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Using satellite imagery to compare land cover and water resources in two counties of the Nebraska Sandhills

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Abstract

The Nebraska Sandhills comprise the most intact grassland habitat in the world and 95% of land use consists of low intensity cattle grazing. Water is a key resource for cattle and for growing hay forage in this semi-arid grassland. Ranchers rely on either naturally occurring wet meadows or center pivot irrigation systems (CPIS) to produce hay. With the possibility of climate change creating more frequent extreme weather events, more flooding events or severe droughts could affect land and water resources in the Sandhills. With potentially more wet/dry extremes in the future, an understanding of the way water resources respond, and the different strategies of landowners, will be important in assessing the overall resilience of the Nebraska Sandhills in the face of a changing climate.

We compared two adjacent, similarly sized, counties, Grant and Hooker, in the central Sandhills that differ in the amount of naturally occurring, ground water-fed meadows during the period 2002-2019, spanning wet and dry years. ArcGIS and the USDA's Cropland Data Layer (known as "CropScape"), an annual, satellite imagery-derived, land cover map, were used to quantify overall landcover, especially the cover of wet meadows and the number of CPIS.

In 2016, an average-to-moderate precipitation year, Grant County had approximately 10 times more open water area and 9 times more wet meadow area than Hooker County. In contrast, Hooker County had 19 times more barren ground area and nearly twice as many CPIS as Grant County. Furthermore, in drought years, the amount of barren ground increased in both counties, nearly doubling in Hooker County in 2006, a year when annual precipitation was only 66% of normal precipitation rates. Drought also increased the acreage devoted to irrigated crops, particularly in 2006 in both counties, with nearly two times as many acres in Grant County and nearly five times as many acres in Hooker County. Additionally, open water acreage decreased by nearly 50% following the 2006 drought and wetland cover types increased.

This analysis showed that different Sandhill counties have contrasting water resources, with an abundance of naturally occurring wet meadows in Grant County, whereas Hooker County has fewer wet meadows and more CPIS. Furthermore, our analysis suggests that the landscape changes during drought years, with a decline in wet meadows, an increase in barren ground and an increase in CPIS and other irrigated systems for crops. In a changing climate, with potentially more extremes in precipitation, the diversity of strategies exemplified by these two counties will be important to inform adaptative responses. Overall, this research will contribute to a better understanding of the sustainability of land use and the future of groundwater resources in the Nebraska Sandhills.

Keywords: Nebraska Sandhills, land cover, CROPSCAPE, water resources, drought, ground water, ranching, hay meadows

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Introduction

The Sandhills comprise a unique ecoregion in north central Nebraska (Fig. 1) and one of the world's largest grass-stabilized, sand dune landforms (Bleed and Flowerday 1998). The landscape is one of undulating, large dunes, with lush wetlands, meadows, and lakes in the valleys (Fig. 2). This dune region is underlain by one of the largest below ground aquifers in the world, the High Plains (Ogallala) Aquifer. This ecoregion is a key area where the eight-state aquifer is "recharged" by water that moves through the sand dunes until it reaches the saturated layers that form the aquifer.

Due to the unstable, sandy soils and semi-arid climate, most of the Sandhill region is unsuitable for row crop agriculture and instead, about 95% of the region is used for grazing livestock. In a recent analysis by Scholtz and Twidwell (2022), the Sandhills ranked number one in the degree of "intactness" compared to all other temperate and tropical grasslands on earth. Ranching, as a low

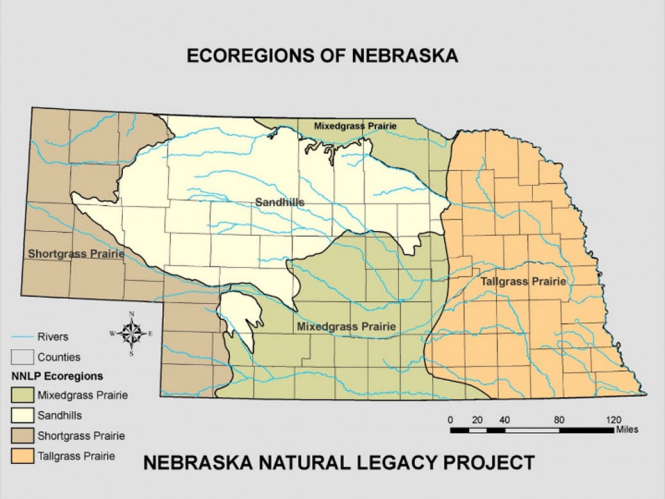


Figure 1: Ecoregions in Nebraska. The Sandhills region is in north-central Nebraska, shown in tan color (Nebraska Invasive Species Program).

