

Range Condition in Relation to Climate, Energy Variables, and Beef Cattle Population Dynamics in New Mexico

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Abstract: Understanding the relationship between range condition and economic, environmental, and biotic factors and providing a description of the range condition cycle plays an important role in promoting the sustainability of ranching in New Mexico State (NM). This study aimed to understand the linkages between range condition and crude oil production, crude oil prices, mean annual precipitation, mean annual temperatures, and beef cattle population as well as to describe the fluctuation in range condition cycle. Data for all study variables were collected for the period 1958–2017 period. The generalized autoregressive conditional heteroscedasticity (GARCH) and its exponential version (EGARCH) models were used to examine the relationships between range condition and all study variables. Range condition cycle was identified by using spectral analysis and seasonal adjustment function. Crude oil prices ($\beta = -0.2669$), mean annual precipitation ($\beta = 0.0963$), and mean annual temperatures ($\beta = -13.2914$) were the only predictors of range condition. The length of range condition cycle was 10 years. Range condition began to decline from the second year and continued through the third year and then began to increase from the fourth year and continued through the tenth year. Generally, range condition showed a declining trend between the 1970s and the mid of 2010s.

Keywords: Range condition cycle, crude oil, temperatures, precipitation, beef cattle population.

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حالة المراعي وعلاقتها بالمناخ ومتغيرات الطاقة وديناميكيات أعداد الماشية في نيو مكسيكو

المستخلص: إن فهم العلاقة بين حالة المراعي والعوامل الاقتصادية والبيئية والحيوية وتقديم وصف لدورة حالة المراعي يلعب دورًا مهمًا في تعزيز استدامة تربية الماشية في ولاية نيو مكسيكو. تهدف هذه الدراسة إلى فهم الارتباطات بين حالة المراعي وإنتاج النفط الخام وأسعار النفط الخام ومتوسط هطول الأمطار السنوي ومتوسط درجات الحرارة السنوية وتعداد ماشية اللحم بالإضافة إلى وصف التقلب في دورة حالة المرعى. كانت بيانات جميع متغيرات الدراسة متاحة للفترة 1958-2017. تم استخدام نماذج التباين غير المتجانس الشرطي الانحداري التلقائي المعمم (GARCH) ونسخته الأسية (EGARCH) لفحص العلاقات بين حالة المراعي وجميع متغيرات الدراسة. تم تحديد دورة حالة المراعي باستخدام التحليل الطيفي ودالة التعديل الموسمي. كانت أسعار النفط الخام ($\beta = 0.2669$) ومتوسط هطول الأمطار السنوي ($\beta = 0.0963$) ومتوسط درجات الحرارة السنوية ($\beta = -13.2914$) هي المتنبئات الوحيدة لحالة المراعي. بلغت مدة دورة حالة المراعي 10 سنوات. بدأت حالة المراعي في الانحدار من السنة الثانية وحتى السنة الثالثة ثم بدأت في الارتفاع من السنة الرابعة وحتى السنة العاشرة، وبشكل عام، أظهرت حالة المراعي اتجاهًا تنازليًا بين السبعينيات ومنتصف العقد الأول من القرن الحادي والعشرين.

الكلمات المفتاحية: دورة حالة المراعي، النفط الخام، درجات الحرارة، هطول الأمطار، أعداد الماشية.



INTRODUCTION

Range forage is considered a critical natural resource for the production of red meat essential for human consumption (Holechek et al., 1989; Stoddart & Smith, 1955). At the beginning of the last century, rangeland was heavily grazed without control (Stoddart & Smith, 1955). This was due to the lack of knowledge of range science, delays in starting research in this field, and giving priority to forest research (Sayre, 2019). Until 1935, management of rangelands was carried out by experts from related fields such as agronomy and forestry (Campbell, 1948). Today, much range research has been conducted, and methods of scientific management that can be utilized to promote range resources and ensure the sustainability of rangelands ecosystem (Campbell, 1948; Stoddart & Smith, 1955). However, many debates are still being held about several subjects such as grazing capacity and a public land management, indicating that more research have to be conducted (Campbell, 1948). This highlights the importance of range condition, which is considered a measure of the efficiency of management in the long term (Holechek et al., 1989). Also, range condition is a term used widely in the range management, and it refers to amount of vegetation remaining on the unit of land (Holechek et al., 1989). Furthermore, range condition cycle refers to the behavior of range production that repeats itself in regular manner over a period of years. Understanding this cycle helps managers to make a good management decision-increase or decrease their herd's size. (Zaied et al., 2021). Range condition can be affected by several factors, including, production and prices of energy (Allred et al., 2015; Holechek & Sawalhah, 2014), climate change (precipitation, temperature) (Stoddart & Smith, 1955), and stocking rates (Sayre, 2019).

