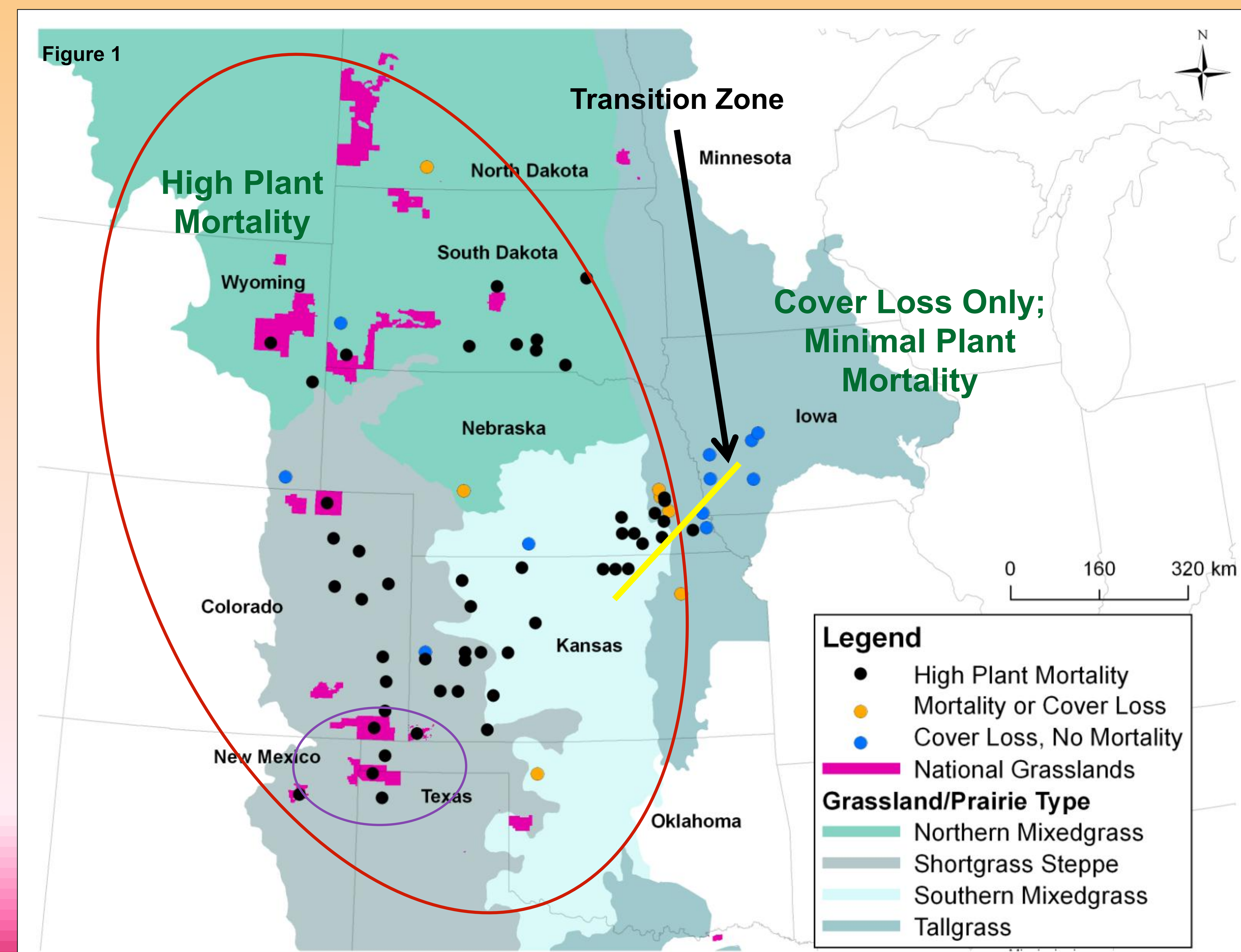
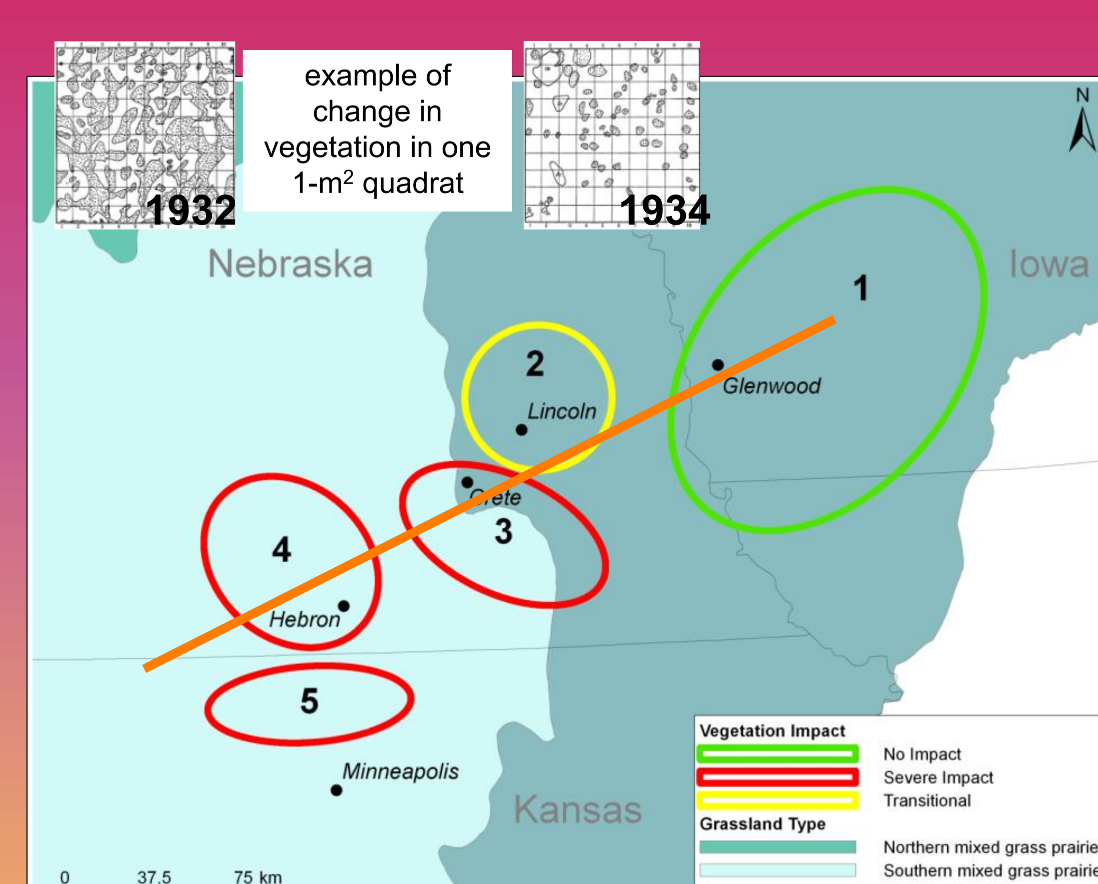
