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The Impacts of Drought on Southwest Tribal Economies

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Research Impact Statement: The results of this study show that drought has significant and negative impacts on the tribal economies in the US Southwest.

ABSTRACT: Droughts negatively impact agriculture in several ways including crop losses and damage to pasture/range. They are particularly concerning in the arid Southwest, where many Indian reservations, which depend on agriculture for income and subsistence, are located. The objective of this study is to evaluate drought impacts on cattle and hay sectors and resulting economic impacts on tribal communities in Arizona, Nevada, New Mexico, and Utah. First, we conduct panel data analysis to estimate impacts of drought, measured using the Palmer Drought Severity Index (PDSI), on cattle inventory and hay yields. Then, we use supply-driven social accounting matrix approach to quantify total economic impacts. Findings show that drought has a more detrimental impact on cattle production than for hay. Each additional year of drought reduces cattle inventory by 1.9% in the following year, while drought duration does not impact hay yields. Further, for every unit decrease in PDSI value in a given year, cattle inventory and hay yields decline by 0.3% and 0.4%, respectively. Examined drought scenarios result in large economic losses, reaching millions of dollars for large reservations such as the Uintah and Ouray Reservation, Navajo Nation, and Tohono O'odham Nation. To alleviate these negative impacts on reservation economies, there is a need to address several challenges, which affect tribal ability to mitigate and adapt to drought and climate change impacts.

(**KEYWORDS:** drought; Indian reservations; economic impact; cattle; hay.)

INTRODUCTION

The climate change and accompanying droughts become an increasingly concerning issue in the U.S. and the rest of the world. They have negative impacts on the productivity of agricultural sectors and food security (Hatfield et al., 2011; Fisher et al., 2012; Kuwayama et al., 2019), as they cause crop losses, damage to pasture/range, and reduced plant growth. In the U.S., climate change and droughts are particularly concerning in the arid Southwest (SW), where many Indian reservations are located. For example, approximately 93% of the area of counties where Navajo Nation—the largest Indian reservation in the U.S.—is located, experienced abnormally dry conditions or worse in 2020, and 58% experienced severe drought or worse (U.S Drought Monitor, 2021). Indian reservations and Native Americans in general, regardless of whether they live on or off reservation land, are plagued by poverty levels above the U.S. average of 11.8% (Akee et al., 2015; Davis et al., 2016; U.S. Census Bureau, 2020a, 2020b). Agriculture represents an important source of livelihood among tribal communities (Deol and Colby, 2018) and the share of jobs in agricultural and mining industry in many reservations exceeds the U.S. national average of 1.8% (U.S. Census Bureau, 2020a, 2020b). Thus, tribal communities are particularly vulnerable to the negative impacts of climate change and droughts.

Threat to a viability of tribal economies is only one of the negative impacts of climate change and droughts on the well-being of Native Americans. A life closely connected to the natural environment is a part of Native American culture, and climate change and droughts affect their ability to maintain certain traditions. Lynn et al. (2013) describe in detail negative impacts of climate change on traditional foods, used in traditional diets or as a part of spiritual ceremonies. Droughts have also negative impact on health of tribal communities through higher microbial contamination of public water, spring flooding, damaged underground drinking water lines, and higher heat exposure during outdoor ceremonies (Doyle et al., 2013). Cozzetto et al. (2013) discuss a variety of factors that make tribes more vulnerable to the impacts of climate change, as well as examples of how tribes across different regions, including SW, are impacted.

As the climate change and drought have a potential to threaten well-being of tribal communities in several ways, it is important that tribes have the ability to prevent or respond to these impacts. However, tribes face several challenges that limit this ability and exacerbate their vulnerability to drought (Redsteer et al., 2013). First, many tribes face unsettled water rights issues that limit their access to water resources (Jacobs et al., 2001). Water rights were reserved to them through the *Winters* doctrine (*Winters* v. *United States*, 1908), but need to be claimed and quantified through a settlement or litigation process, which can be lengthy and complex. Even if they succeed in securing their water rights, they may lack funding to build the infrastructure needed to exercise their rights (Cozzetto et al., 2013). In addition to that, tribes have a weak authority when it comes to preventing the pollution of the water resources outside their reservation area, which affects the quality of the water on reservation (Cozzetto et al., 2013, Chief et al., 2016). Another issue that tribes experience is a lack of human and financial resources to monitor weather, soil and vegetation conditions, identify onset of a drought, and take action to prevent or mitigate damaging drought impacts (Knutson et al., 2007; Redsteer et al., 2013). Understanding the impacts of drought on agricultural production and overall tribal economies can support adoption of policies that will improve the ability of tribes to monitor, prepare for, and respond to droughts.

Several studies examined economic impacts of drought on agricultural sectors (e.g. Diersen and Taylor, 2003; Wheaton et al., 2008; Pérez and Hurlé, 2009; Dellal and McCarl, 2010; Bauman et al., 2013). However, so far few studies quantified the economic impacts of drought on tribal communities, and particularly those that are vulnerable to drought due to their location in SW and reliance on agriculture for subsistence and as part of their culture. Specifically, Knutson et al. (2007) estimated that livestock producers in the Hualapai Tribe lost $1.6 million between 2001 and 2007 as a result of herd reduction by 30% and reduction of grazing by 50% due to drought. This study aims to fill the gap by estimating the drought impacts on the productivity of selected agricultural sectors, as well as overall impacts on tribal economies in Southwestern U.S. We focus on the cattle and hay sectors, since cattle and hay production are among the major agricultural activities in the studied regions. For example, livestock sales on Navajo Nation make 21% of all agricultural sales, and cattle and calves are the second most important livestock group after sheep and lambs (USDA NASS, 2019). Also, livestock is a traditional source of livelihood and plays a significant role in many tribal economies in SW, including Navajo Nation, San Carlos Apache, White Mountain Apache, Hopi, Ute Indian, and Tohono O'odham Nation (Redsteer et al., 2013).

Nania et al. (2014) provide examples of how climate change and drought impact livestock production in SW, focusing on Navajo Nation. They describe how drought impacts availability and quality of forage rangeland, water, and livestock health, as well as what factors make this region more vulnerable to drought and what adaptation and mitigation strategies can be implemented. The objective of this study is to quantify how drought affects output of cattle and hay sectors on reservations in SW, and how the reduced output affects activity in other sectors to demonstrate the economic significance of the drought in the economically disadvantaged tribal communities.