Crude oil production might affect range condition. The loss of land to crude oil production is a big issue, impacting rangelands (Allred et al., 2015). About 3 million hectares of land have been utilized for crude oil pads, roads, and other supporting infrastructures in North America during the 2000-2015 period (Allred et al., 2015). In addition, since 1920s, cheap fossil fuels (oil) have led to rapid increase in tractors' utilization (Holechek, 2009). As result, vast area of rangelands was plowed although it was not suitable for sustained cultivation (Holechek, 2009). However, in USA, agricultural sector highly relies on fossil fuels (oil) to power agricultural machineries, produce nitrogen fertilizer, and goods transportation (Holechek, 2006). Therefore, low oil prices lead to decline forage crops prices (Zaied et al., 2020). This makes raising cattle using harvested forage and feed grains economically feasible (Holechek, 2006). This may result in decreased pressure on rangelands. Furthermore, the several range management procedures require fossil fuel inputs, but these are lower compared to pasturelands (Holechek, 2006).

In New Mexico State (NM), drought and high temperatures may have a negative effect on range condition. Since the 1970s, severe and longer droughts and higher temperatures have been observed (CHANGE, 2007). This will have intense impacts on rangeland, especially those located in semiarid and arid areas (CHANGE, 2007; Sawalhah et al., 2019). When drought lasts more than one year, severe mortality among forage plants-such as black grama-will occur, leading to decline carrying capacity to 50-60% (Herbel et al., 1972). After this event, restoration of the indigenous ecosystem may require at least 5-15 years (Boykin et al., 1962; Stoddart & Smith, 1955). Moreover, high temperatures lead to lose water from plant and soil through high evaporation-reaches 250 cm annually in NM. This results in requiring greater amount of water that may not be met, affecting plant performance (Stoddart & Smith, 1955).

Beef cattle population may impact range condition in NM. One of the most significant potential effects of climate change on livestock ranching is the reduction in rangelands carrying capacity (Polley et al., 2013; Woodworth-Jefcoats et al., 2017), to levels at which ranching is economically unviable (Holechek et al., 2020). For instance, the carrying capacity-in Chihuahua Desert, NM, USA- has declined by approximately 43% between 1967–2018 (McIntosh et al., 2019). It has been esti-

mated that financial loss is the only results when forage production of one acre drops to less than 45.3 kg (Holechek, 1996b). To ensure range condition improvement, conservative stocking rate is 10-30% below grazing capacity should be applied (Holechek, 1996b; Holechek et al., 1998). NM is one of the driest states in the USA (Driest States in the US - Current Results, 2024), so poor practices such as using incorrect stocking rates may lead to rangelands degradation, while its recovery may be extremely difficult (Holechek et al., 1989).

A change in pastoral society and rangelands will be empty is predicted in the future (Reid et al., 2014). The income from rangelands cannot longer meet the demand for needed services such as schools, health care, and media, resulting in moving young people to cities where job opportunities are available (Reid et al., 2014). This trend will be further accelerated due to drought and increased temperatures caused by global warming that makes it very difficult to continue ranching beef cattle on rangelands (Reid et al., 2014). Therefore, understanding the linkages between range condition and climatic, economic, and biological factors and providing quantitative descriptions of forage production is essential to enhance resilience to drought and economic impacts (Zaied et al., 2021). The objectives of this study were to understand the relationships between range condition and production and prices of crude oil, mean annual precipitation, mean annual temperatures, beef cattle population and provide a description of range condition cycle.