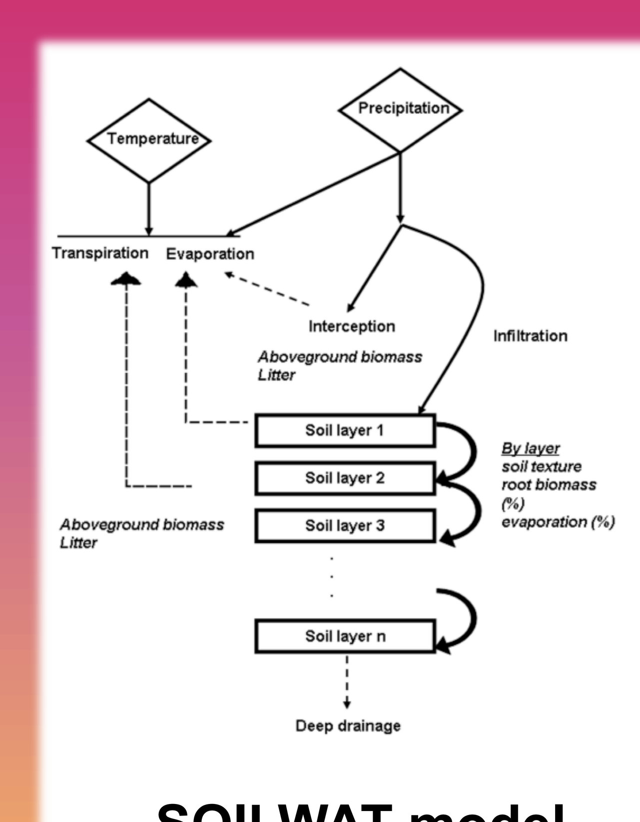