intensity land use on large parcels, can contribute to intact landscapes and be consistent with wildlife habitat and biodiversity conservation (Schneider et al. 2012), but also requires water for both animals and forage production. Since groundwater is such a key resource in the Sandhills, and intimately connected to the region's primary land use of livestock production, it is important to understand how groundwater is used and how it changes in different parts of the Sandhills. In addition, the groundwater resource represents a key factor in the sustainability of the ranching economy in this region because it provides water in a relatively dry grassland and may imbue the region with enhanced resilience under extreme climate or drought conditions (Vinton and Larsen, 2022).

Land use and land cover change (LULCC) research helps observers better understand how ecosystems change through time and how factors such as climate

Figure 2: A typical landscape consists of grass-stabilized sand dunes, interspersed with wetlands, meadows, and lakes in the Nebraska Sandhills. Photo shows the Rosebud Lake system (looking west), on the headwaters of the north fork of the Dismal River in Hooker County, Nebraska

Figure 3: Grant and Hooker counties in the Sandhills of Nebraska. More obvious dune-valley topography exists in Grant County, with more interdunal wetlands (green) and lakes than in Hooker County. Round, green center pivot irrigation features are more numerous in Hooker than Grant County. Also visible in Hooker County are the north and south headwaters of the Dismal River, as well as light colored, bare sand areas. Images are derived from Sentinel data from May 2020.

and economic factors drive patterns in human land use. An analysis of Landsat imagery from 1973 to 2000 quantified LULCC in the Sandhills region and showed little overall change in land cover types over this time period, especially in comparison to other grassland ecoregions (Taylor 2015). The stability of land use probably reflects the fact that stabilized sand dunes cannot easily be converted to row crops and instead livestock grazing and hay production remain as consistent and dominant land uses from year to year. Interestingly, the changes that Taylor (2015) observed were attributed primarily to the adoption of center pivot irrigation systems (CPIS) as row crop commodity prices were high in the 1970s, and the subsequent abandonment of CPIS in the Sandhills when it became clear that sandy or high ground-water areas turned out to be unsuitable for CPIS. Taylor (2015) also notes a shift from wetland to open water, attributed to more rainfall from 1973-2000, a trend that has continued to present day as evidenced by water-related road closures in the Sandhills (Hammel 2019).

Our research focused on detecting the extent and change in land cover types, surface water and irrigation systems within two contrasting counties in the Nebraska Sandhills from 2002-2019, a period that includes both dry and wet years. We chose to use "counties" as a unit because county-level patterns in land cover types are reported by the USDA's National Agricultural Statistics Service, "CropScape", based on Landsat imagery (USDA). Further, even though counties are an administrative boundary, in this case, a sharp contrast exists in a key natural feature. Grant County, with more dune-valley relief, has more naturally occurring lakes and wetlands in the valleys than does Hooker County (Fig. 3). This difference may dictate contrasting strategies of land management in the two counties and help describe the range of adaptation strategies to climate extremes in the Sandhills.

Our overall hypothesis is that LULCC would be related to precipitation. Specifically, open water cover would decrease in periods of drought but would increase in periods of above average precipitation. We expected the use of CPIS to increase after sustained periods of drought when land managers either construct them or shift existing ones into service in order to have a reliable source of hay during dry periods. Finally, we expected barren ground to increase in years of drought and decrease in years of above average precipitation. How these responses play out in contrasting counties was also of interest; for instance, the larger cover of naturally occurring open water and wetlands in Grant County may lessen a shift to CPIS when compared to Hooker County.

Methods

We selected two similarly sized counties, Grant and Hooker, in the central Nebraska Sandhills for our analysis. Grant County, with more dune-valley relief, has more naturally occurring lakes and wetlands in the valleys than does Hooker County (Fig. 3). Precipitation for 2002-2019 in Grant and Hooker County was collected from the PRISM Climate Group (https://prism.oregonstate.edu/). Through spatially interpolating the data from existing meteorological stations, the PRISM Climate Group yields point-based estimates and county-wide averages of climate variables for counties (Daly et al. 2008).

To classify years in terms of drought status, we used an analysis by Poděbradská et al. (2019). They used a model incorporating site potential, drought indices derived from climate data, and a satellite-derived, Normalized Difference Vegetation Index (NDVI) to analyze plant biomass in 2000-2016. They compared predicted versus actual amounts of biomass in order to classify years as dry, wet, or normal based on deviation from predicted amount of biomass (e.g., dry years had a lower actual biomass than predicted). Their analysis suggested that drought years in the Nebraska Sandhills were 2002, 2006, and 2012, whereas wetter than normal years were 2009, 2015, and 2016 (Poděbradská et al. 2019), which generally matches precipitation data from PRISM Climate Group (Fig. 4).