METHODS

Data

To estimate the impacts of drought on cattle inventory and hay yield we use county-level data (N=34) from 1981 to 2016 (T=36). The data is collected for counties in Arizona, Nevada, New Mexico, and Utah, where selected Native American reservations are located. Table 1 provides the list of the reservations and information in which counties they are located, i.e. counties included in the panel data analysis, which is described in the next section. Data needed for this part of the analysis is not available on the reservation level. However, the use of county-level data is suitable, considering that the average impact of drought on cattle inventory and hay yields, which will be estimated across studied counties, should approximate well the average impact across reservations, which are located within the same counties.

Table 1. Indian reservations, their area and location.

Reservation	Area (mi^2)	State and counties (% share of reservation area in a county)
Hopi	2,533	AZ – Coconino (5%), Navajo (17%)
Navajo Nation	23,965	AZ – Apache (61%), Coconino (27%), Navajo (40%); NM – Cibola (5%), McKinley (43%), Rio Arriba (.04%), San Juan (60%), Sandoval (4%); UT – San Juan (25%)
San Carlos	2,926	AZ – Gila (21%), Graham (37%), Pinal (4%)
Tohono O’odham	4,454	AZ – Maricopa (2%), Pima (42%), Pinal (8%)
White Mountain	2,631	AZ – Apache (7%), Gila (17%), Navajo (10%)
Duck Valley	453	NV – Elko (1%); ID – Owyhee (3%)
Goshute	188	NV – White Pine (1%); UT – Juab (2%), Tooele (.04%)

Moapa River	111	NV – Clark (1%)
Pyramid Lake	730	NV – Lyon (.02%), Storey (0.25%), Washoe (11%)
Washoe	139	NV – Douglas (19%)
Acoma	596	NM – Catron (.23%), Cibola (11%), Socorro (1%)
Jicarilla Apache	1,162	NM – Rio Arriba (20%)
Laguna Pueblo	784	NM – Bernalillo (7%), Cibola (11%), Sandoval (3%), Valencia (9%)
Mescalero Apache	720	NM – Lincoln (.01%), Otero (11%)
Pueblo of Isleta	179	NM – Bernalillo (15%)
Zuni	705	NM – Catron (.01%), Cibola (4%), McKinley (9%)
Uintah and Ouray	6,728	UT – Duchesne (89%), Grand (9%), Uintah (64%), Wasatch (53%)

The reservations included in this study differ in terms of poverty levels, unemployment rates, as well as share of employment in the agriculture and mining sector. All of them have poverty levels above U.S. average of 11.8% in 2018, but they range widely from 13.8% for Washoe Tribe to 47% in San Carlos Apache Indian Reservation (U.S. Census Bureau, 2020b). Also, unemployment rate is higher among studied reservations compared to U.S. average of 5.9% in 2018, ranging from 6.4% in Hopi Reservation to 30.4% in San Carlos Apache Indian Reservation (U.S. Census Bureau, 2020b). Share of employment in agriculture and mining sector ranges from 0% in White Mountain Apache Reservation and Moapa River Indian Reservation to 21.4% in Uintah and Ouray Reservation (U.S. Census Bureau, 2020b).

Table 2 provides an overview and summary statistics of the variables used in the regression models. Yearly cattle inventory including calves (heads) and hay yield including alfalfa (tons per acre) data were collected from USDA National Agricultural Statistical Service (USDA NASS, 2020). The range of values for cattle inventory and hay yield in the sample is relatively large—for example, cattle inventory ranges from 100 to 410,000 heads. Transformation using natural logarithm reduces the range and this form was also used in the final regression models.

Table 2. Summary statistics.

Variable	Definition (measurement)	Obs.	Mean	St. dev.	Min	Max
$Cattle$	Cattle inventory, incl. calves (heads)	1,194	44,464	55,099	100	410,000
$\ln Cattle$	Natural log of cattle inventory	1,194	10.20	1.09	4.61	12.92
$HayYield$	Hay yield, incl. alfalfa (ton/acre)	972	4.44	1.58	0.90	10.00
$\ln HayYield$	Natural log of hay yield	972	1.43	0.35	-0.11	2.30
$PDSI$	PDSI value	1,224	-0.34	2.61	-5.27	7.40
$DryDur$	Consecutive dry years, if PDSI<-1.9	1,224	0.57	1.03	0.00	6.00
$WetDur$	Consecutive wet years, if PDSI>1.9	1,224	0.43	1.03	0.00	6.00

Notes: Data collected over T=36 years (1981-2016) and N=34 counties. Cattle inventory and hay yield data not observed for some years/counties.

Monthly PDSI data on a county-level, compiled by the Cooperative Institute for Climate and Satellites, North Carolina, were collected from the Center for Disease Control and Prevention (CDC, 2018), and they were averaged to obtain yearly PDSI data. PDSI values are calculated using temperature and precipitation data, and can range from -10 to 10, but typically from -4 to 4, where more negative/positive values represent drier/wetter conditions. Variables $DryDur$ and $WetDur$ were constructed as counts of consecutive years when yearly PDSI values were less than -1.9 and more than 1.9, respectively. PDSI values between -1.9 and 1.9 are considered near normal conditions according to the National Weather Service, Climate Prediction Center. During the observed time period, continuous dry and wet conditions lasted up to six years at most. Figure 1 plots how PDSI evolved over time alongside a) cattle inventory and b) hay yields, suggesting there might be a relationship between these variables.