Figure 1. Plant mortality status in the central grasslands region from 1930-1940.

Data sources and process-based modeling

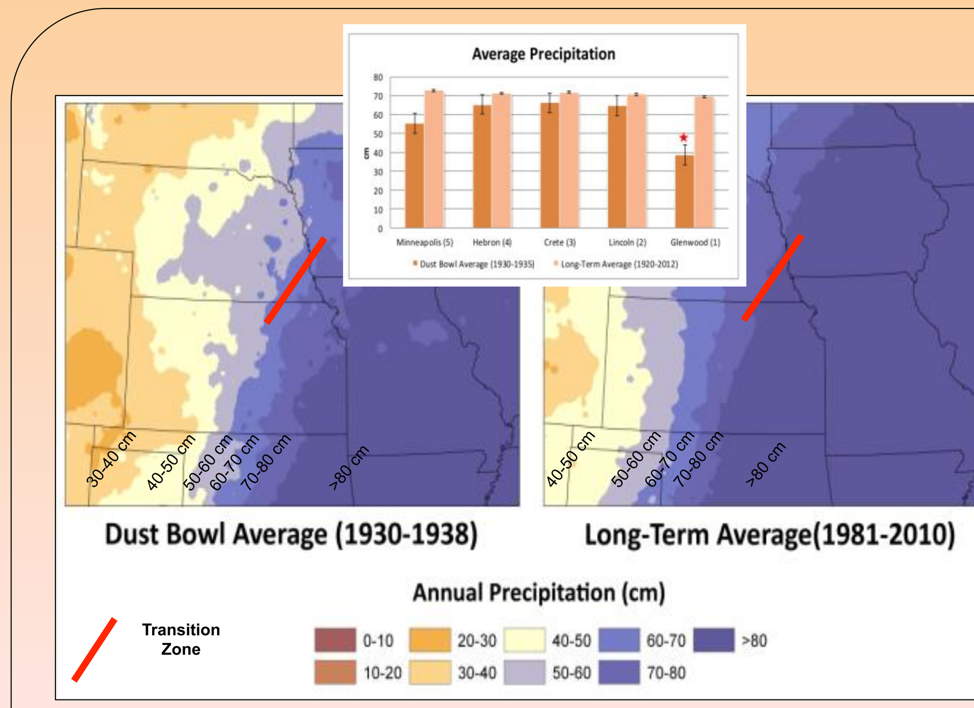
Vegetation data on 1-m^2 quadrats were available from the literature for five locations along the transition zone that included mixedgrass and tallgrass prairie (Albertson and Weaver 1936). Daily precipitation and temperature data were obtained for one town in each location from the National Climate Data Center (http://www.ncdc.noaa.gov/). Towns were selected based on the availability of data for the entire 1930-2012 period. Historic soil texture data (pre 1930) by depth for each quadrat sample location were obtained from Soil Conservation Service soils maps and text documentation. Overlaying the quadrat locations with the soils maps allowed us to identify a soil type for each grassland location. Based on these maps, we examined explanatory variables for three soil types (loam, silt loam, silt clay) in all five locations. We integrated climate and soils for each soil type in each location in two ways. First, the PDSI was calculated using monthly climate data that were averaged for each year. Second, the daily data were used to parameterize a process-based model (SOILWAT) to simulate daily soil water dynamics, including plant available water, that were averaged for two soil layers (0-10cm, 10-20cm) in each year.