To quantity land cover types, we used the USDA's National Agricultural Statistics Service, 'CropScape.' CropScape is a Cropland Data Layer Program that estimates land cover types and acreage amounts based on Landsat imagery and data (USDA). The cropland data layers in CropScape can be used as effective tools to determine trends in agriculture. The CropScape classification technique was refined significantly in 2006, (Lark et al. 2017), so we began our analysis for most categories in 2006. For the grass-pasture classification, which comprises the majority of the landscape and was unlikely to be affected by

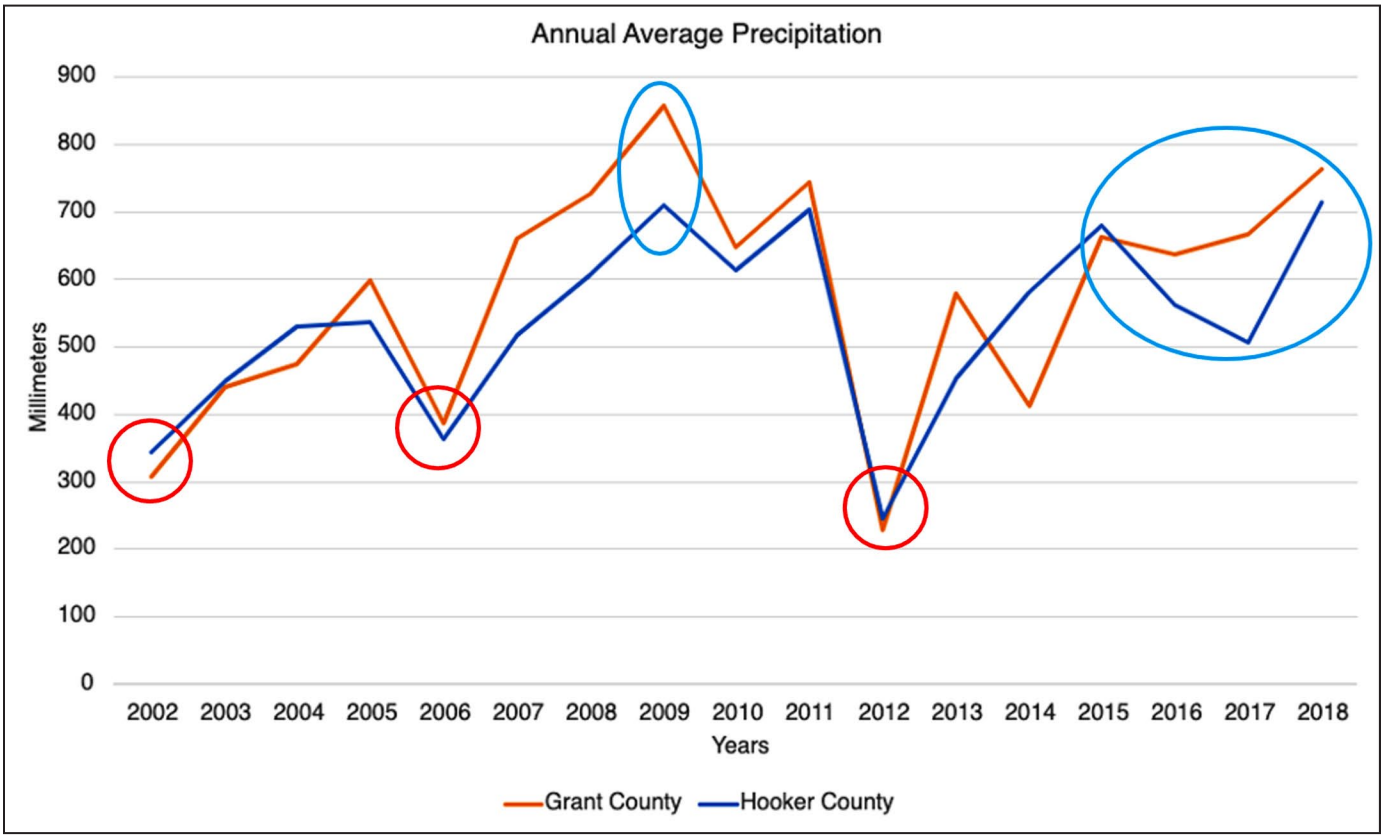


Figure 4: Annual average precipitation data, acquired from the PRISM Climate Group, in Grant and Hooker counties in the Sandhills of Nebraska. Years circled in red indicate drought events while the blue circles indicate wet years, using the analysis by Poděbradská et al. (2019).

the 2006 change in classification technique, we began our analysis in 2002.