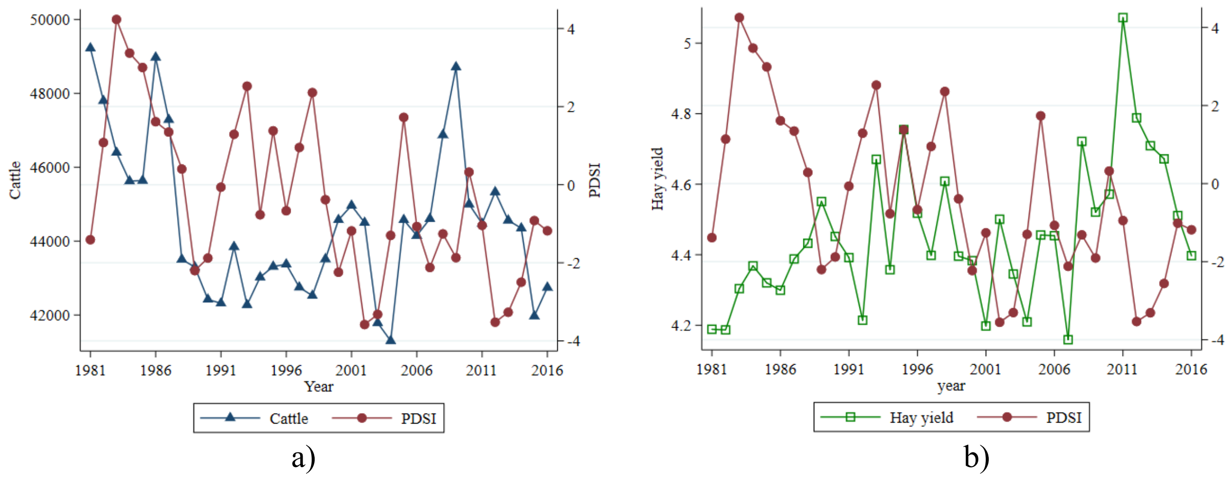

Figure 1. PDSI compared to a) cattle inventory and b) hay yield in the studied area, 1981-2016.

Notes: PDSI value, cattle inventory, and hay yield are averages across counties in a given year.

Drought Impacts on Cattle Inventory and Hay Yield

As the first step, we use panel data analysis to examine the direct impact of drought on the cattle inventory and hay yields. Panel data analysis is applicable, because we observe data for multiple cross-sectional units (N=34 counties) over multiple time periods (T=36 years), i.e. the data has a panel structure. For drought impacts on the cattle inventory, we estimate the following dynamic panel data model:

$$\ln Cattle_{c,t} = \beta_0 + \gamma \ln Cattle_{c,t-1} + \delta_1 PDSI_{c,t} + \delta_2 DryDur_{c,t-1} + \delta_3 WetDur_{c,t-1} + \beta_1 Trend_t + \upsilon_c + \varepsilon_{c,t} \quad (1)$$

Here, $\ln Cattle_{c,t}$ is natural log of cattle inventory in county *c* and year *t* and $\ln Cattle_{c,t-1}$ is natural log of cattle inventory in the previous year. We assume that ranch managers maintain some inventory for breeding purposes and dairy production, and so there is some dependency between cattle inventory in different time periods. Including lagged dependent variable as a predictor accounts for this dependency, and dynamic panel data model specifically needs to be estimated to obtain correct coefficient estimates. $Trend_t$ accounts for the changes in cattle inventory over time, possibly due to the operating and technological improvements, and υ_c and $\varepsilon_{c,t}$ are time-invariant and time-variant components of the error term.

To examine the effect of drought, the model includes $PDSI_{c,t}$, a PDSI value in the current year, and $DryDur_{c,t-1}$ and $WetDur_{c,t-1}$, which are counts of consecutive years of dry and wet conditions, respectively, recorded in the previous year. It is assumed that dry conditions affect negatively the availability and/or cost of feed, such as hay and pasture, and water. Depending on the severity of drought, this may motivate ranch managers to cull and sell a part of their herd earlier than planned, which affects the cattle inventory immediately during the first year of drought, as measured by the $PDSI_{c,t}$ coefficient in equation (1). However, it is assumed that reduced breeding stock due to drought in one year will affect the cattle inventory in the next year as well, and $DryDur_{c,t-1}$ coefficient measures the lagged effect of the drought. In addition, it measures the negative effect of a long-term drought on the cattle inventory, assuming that it increases with each additional year of drought. Further, there is likely a non-linear relationship between the change in PDSI and cattle inventory, assuming that neither extremely dry nor wet conditions are optimal for cattle production. Change of PDSI value by several units is assumed to affect cattle inventory differently, depending on whether the conditions in the previous year were dry, normal, or wet. Including $DryDur_{c,t-1}$ and $WetDur_{c,t-1}$ variables in equation (1) controls for the conditions in the previous year when estimating the impact of change in PDSI between two time periods.

For the analysis of drought impacts on hay yield, we applied the standard panel data model, since there is no dependency between hay yield in two consecutive years. We have verified that by estimating the dynamic panel data model as well and finding insignificant coefficient estimate for lagged hay yield variable. Hausman test (Hausman, 1978) was performed to decide between fixed effects and random effects models. We estimated the following model

$$\ln HayYield_{c,t} = \beta_0 + \delta_1 PDSI_{c,t} + \delta_2 DryDur_{c,t-1} + \delta_3 WetDur_{c,t-1} + \\ + \beta_1 Trend_t + \upsilon_c + \varepsilon_{c,t} \quad (2)$$

where $\ln HayYield_{c,t}$ is hay yield in county *c* and time *t*, and the remaining variables are the same as described previously for the cattle model. It is assumed that drought will impact the hay yield negatively in the current year, which is captured by the $PDSI_{c,t}$ coefficient, but $DryDur_{c,t-1}$ is also included to capture the potential lagged effect of drought, as well as effect of drought duration.

Economic Impacts of Drought

Estimated coefficients for the impacts of drought on cattle inventory and hay yields from equations (1) and (2) were used to calculate the cattle and hay output losses under specified drought scenarios and the dollar value of the losses on each reservation. The dollar values represent the direct impacts of drought on cattle and hay sector. Cattle inventory and hay production data for each reservation are needed to calculate the direct impacts. Since these data are not available, we use data for counties where each reservation is located and estimate a reservation share of cattle and hay production within each county in proportion to the area share of a given reservation in the county. Obtained county-level estimates of cattle inventory and hay production for each reservation are summed up to obtain total reservation estimates. These estimates may be either overestimates or underestimates of true values for each reservation, but overall they represent a fair approximation to the true, but unobserved data.