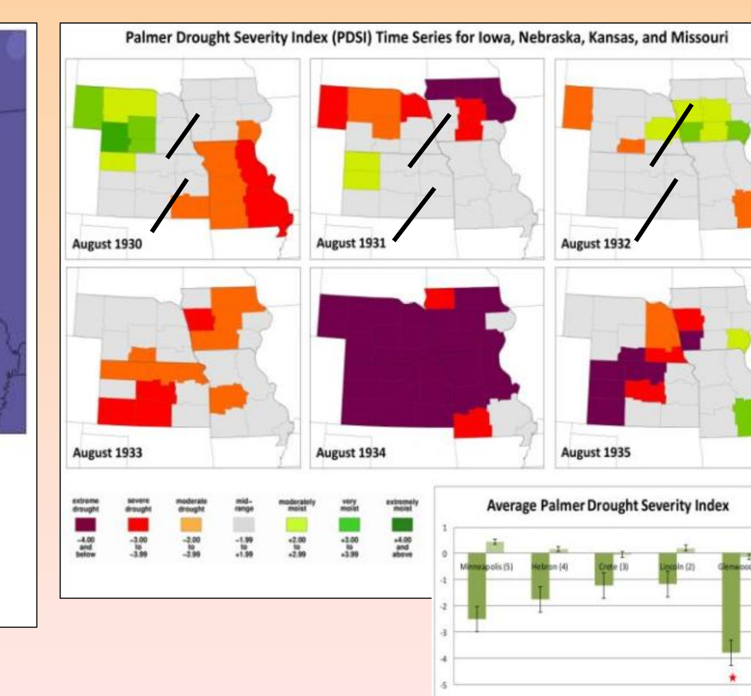


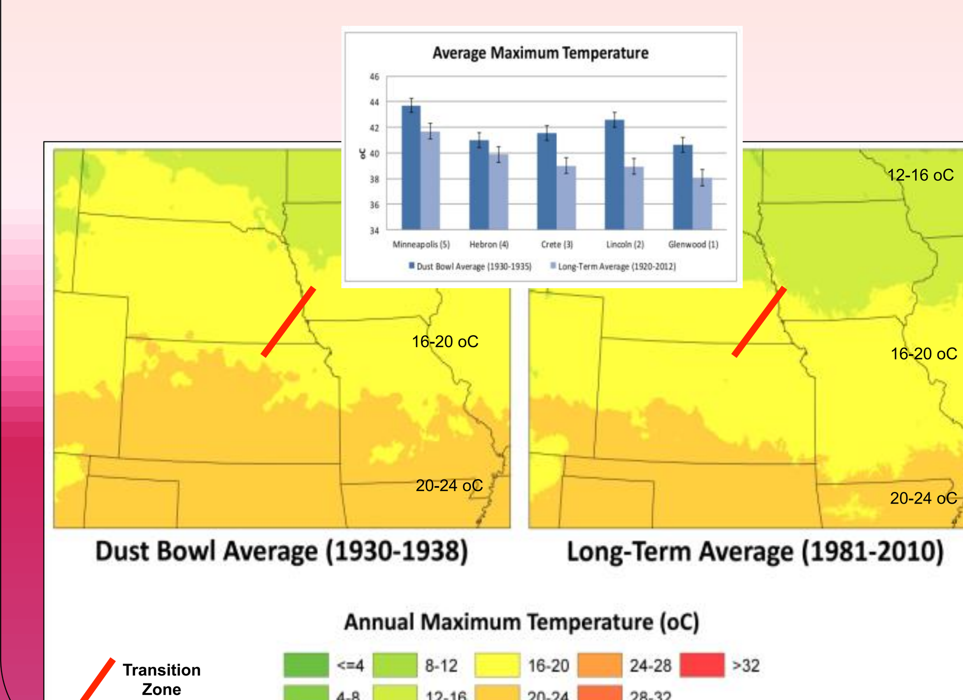


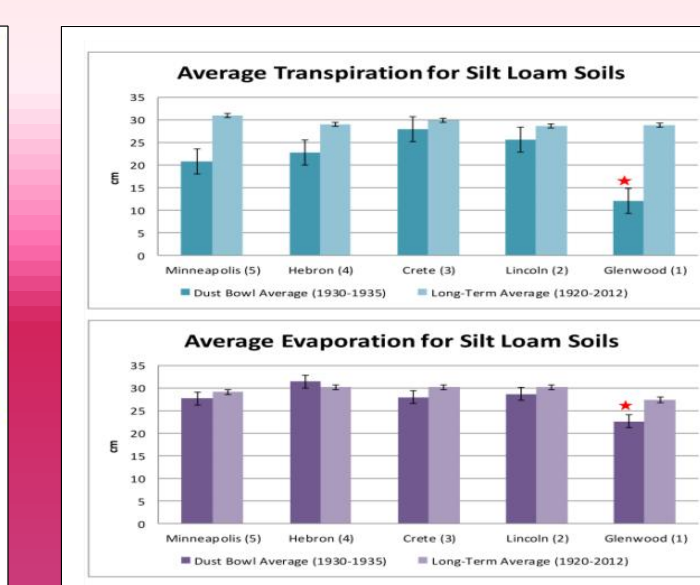
Results

Our results show that the transition between high grass mortality in SE Nebraska and cover loss without grass mortality in SW Iowa is not explained by spatial variation in precipitation, temperature, drought indices, or soils. In fact, Iowa had lower precipitation and more severe drought compared with locations in Nebraska during the 1930-1935 period of vegetation sampling. Integrating climate and soil properties in SOILWAT resulted in lower plant available water (transpiration) that should have led to increased plant mortality in the Iowa grasslands compared to Nebraska. Similar results were found for silt clay and loam soils. Because these results are opposite of observations, additional explanatory variables need to be considered, such as intra-annual timing and amount of precipitation and temperature as well as wind speed, that can influence soil water available to plants.









Conclusions

Given that extreme climatic events are expected to increase in the near future, an improved understanding of historic events is critical to predicting impacts of future catastrophes. Drivers of spatial patterns in cover and mortality during the Dust Bowl remain a mystery, such that more research is needed to determine the relationships among climate, soil properties, and ecological responses.

Literature Citations

- Albertson, J.E. and Weaver, F.W. 1936. Effects of the Great Drought on the Prairies of Iowa, Nebraska, and Kansas. *Ecology* 17(4): 567-639.
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