We used the CropScape web interface (https://nassgeodata.gmu.edu/CropScape/) to select both Grant and Hooker County and generate the quantity of land in each land cover type for the years 2006-2019. To compare landcover of selected landscapes in the two counties, we calculated the mean area in Grant and Hooker County from 2006-2019 in open water, barren ground, grass/pastureland, irrigated crops, herbaceous wetlands, and woody wetlands. To detect relative change in landcover, we calculated the percent change from the mean over 2006-2019 for all of the land cover types of interest, as:

$$\frac{\text{Year Amount} - \text{Mean Amount}}{\text{Mean Amount}} \times 100$$

To study the potential of precipitation to influence land cover, we used R to perform a linear correlation. We report only the land cover types that showed statistically significant correlations, i.e., Grant County irrigated crop cover.

Results

Both Grant and Hooker County had grass/pasture as their major land cover type, comprising 91-96% of the total cover (Table 1). Barren ground was a minor cover type but can be ecologically significant as a signal of sand dune erosion and movement. Grant County had 9.6 times more open water and 43.5 times less barren ground than Hooker County (Table 1). Further, Grant County had more wetland cover than Hooker, with 11.1 times more herbaceous wetlands and 1.6 times more woody wetlands. Finally, Hooker County had 1.6 times more irrigated crop cover than Grant County (Table 1).

The counties had somewhat consistent changes in open water through time, with a general increase occurring over the past decade (Fig. 5). Open water percent change has been slightly more dynamic in Hooker than Grant County, probably because of the fact that Hooker has nearly 10 times less open water than Grant (Table 1). Open water declined, especially in Hooker Co. following the 2006 drought, whereas open water increased following the wet year of 2009 and has been increasing since the severe drought of 2012 (Fig. 5). The relatively wet period in 2015-2016 likely contributed to a general increase in open water, until 2019, when it declined again.

Hooker County tended to have increased barren ground since 2006, with noted increases immediately following the drought years of 2006 and 2012, whereas the wet years of 2015-16 were associated with declines (Fig. 6). Grant County shows an increase in barren ground during recent wet years (Fig. 6).

Grass/pastureland cover was more dynamic in Hooker than Grant County, with the droughts of 2002 and 2012 followed by large decreases in grass/pastureland cover in Hooker County (Fig. 7).

Like open water, herbaceous wetlands generally increased over the past decade in both Hooker and Grant County and show a strong increase in recent years (Fig. 8a). The only decline in herbaceous wetlands occurred in 2014 in Hooker County, possibly due to the after-effects of the severe drought of 2012. In contrast to herbaceous wetlands, woody wetlands showed a decline in both counties over the past decade, especially since 2012 (Fig. 8b).

Irrigated crop cover changed from 2006 to 2019 and with drought. The drought years, 2006 and 2012 coincided with large increases in irrigated crop cover in both counties (Fig. 9). Overall, there is a general decline in irrigated crops in these counties, perhaps due to an overall increase in precipitation in the region from 2002-2019 (Fig. 4).

Table 1: Total and percent area of selected landcover types in Grant and Hooker Counties in the Nebraska Sandhills, averaged from 2006-2019. Data were acquired from USDA database CropScape, a satellite imagery-based classification of landscape types (https://nassgeodata.gmu.edu/CropScape/).

County	Grant (km^2)	Hooker (km^2)	Grant (%)	Hooker (%)
Open Water	25.27	2.62	0.3	0.1
Barren Ground	0.04	1.74	0.002	0.1
Grass/Pasture	1857.39	1791.92	91	96
Irrigated Cropland	3.65	5.84	0.05	0.3
Herbaceous Wetlands	133.05	12.03	1.8	0.6
Woody Wetlands	3.60	2.20	0.05	0.1