Due to linkages between economic activities, reduced production in cattle and hay sectors will indirectly reduce production in other sectors, which have a backward or forward relationship to the cattle and hay sector. Sectors that provide inputs to cattle and hay producers have a backward relationship, while sectors that purchase output of cattle and hay producers have a forward relationship. For example, labor, machinery, feed, insurance, and veterinary services are inputs needed by cattle producers, and their demand for these inputs will decrease if they reduce the herd size due to drought. In turn, if they reduce the cattle production, they will have less cattle to sell to food processors and their production will decrease as well. The sum of impacts on these sectors are indirect impacts of the drought (drought will likely affect some of these sectors directly as well, but the analysis of the overall impact of drought on all sectors is beyond the scope of this study). In addition, employee compensation within affected sectors will decrease and resulting reduced household spending will affect additional sectors throughout the local economy. This effect combined with reduced tax revenues represent induced impacts of the reduced cattle and hay production in the region due to drought. The sum of direct, indirect, and induced impacts represent the total economic impacts.

To estimate indirect and induced impacts of the reduced cattle and hay output due to drought, we use a supply-driven social accounting matrix (SDSAM) approach, which is described in detail in Kim et al. (2017). Social accounting matrix (SAM) captures all economic relationships in a region (including transactions among sectors, government, and households), and supply-driven approach to the economic impact analysis estimates impacts due to initial change on a supply side. Social accounting matrix with the data is taken from IMPLAN (IMpact analysis for PLANning) and is modified to calculate the supply-driven impacts.

RESULTS AND DISCUSSION

Drought Impacts on Cattle Inventory and Hay Yield

Table 3 reports results of the models in equations (1) and (2). Both models show that drought affects cattle inventory and hay yields significantly, but differently. Focusing on the cattle model first, one unit decrease in PDSI (i.e. a change towards drier conditions) is associated with 0.3% reduction in cattle inventory, as expected. Further, negative and significant coefficient for $DryDur_{t-1}$ means that drought, defined as PDSI < -1.9, has a lingering negative effect on cattle inventory. One-year drought is associated with 1.9% decrease in cattle inventory in the year following the drought, and the overall impact of a particular drought increases with the number of years in drought. In summary, change in PDSI and drought duration (i.e. consecutive years of PDSI < -1.9) have a significant impact on the cattle inventory, and both need to be considered for the overall impact of drought on the cattle sector.

Table 3. Panel data model estimation results.

Dependent variable	$\ln Cattle_t$		$\ln HayYield_t$	
Independent variables	Coefficient	St. error	Coefficient	St. error
$\ln Cattle_{t-1}$	0.721***	0.102	-	-
$PDSI_t$	0.003*	0.002	0.004*	0.002
$DryDur_{t-1}$	-0.019**	0.007	-0.006	0.007
$WetDur_{t-1}$	-0.002	0.010	0.013**	0.005

Constant	8.939**	3.705	2.016	1.387
$Trend_t$	-0.003**	0.001	0.000	0.001
Number of obs.	1155		950	
Wald $\chi^2(5)$	196.49***		19.93***	
Arrelano-Bond AR(1) test p-value[a]	0.003***		-	
Arrelano-Bond AR(2) test p-value[a]	0.373		-	
Hansen test p-value[b]	0.226		-	
Hausman test p-value	-		0.445	

Notes: Dynamic panel data model estimated with cattle data, random effects model estimated with hay data. Asterisks ***,**,* denote significance at 1%, 5%, and 10% level, respectively.

[a] These tests examine autocorrelation in the error term of the first order, AR(1), and second order, AR(2). Null hypothesis is that the autocorrelation is not present. The model is correctly specified if the null is rejected for the AR(1) test and not rejected for the AR(2) test.

[b] This test examines whether the instruments used during the estimation are valid. Null hypothesis is that the instruments are valid and uncorrelated with model residuals.

Similarly as for cattle, one unit decrease in PDSI value is associated with 0.4% decrease in hay yield. However, coefficient for $DryDur_{t-1}$ is insignificant. This means that even if PDSI decreases below -1.9, yields in that year only are affected negatively and they are not affected in the following year, unless the conditions become even drier. On the other hand, positive and significant coefficient for $DryWet_{t-1}$ means that wet conditions (PDSI > 1.9) in the past year, as well as duration of the wet conditions, affect hay yields positively.

Direct Impacts of Drought on Cattle and Hay Sector

Table 4 provides an overview of the defined, hypothetical drought scenarios and their impacts in terms of percentage change in cattle inventory and hay yield. The scenarios are worded similarly to allow some comparison. However, since results of the cattle model show that duration of drought (defined as PDSI < -1.9) matters, the scenario related to the cattle inventory ends with the return to pre-drought conditions at time *t*. The overall impact on cattle inventory at the end of the drought is approximately $d * \delta_2$, where d is duration of drought in years and δ_2 is the coefficient estimate for the drought duration (for simplicity, we assume that the effect of PDSI change at the beginning and the end of the drought cancels out).

Table 4. Drought impacts on cattle inventory and hay yields.

Model	Scenario description	Total impact
Cattle	Near normal at *t-3*, PDSI decrease by 2 units at *t-2* below -1.9 and stays the same at *t-1*, PDSI increase to pre-drought level at *t*	-3.72%
Hay	Near normal at *t-3*, PDSI decrease by 2 units at *t-2* below -1.9 and stays the same	-0.87%

Notes: Scenario impact represents percentage change in the cattle inventory (heads) or hay yields (tons/acre) based on the results of cattle and hay models, respectively.

For hay, only the change in PDSI affects yields and the drought duration does not matter. The overall impact on hay yield is $x * \delta_1$, where x is the change in PDSI in units and δ_1 is the coefficient estimate for the PDSI. The percentage changes in cattle inventory and hay yields given the drought scenarios, as reported in Table 4, represent changes on a county-level. However, they represent an appropriate estimate of average impacts on Indian reservations, located in the counties included in the econometric analysis. Another important note is that although the estimated economic impacts reported on the following pages are based on the simplified and very specific drought scenarios in Table 4, the calculated impacts can be scaled up or down in proportion to any percentage changes in cattle inventory and hay yield.

In the next step, we calculated the production losses and dollar value of the losses (i.e. direct impacts) in cattle and hay sectors for each Indian reservation. Besides cattle inventory and hay yield data needed for the calculations, additional data—value of cattle ($/head), value of hay ($/ton), and hay production (acres harvested)—were obtained from USDA NASS (2020). In the calculations of losses we used actual cattle and hay prices, which were observed in the year for which IMPLAN dataset was available. Usually, reduction of agricultural commodity supply due to drought leads to increased pricing, which partially offsets the losses due to drought. However, our calculations do not reflect that, which means that the direct impacts are partially overestimated.