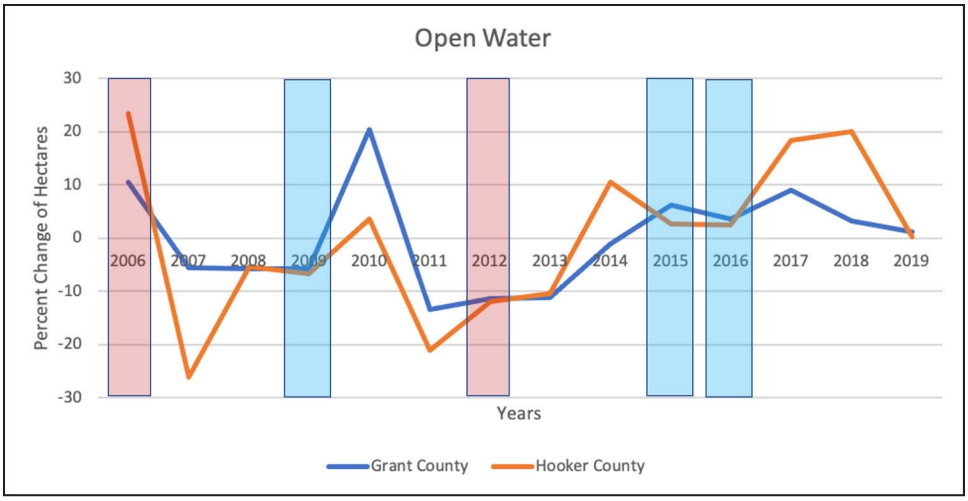


Figure 5: Percent change in open water area cover in Grant and Hooker County in the Sandhills of Nebraska from 2006 to 2019, derived from Landsat imagery classifications from USDA's CropScape. Red bars correspond to dryer than normal years and blue bars indicate wetter than normal years, according to an analysis by Poděbradská et al. (2019).

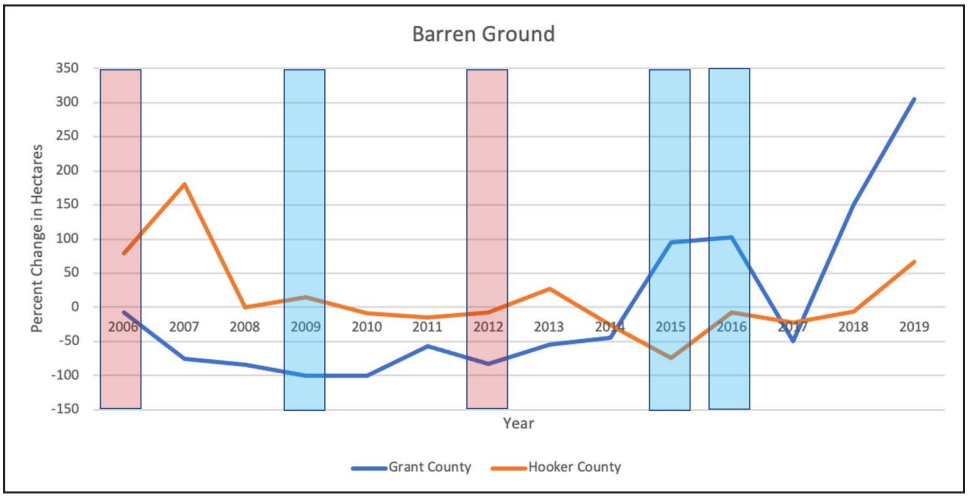


Figure 6: Percent change in barren ground area cover in Grant and Hooker County in the Sandhills of Nebraska from 2006 to 2019, derived from Landsat imagery classifications from USDA's CropScape. Red bars correspond to dryer than normal years and blue bars indicate wetter than normal years, according to an analysis by Poděbradská (2019).

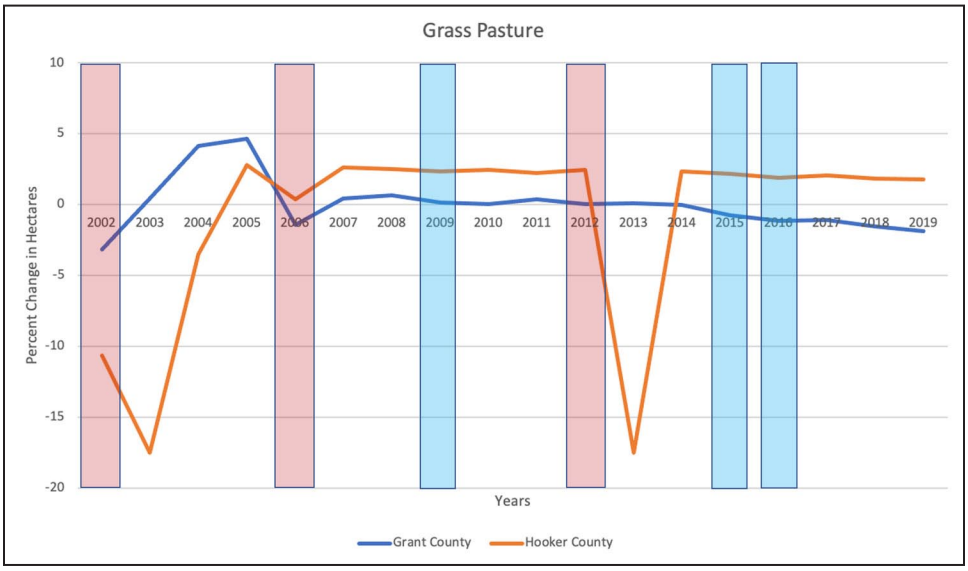
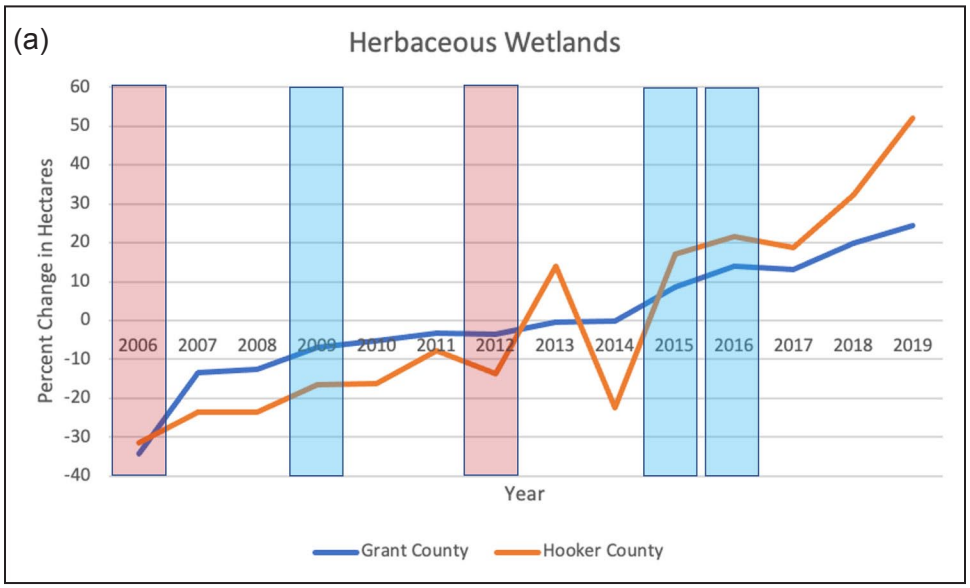


Figure 7: Percent change in grass pasture area cover in Grant and Hooker County in the Sandhills of Nebraska from 2006 to 2019, derived from Landsat imagery classifications from USDA's CropScape. Red bars correspond to dryer than normal years and blue bars indicate wetter than normal years, according to an analysis by Poděbradská (2019).



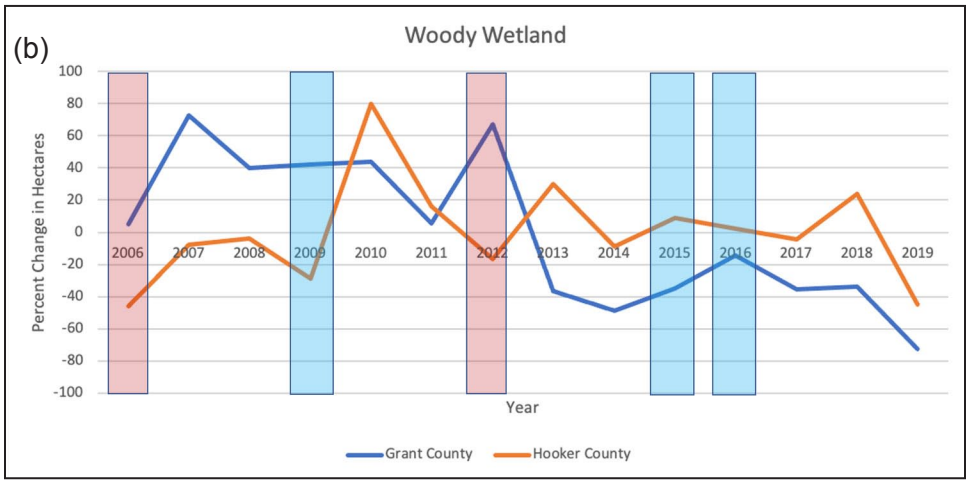


Figure 8: Percent change in herbaceous wetlands area cover (a) and in woody wetland cover (b) in Grant and Hooker County in the Sandhills of Nebraska from 2006 to 2019, derived from Landsat imagery classifications from USDA's CropScape. Red bars correspond to dryer than normal years and blue bars indicate wetter than normal years, according to an analysis by Poděbradská (2019).