Table 5 provides a summary of the calculated direct impacts of drought on cattle and hay sectors (based on the drought scenarios in Table 4) in the studied reservations, grouped by the state where they are located (primarily, for some) and ordered by the size of the impacts within each group.

Table 5. Direct impacts of drought on cattle and hay sectors in reservations.

Group # and reservation name	State(s) where located	Loss in cattle inventory (head)	Loss in cattle value ($)	Loss in hay production (tons)	Loss in hay value ($)
#1 Uintah and Ouray[b]	UT	2,748	3,242,800	1,917	256,900
#2 Navajo[a,1]	AZ, NM, UT	2,438	3,502,300	674	110,900
#2 Tohono O'odham[a]	AZ	1,298	1,804,700	584	88,800
#2 San Carlos Apache[a]	AZ	708	983,800	194	29,500
#2 White Mountain Apache[a]	AZ	253	351,600	2	300

#2 Hopi[a]	AZ	251	348,300	0	0
#3 Washoe Tribe[a]	NV	69	100,500	28	4,200
#3 Duck Valley[a,2]	NV	61	88,900	3	500
#3 Pyramid Lake[a]	NV	42	61,100	0	0
#3 Goshute[a,1]	NV	9	13,700	4	600
#4 Laguna Pueblo[c]	NM	152	199,200	31	7,600
#4 Jicarilla Apache[c]	NM	125	163,300	0	0
#4 Zuni[c]	NM	102	133,900	0	0
#4 Acoma[c]	NM	82	107,900	3	600
#4 Mescalero Apache[c]	NM	66	86,400	0	0
#4 Pueblo of Isleta[c]	NM	0	0	8	1,900

Notes: [a,b,c] denote that the impacts were calculated based on 2016, 2017, 2018 data, respectively. The year was determined based on the availability of IMPLAN dataset, used for economic impact analysis. Cattle and hay value losses are rounded to the nearest $100.

[1] Direct impacts do not include counties in Utah, due to unavailability of 2016 IMPLAN dataset for Utah.

[2] Direct impacts do not include county in Idaho, due to unavailability of 2016 IMPLAN dataset for Idaho.

Total Economic Impacts of Drought

Tables 6-11 report total economic impacts of the drought scenarios for cattle and hay sectors. The impacts were calculated either separately for the largest studied reservations—Uintah and Ouray Reservation (Table 6), Navajo Nation (Table 7), Tohono O'odham Nation (Table 8)—or they were combined for the smaller reservations in Arizona (Table 9), Nevada (Table 10), and New Mexico (Table 11). Overall, the economic impacts of a drought on the cattle sector (two-year drought) are larger than impacts of a drought on hay sector (conditions becoming drier by two-unit PDSI decrease) across all studied reservations. Backward impacts (i.e. impacts on the suppliers to the cattle and hay producers) range from $0.3 million combined for studied reservations in Nevada to $4.8 million in Tohono O'odham Nation for cattle sector, and from $0.01 million in Nevada reservations to $0.4 million in Uintah and Ouray Reservation for hay sector. Forward impacts (i.e. impacts on the buyers from the cattle and hay producers) range from $0.02 million in Nevada reservations to $1.4 million in Uintah and Ouray Reservation for cattle sector, and from $0 in Nevada reservations to $0.1 million in Tohono O'odham Nation for hay sector. Total economic impacts range from $0.6 million in Nevada reservations to $8.2 million in Uintah and Ouray Reservation and Navajo Nation for cattle sector, and from $0.02 million in Nevada reservations to $0.7 million in Uintah and Ouray Reservation for hay sector.

As mentioned earlier, note that the overall economic impact can be scaled up or down in proportion to the change in the direct impact, which in turn depends on the actual drought scenario (e.g., for one-year drought affecting cattle producers, estimated direct impacts and resulting total economic impacts would be half, keeping all other conditions constant). Also, note that the drought affecting cattle ranchers directly affects hay producers indirectly at the same time, since there is a backward linkage from cattle ranchers to hay producers, who supply hay to ranchers. Similarly, drought affecting hay producers directly affects cattle ranchers indirectly, since there is a forward relationship from hay producers to cattle ranchers, who demand hay. The impacts in tables 6-11 represent impacts when these two sectors are affected by drought separately, not considering that they might be affected by drought directly at the same time.

Table 6. Economic impact of drought on cattle and hay sectors in Uintah and Ouray Reservation.

	Cattle sector (million $)			Hay sector (million $)		
	Backward	Forward	Total	Backward	Forward	Total

Impact on sectors (indirect)	1.142	1.384	2.526	0.108	0.014	0.122
Ag forest & hunting	0.065	0.011	0.076	0.007	0.002	0.009
Hay	0.092	0.005	0.097	n/a	n/a	n/a
Cattle ranching	n/a	n/a	n/a	0.000	0.007	0.008
Other livestock	-	-	-	-	-	-
Mining	0.041	0.000	0.041	0.007	0.000	0.007
Utility	-	-	-	-	-	-
Construction	0.034	0.000	0.034	0.003	0.000	0.004
Manufacturing	0.035	0.027	0.062	0.002	0.001	0.002
Slaughtering	0.000	1.338	1.338	0.000	0.004	0.004
Wholesale	0.225	0.000	0.225	0.008	0.000	0.008
Other retail	0.043	0.000	0.043	0.007	0.000	0.007
Food retail	0.008	0.000	0.009	0.001	0.000	0.001
Transportation	0.096	0.000	0.096	0.004	0.000	0.004
FIRE[1]	0.429	0.000	0.429	0.062	0.000	0.062
Government	0.075	0.000	0.075	0.006	0.000	0.006
Impact on VA (indirect)	1.571	0.002	1.572	0.181	0.000	0.182
Employment compensation	0.449	0.000	0.449	0.107	0.000	0.107
Proprietary income	-0.233	0.000	-0.233	-0.016	0.000	-0.016
Other property income	1.290	0.000	1.290	0.090	0.000	0.090
Indirect business taxes	0.065	0.000	0.066	0.000	0.000	0.000
Impact on HH income (induced)	0.706	0.005	0.711	0.117	0.001	0.118
Low income HH (up to 35k)	0.091	0.003	0.094	0.014	0.000	0.014
Medium income HH (35k-100k)	0.388	0.002	0.390	0.068	0.000	0.069
High income HH (over 100k)	0.226	0.001	0.227	0.035	0.000	0.035

State revenue (induced)	0.190	0.001	0.191	0.015	0.000	0.016
Indirect + induced impact	3.608	1.392	**5.000**	0.421	0.015	**0.436**
Total regional impact			**8.243**			**0.693**

Notes: [1] Finance, Insurance, Real estate, and Education

Table 7. Economic impact of drought on cattle and hay sectors in Navajo Nation.