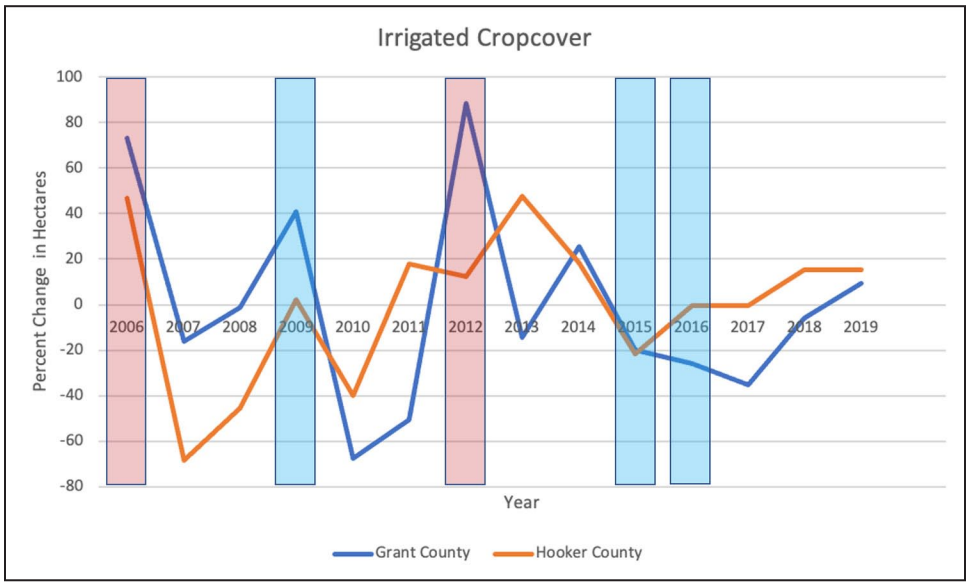


Figure 9: Percent change in irrigated crop area cover in Grant and Hooker County in the Sandhills of Nebraska from 2006 to 2019, derived from Landsat imagery classifications from USDA's CropScape. Red bars correspond to dryer than normal years and blue bars indicate wetter than normal years, according to an analysis by Poděbradská et. al (2019).

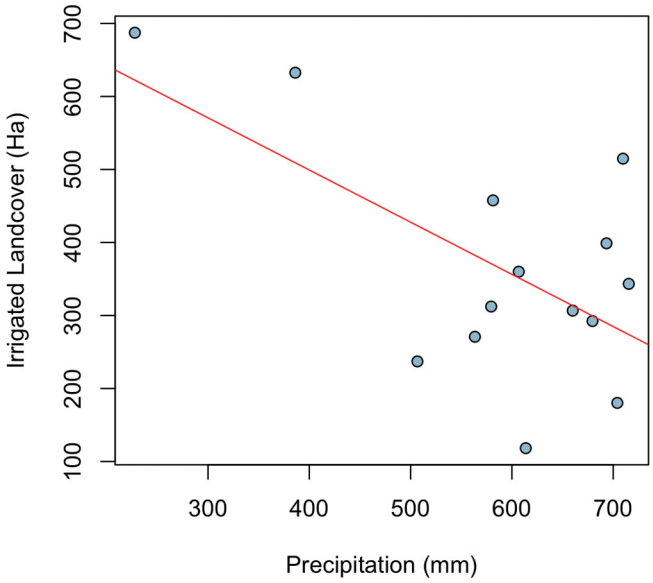


Figure 10: Relationship between irrigated landcover and precipitation in Grant County. Linear regression analysis showed a statistically significant relationship between irrigated landcover and precipitation (R^2 = 0.3728, p= 0.0204)

Much of the data shown in Figures 5-9 suggest that land cover responds to drought years and wet years. To further study the potential for precipitation to affect land cover, we correlated land cover with precipitation. Most land cover categories did not show significant correlations with annual precipitation. However, we did see a significant (p=.0204; R^2 = 0.3728) relationship in Grant County, with an increase in precipitation associated with lower amounts of irrigated crop cover (Fig. 10).