	Cattle sector (million $)			Hay sector (million $)		
	Backward	Forward	Total	Backward	Forward	Total
Impact on sectors (indirect)	1.310	1.119	2.429	0.060	0.047	0.107
Ag forest & hunting	0.107	0.006	0.114	0.004	0.001	0.006
Hay	0.027	0.004	0.031	n/a	n/a	n/a
Cattle ranching	n/a	n/a	n/a	0.000	0.014	0.014
Other livestock	0.005	0.012	0.017	0.000	0.000	0.000
Mining	0.016	0.000	0.016	0.001	0.001	0.003
Utility	0.062	0.000	0.063	0.004	0.001	0.005
Construction	0.024	0.001	0.025	0.001	0.006	0.007
Manufacturing	0.081	0.018	0.098	0.002	0.016	0.018
Slaughtering	0.000	1.069	1.069	0.000	0.000	0.000
Wholesale	0.240	0.000	0.241	0.003	0.000	0.004
Other retail	0.042	0.000	0.043	0.003	0.000	0.004
Food retail	0.007	0.000	0.008	0.001	0.000	0.001
Transportation	0.110	0.000	0.111	0.002	0.000	0.002
FIRE[1]	0.490	0.000	0.491	0.033	0.004	0.037
Government	0.097	0.007	0.104	0.005	0.002	0.007
Impact on VA (indirect)	1.398	0.001	1.400	0.084	0.004	0.089
Employment compensation	0.408	0.000	0.408	0.062	0.003	0.065
Proprietary income	0.001	0.000	0.001	-0.002	0.000	-0.002
Other property income	0.923	0.000	0.923	0.021	0.001	0.022
Indirect business taxes	0.067	0.000	0.067	0.003	0.001	0.004
Impact on HH income (induced)	0.736	0.004	0.740	0.063	0.007	0.069

Low income HH (up to 35k)	0.132	0.002	0.134	0.011	0.002	0.013
Medium income HH (35k-100k)	0.388	0.001	0.390	0.036	0.003	0.039
High income HH (over 100k)	0.215	0.001	0.216	0.016	0.001	0.017
State revenue (induced)	0.140	0.001	0.141	0.007	0.004	0.012
Indirect + induced impact	3.584	1.126	**4.709**	0.214	0.063	**0.276**
Total regional impact			**8.212**			**0.387**

Notes: [1] Finance, Insurance, Real estate, and Education

Table 8. Economic impact of drought on cattle and hay sectors in Tohono O'odham Nation.

	Cattle sector (million $)			Hay sector (million $)		
	Backward	Forward	Total	Backward	Forward	Total
Impact on sectors (indirect)	1.907	0.740	2.647	0.104	0.082	0.186
Ag forest & hunting	0.050	0.004	0.054	0.004	0.002	0.005
Hay	0.045	0.002	0.047	n/a	n/a	n/a
Cattle ranching	n/a	n/a	n/a	0.000	0.009	0.009
Other livestock	0.001	0.010	0.011	0.000	0.000	0.000
Mining	0.004	0.001	0.005	0.000	0.000	0.001
Utility	0.050	0.001	0.051	0.004	0.001	0.005
Construction	0.036	0.001	0.038	0.002	0.012	0.014
Manufacturing	0.107	0.012	0.120	0.004	0.032	0.036
Slaughtering	0.001	0.702	0.703	0.000	0.003	0.003
Wholesale	0.265	0.001	0.266	0.007	0.001	0.008
Other retail	0.085	0.001	0.087	0.005	0.002	0.007
Food retail	0.014	0.001	0.015	0.001	0.000	0.001
Transportation	0.127	0.001	0.128	0.004	0.001	0.005
FIRE[1]	1.029	0.001	1.031	0.068	0.017	0.085
Government	0.091	0.001	0.092	0.005	0.002	0.007
Impact on VA (indirect)	1.557	0.004	1.561	0.093	0.013	0.106
Employment compensation	0.673	0.001	0.674	0.056	0.008	0.065
Proprietary income	0.416	0.001	0.417	0.016	0.001	0.017
Other property income	0.384	0.001	0.384	0.016	0.002	0.018
Indirect business taxes	0.084	0.001	0.085	0.004	0.002	0.006
Impact on HH income (induced)	1.196	0.014	1.210	0.075	0.017	0.092

Low income HH (up to 35k)	0.146	0.007	0.153	0.009	0.005	0.015
Medium income HH (35k-100k)	0.576	0.005	0.580	0.038	0.009	0.047
High income HH (over 100k)	0.475	0.002	0.477	0.027	0.003	0.031
State revenue (induced)	0.182	0.004	0.186	0.010	0.007	0.017
Indirect + induced impact	4.841	0.762	**5.604**	0.282	0.119	**0.401**
Total regional impact			**7.408**			**0.490**

Notes: [1] Finance, Insurance, Real estate, and Education

Table 9. Combined economic impact of drought on cattle and hay sectors in additional reservations in Arizona.

	Cattle sector (million $)			Hay sector (million $)		
	Backward	Forward	Total	Backward	Forward	Total
Impact on sectors (indirect)	0.426	0.301	0.727	0.009	0.007	0.016
Ag forest & hunting	0.045	0.002	0.047	0.001	0.001	0.002
Hay	0.026	0.002	0.028	n/a	n/a	n/a
Cattle ranching	n/a	n/a	n/a	0.000	0.004	0.004
Other livestock	0.002	0.003	0.005	0.000	0.000	0.000
Mining	0.002	0.000	0.002	0.000	0.000	0.000
Utility	0.011	0.000	0.011	0.000	0.000	0.000
Construction	0.010	0.000	0.010	0.000	0.000	0.001
Manufacturing	0.007	0.005	0.012	0.000	0.002	0.002
Slaughtering	0.000	0.288	0.288	0.000	0.000	0.000
Wholesale	0.042	0.000	0.042	0.000	0.000	0.000
Other retail	0.020	0.000	0.020	0.001	0.000	0.001
Food retail	0.004	0.000	0.004	0.000	0.000	0.000
Transportation	0.035	0.000	0.035	0.000	0.000	0.000
FIRE[1]	0.185	0.000	0.185	0.005	0.000	0.005
Government	0.040	0.000	0.040	0.001	0.000	0.001
Impact on VA (indirect)	0.569	0.000	0.570	0.016	0.000	0.016
Employment compensation	0.148	0.000	0.149	0.009	0.000	0.009
Proprietary income	0.217	0.000	0.217	0.005	0.000	0.005
Other property income	0.192	0.000	0.192	0.002	0.000	0.002
Indirect business taxes	0.012	0.000	0.012	0.000	0.000	0.000

Impact on HH income (induced)	0.438	0.001	0.440	0.014	0.000	0.014
Low income HH (up to 35k)	0.076	0.001	0.076	0.002	0.000	0.003
Medium income HH (35k-100k)	0.242	0.000	0.242	0.008	0.000	0.008
High income HH (over 100k)	0.121	0.000	0.121	0.003	0.000	0.003
State revenue (induced)	0.058	0.000	0.058	0.002	0.000	0.002
Indirect + induced impact	1.491	0.303	**1.794**	0.040	0.008	**0.048**
Total regional impact			**3.478**			**0.078**

Notes: Economic impacts combined for Hopi Res., San Carlos Apache Indian Res., and White Mountain Apache Indian Res. for cattle sector, and San Carlos Apache Indian Res. and White Mountain Apache Indian Res. for hay sector.

[1] Finance, Insurance, Real estate, and Education

Table 10. Combined economic impact of drought on cattle and hay sectors in reservations in Nevada.

	Cattle sector (million $)			Hay sector (million $)		
	Backward	Forward	Total	Backward	Forward	Total
Impact on sectors (indirect)	0.110	0.018	0.127	0.003	0.000	0.003
Ag forest & hunting	0.003	0.000	0.003	0.000	0.000	0.000
Hay	0.006	0.000	0.007	n/a	n/a	n/a
Cattle ranching	n/a	n/a	n/a	0.000	0.000	0.000
Other livestock	0.000	0.000	0.001	0.000	0.000	0.000
Mining	0.000	0.000	0.000	0.000	0.000	0.000
Utility	0.002	0.000	0.002	0.000	0.000	0.000
Construction	0.002	0.000	0.002	0.000	0.000	0.000
Manufacturing	0.002	0.001	0.002	0.000	0.000	0.000
Slaughtering	0.000	0.016	0.016	0.000	0.000	0.000
Wholesale	0.024	0.000	0.024	0.000	0.000	0.000
Other retail	0.005	0.000	0.005	0.000	0.000	0.000
Food retail	0.001	0.000	0.001	0.000	0.000	0.000
Transportation	0.008	0.000	0.008	0.000	0.000	0.000
FIRE[1]	0.050	0.000	0.050	0.002	0.000	0.002
Government	0.006	0.000	0.006	0.000	0.000	0.000
Impact on VA (indirect)	0.105	0.000	0.105	0.004	0.000	0.004
Employment compensation	0.048	0.000	0.048	0.004	0.000	0.004
Proprietary income	-0.011	0.000	-0.011	0.000	0.000	0.000
Other property income	0.060	0.000	0.060	0.001	0.000	0.001
Indirect business taxes	0.008	0.000	0.009	0.000	0.000	0.000

Impact on HH income (induced)	0.079	0.000	0.079	0.004	0.000	0.004
Low income HH (up to 35k)	0.009	0.000	0.009	0.000	0.000	0.000
Medium income HH (35k-100k)	0.042	0.000	0.042	0.002	0.000	0.002
High income HH (over 100k)	0.028	0.000	0.028	0.001	0.000	0.001
State revenue (induced)	0.013	0.000	0.013	0.000	0.000	0.000
Indirect + induced impact	0.307	0.018	**0.325**	0.011	0.000	**0.011**
Total regional impact			**0.589**			**0.017**

Notes: Economic impacts combined for Washoe Tribe, Duck Valley Indian Res., Pyramid Lake Indian Res., Goshute Res. for cattle sector and hay sector.

[1] Finance, Insurance, Real estate, and Education

Table 11. Combined economic impact of drought on cattle and hay sectors in reservations in New Mexico.

	Cattle sector (million $)			Hay sector (million $)		
	Backward	Forward	Total	Backward	Forward	Total
Impact on sectors (indirect)	0.192	0.105	0.297	0.008	0.010	0.018
Ag forest & hunting	0.007	0.000	0.008	0.000	0.000	0.000
Hay	0.001	0.000	0.002	n/a	n/a	n/a
Cattle ranching	n/a	n/a	n/a	0.000	0.000	0.000
Other livestock	0.000	0.001	0.001	0.000	0.000	0.000
Mining	0.001	0.000	0.001	0.000	0.000	0.000
Utility	0.004	0.000	0.004	0.000	0.000	0.000
Construction	0.002	0.000	0.002	0.000	0.001	0.001
Manufacturing	0.008	0.002	0.010	0.000	0.004	0.004
Slaughtering	0.000	0.101	0.101	0.000	0.000	0.000
Wholesale	0.030	0.000	0.030	0.001	0.000	0.001
Other retail	0.008	0.000	0.008	0.000	0.000	0.001
Food retail	0.001	0.000	0.001	0.000	0.000	0.000
Transportation	0.014	0.000	0.014	0.000	0.000	0.000
FIRE[1]	0.099	0.000	0.099	0.006	0.003	0.009
Government	0.016	0.000	0.016	0.000	0.001	0.001
Impact on VA (indirect)	0.415	0.000	0.416	0.010	0.004	0.014
Employment compensation	0.087	0.000	0.087	0.009	0.003	0.011
Proprietary income	-0.038	0.000	-0.038	0.000	0.000	0.000
Other property income	0.362	0.000	0.362	0.002	0.001	0.003
Indirect business taxes	0.004	0.000	0.004	-0.001	0.000	0.000