Discussion

We observed variation in water and landcover resources in the central Nebraska Sandhills from 2006 to 2019. Land cover patterns showed a clear difference between Grant and Hooker County, with Grant having more wet meadows and open water, whereas Hooker County had more CPIS. It is likely that in Hooker County, land managers must rely more on irrigation, outside hay/feed sources, and rangeland to support cattle whereas the wet meadows in Grant County can provide greater local hay sources. In a 2020 interview with 98-year-old resident, Frank Harding, of Mullen, NE, (Caroline Adrian, pers. comm.) he noted the Grant vs. Hooker County distinction, referring to Hooker County as "cake and range country". "Cake" in this context refers to pressed pellets of livestock food, often made from cotton seeds or other high protein material and used as a source of winter forage, especially in the absence of adequate hay.

Precipitation trends, drought and flooding events affect water resources and land cover types in the central Nebraska Sandhills. Some years (e.g., 2012) were very intense, but short-lived droughts while other droughts have been more prolonged (e.g., 2004-2006). In dry years, we observed more reliance on CPIS and more barren ground following these years (especially in Hooker County). Following wet years there were generally more open water hectares and a decreased land cover of CPIS. Changes in barren ground in Grant County may lack interpretable patterns due to the fact that this land cover type is so small (mean of 9 ha) in contrast to the 430 ha in Hooker County (Table 1).

Recently, the Sandhills has experienced wetter conditions and an increased amount of ground water rising to the surface, often resulting in problems with flooded hay meadows and road closures (Hummel 2019). The recent wet years have been associated with improved rangeland conditions and more productivity in uplands (Poděbradská et al. 2019). However, one of the unexpected trends we observed (the increase in "barren" ground in Grant County in recent wet years) might be due to standing water-induced death of plants in wet valleys. We have heard from ranchers in oral interviews associated with this project (Daniel Vinton, pers. comm.) that wet years can result in standing water-induced plant death that may have contributed to barren patches in recent wet years. Interestingly, this phenomenon may be more likely to occur in Grant than Hooker County due to the more abundant wet valleys in Grant than Hooker. Certainly, land managers in the Sandhills confront a complex array of conditions, with wet years being a boon to most of the landscape (the upland rangelands) while presenting some disadvantages in valleys, which can become flooded, making them unusable for hay crops that year and perhaps detrimentally affecting plants in following years.

In both counties, we observed a trend of herbaceous wetlands increasing and woody wetlands decreasing. Since these two ecosystem types tend to occur in wet valleys, together with open water, it is possible that woody wetlands are being replaced by herbaceous wetlands and open water as conditions have become wetter in recent years. This trend may be explained by the fact that

woody plants tend to have less tolerance to inundated and low-oxygen soils than some other herbaceous, wetland plants (Kozlowski 1997).

With the overall wetting trend, irrigated crop hectares generally decreased, especially obvious since 2015. A study of conditions in 1973 to 2000 also observed land cover changes likely induced by wetter conditions (Taylor 2015). Collectively, our study and others are consistent with a picture of changing conditions in the Nebraska Sandhills, brought about by changes in climate conditions, especially ground water dynamics. Also, consistent with these satellite-based observations of changes in land cover, regional highways have experienced common road closures due to water flowing over the road at low elevation points in recent years (Clark 2019, Hummel 2019).

Conclusions

This research characterizes the variation that exists in water resources and landcover composition in the central Nebraska Sandhills. Some areas have more wet meadows and more open water (such as Grant County) whereas other areas have fewer wet meadows and tend to depend more on irrigation wells (such as Hooker County). These resources are dependent on precipitation and are likely affected by extreme weather (e.g., droughts and floods). The CropScape land cover database indicates changes in land use with wet/dry years, more open water following wet years, more reliance on CPIS in dry years, and more barren ground following dry years, especially in Hooker County. The contrasting resources in each county may dictate potential strategies and vulnerabilities of land managers. For instance, the more abundant wet valleys in Grant County may buffer the social ecological system more from drought, by providing a reliable source of hay and forage. However, the wet valleys are vulnerable to flooding/standing water, which can cause a decline in the amount of area available for hay and forage production. Hooker County, having fewer naturally occurring wet valleys, may be more vulnerable to drought-induced loss of forage, yet land managers in some cases have systems to acquire adequate forage, via irrigation, and a tradition of relying on external sources of livestock feed, albeit at a financial cost.

Consistent with earlier studies, our data indicate an overall wetting trend that has continued in the Sandhills in the past decade. With the possibility of climate change creating more frequent extreme weather events, more flooding events or severe droughts could affect land and water resources in the Sandhills. With potentially more wet/dry extremes in the future, an understanding of the way water resources respond, and the different strategies of landowners, will be important in assessing the overall resilience of the Nebraska Sandhills in the face of a changing climate.

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