Impact on HH income (induced)	0.162	0.001	0.162	0.008	0.005	0.013
Low income HH (up to 35k)	0.038	0.000	0.038	0.001	0.002	0.003
Medium income HH (35k-100k)	0.084	0.000	0.084	0.004	0.003	0.007
High income HH (over 100k)	0.040	0.000	0.040	0.002	0.001	0.003
State revenue (induced)	0.019	0.000	0.019	0.000	0.001	0.001
Indirect + induced impact	0.788	0.106	**0.894**	0.025	0.021	**0.046**
Total regional impact			**1.585**			**0.056**

Notes: Economic impacts combined for Acoma Indian Res., Jicarilla Apache Nation, Laguna Pueblo, Mescalero Apache Res., and Zuni Indian Res. for cattle sector, and Acoma Indian Reservation, Laguna Pueblo, and Pueblo of Isleta for hay sector.

[1] Finance, Insurance, Real estate, and Education

CONCLUSIONS

This study examined impacts of drought on cattle and hay sectors in selected Indian reservations, located in drought-prone states of Arizona, Nevada, New Mexico, and Utah. First, data collected for counties, where the reservations are located, was used in the panel data analysis to estimate the effect of change in PDSI (i.e. temperature and precipitation) on cattle inventory and hay yields. Estimated percentage changes in cattle inventory and hay yields based on defined drought scenarios were used to calculate the direct impact of drought conditions on the output value of cattle and hay sectors in the studied reservations. Finally, we applied SDSAM approach to economic impact analysis to estimate total regional impacts of the drought-induced reduction of cattle and hay output.

The findings show that in the year when the conditions become drier, hay yields decrease significantly, which results in reduced hay output, declined economic activity in related industries, and economic losses throughout the regions where Indian reservations are located. Cattle producers, as hay buyers, are impacted by drought through reduced hay availability, but also reduced availability and quality of grazing and water resources, and even increased susceptibility to worms and ticks (USDA, 2017). These issues may motivate cattle ranchers and producers to cull or sell cattle earlier than planned, which reduces the breeding stock and negatively impacts cattle inventory in the following years as well. As in case of hay, reduced economic activity in cattle sector also leads to significant economic losses in Indian reservations.

We find that a change towards drier conditions impacts hay and cattle productivity differently. Hay producers experience reduction in productivity through reduced hay yields immediately during the year when the conditions become drier, but the yields in the next year are not impacted. On the other hand, if cattle producers respond to drier conditions by reducing cattle inventory, this implies a smaller breeding stock and less cattle production in the year following the drought, i.e. the effect of drought on cattle production is both immediate and lagged. Larger economic contribution of cattle production compared to hay production in a region, coupled with the extended effects of drought on cattle production beyond the year of drought, results in larger estimated regional economic losses derived from the direct impacts of drought on cattle sector compared to hay sector. Although estimated disruptions in hay production due to drought are smaller, reduced hay availability may have considerable negative consequences for cattle production if it depends heavily on hay for feed as a result of reduced grazing efficiency.

This study is the first one to examine direct impact of drought on selected agricultural sectors and resulting regional economic impact, specifically in Indian reservations. However, it is important to highlight the lack of data available directly for the reservations as one of the study limitations. The calculated direct and total economic impacts are based on the estimates of the initial cattle and hay production within each reservation, but they may be larger or smaller than the actual (unobserved) production in a given reservation, which would have an over- or underestimating effect on the calculated impacts. Another limitation is use of fixed cattle and hay prices in the calculation of the economic impacts, although commodity prices are volatile and respond to events such as droughts. This causes overestimation of the calculated economic impacts. It is unclear whether the underestimation of the impacts due to potentially underestimated cattle and hay production in the reservations is compensated with the overestimation of the impacts due to not accounting for the change in cattle and hay prices during drought. Despite that, our findings represent a fair approximation to the actual impacts.

The findings show that drought can have significant negative effects on tribal economies by negatively impacting productivity of the agricultural sectors, similarly as it does across the U.S. However, the issue of drought and climate change is more severe for reservations, where agriculture plays an important role in tribal economies and is a source of subsistence in many communities, and where the ability of tribal governments to respond to drought is limited. Our findings show that it is important that the tribes are able to monitor drought, and identify and implement actions for climate change and drought adaptation and mitigation. For them to do so successfully, financial and human resources as well as collaboration with researchers, policy makers, state and local governments and stakeholders may be critical (Knutson et al., 2007; Redsteer et al., 2013, Chief et al., 2016). Agricultural producers specifically may benefit from a training to recognize the onset of a drought, learning about different strategies to respond to drought and their implications, as well as access to financial assistance needed to implement these strategies (Knutson et al., 2007). Finally, allowing reservations easier access to their water resources by simplifying the water rights settlement process and providing financial support to build the necessary infrastructure can help alleviate the drought and its negative impact on reservation economies.

ACKNOWLEDGMENTS

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Table. Selected economic indicators by reservation (2018).

Reservation name	Population below poverty level (%)	Employment in Agriculture, forestry, fishing and hunting, and mining (%)	Unemployment rate (%)
Hopi	36.8	0.6	6.4
Navajo	39.5	3.5	18.1
San Carlos	47.0	5.4	30.4
Tohono O'odham	46.3	1.8	28.8
White Mountain	43.2	2.8	34.4
Duck Valley	36.2	9.5	18.4
Goshute	33.6	1.9	25.7
Moapa River	24.8	0.0	14.2
Pyramid Lake	19.0	6.5	18.7
Washoe	13.8	1.1	10.0
Acoma	21.7	3.4	17.8
Jicarilla Apache	27.3	3.8	18.6
Laguna Pueblo	27.0	3.2	21.3
Mescalero Apache	32.4	2.5	20.4
Pueblo of Isleta	26.6	2.0	13.0
Zuni	34.5	1.6	22.0
Uintah and Ouray	14.5	21.4	7.7
U.S. Total	11.8	1.8	5.9

Source: U.S. Census Bureau, 2014-2018 American Community Survey 5-Year Estimates