MATERIALS AND METHODS

Study Area: The study focused on range condition in NM that is located in southwestern USA. About 92% of NM's area is classified as suitable rangelands. The average of oil production in 1958-2017 period was 78,625,815 barrels, consisting of 5% of USA total oil production (Federal Reserve Economic Data | FRED | St. Louis Fed, 2024). In this State, there are 4 types of climates which are mild, arid or semiarid, and continental climate. Mean annual precipitation varies from less than 254 mm in the south to more than 508 mm at higher elevations in the State. Most of the precipitation falls in July and August. The average annual temperatures vary from 17° C in the southeast to 4.4° C in the northern high mountains and valleys (New Mexico Weather, 2024). Between 1979-2017, the average of beef cattle population was 525,589 head (USDA - National Agricultural Statistics Service - New Mexico, 2024).

Data Retrieval and Documentation: The data used in this paper cover the 60-years period from 1958 to 2017. These data included biological, environmental, and economic variables. The biological data included annual range condition (%) and beef cattle population (numbers of cows that were more than two years old) that were retrieved from (USDA - National Agricultural Statistics Service - New Mexico, 2024). The environmental data consisted mean annual precipitation (mm) and mean annual temperature (°C) that were downloaded from (Western Regional Climate Center, 2024). The economic data including crude oil production (barrel), crude oil prices (\$/barrel), and consumer price index (CPI) were obtained from (Federal Reserve Economic Data, 2024).

Data Analysis: The CPI was used to adjust crude oil prices to reflect their value in 2017 dollars. Normal distribution, heteroscedasticity, and autocorrelations were tested by using Shapiro-wilk test, portmanteau test statistics and the Engle-Lagrange multiplier tests at time lags (years) 1-12, and Durbin-Watson tests, respectively. Our data exhibited both heteroscedasticity and autocorrelation. Therefore, to examine the linkages between mean annual range condition and all study variables the generalized autoregressive conditional heteroscedasticity (GARCH) and its exponential version (EGARCH) models were utilized at alpha level of 0.05. SAS 9.4 (SAS Institute, Cary, NC, US) was used to obtain these objectives. These models are particularly suitable for time-series data

exhibiting heteroscedasticity and volatility clustering, which are common in ecological and economic datasets. The choice of GARCH/EGARCH was based on preliminary tests (e.g., ARCH effect test, stationarity check) that confirmed the presence of time-varying variance in the data. The duration of the annual range condition cycle was assessed through spectral analysis, a feature accessible within the SPSS software. The variations within the mean annual range condition cycle were analyzed using the seasonal adjustment function, which is available in the EViews software. This study did not involve any human participants or experimental use of animals. All data were obtained from publicly available sources or official databases, and the research complies with institutional and international ethical standards.

RESULTS AND DISCUSSION

Variables Predicting Range Condition: A summary of simple regression analysis for variables predicting mean annual range condition was reported in Table 1. As can be seen, mean annual crude oil prices, mean annual precipitation, and mean annual temperatures were the only predictors of mean annual range condition. GARCH model revealed that mean annual crude oil prices were negatively correlated with mean annual range condition ($\beta = -0.2669$) and explain about 28% of its variations. This can be attributed to increased fossil fuel prices that may limit range management procedures-such as brush control-that aim to improve rangeland production (Holechek, 2006; Holechek et al., 1989). Another possible explanation for this relation is that increased fossil fuel prices might lead to increased relay on alternative energy sources such as wind and bio fuels (Brown, 2008; Holechek et al., 1989). This may require vast area of rangelands and considerable amount of range plants material, respectively, resulting in a decline in range condition.

Table:(1).. Results of simple regression analyses of independent variables used to forecast mean annual range condition (%) in NM between 1958 and 2017 using GARCH or EGARCH model.

Independent Variables	Intercept	Estimate (β)	P-value	AR1	R ²
Crude oil production ¹	54.328	1.5835E-7	0.248		
Mean annual crude oil prices ¹	81.7138	-0.2669	0.026	-0.4283	0.28
Mean annual precipitation ²	35.1144	0.0963	0.0001	-0.5822	0.33
Mean annual temperatures ¹	229.0969	-13.2914	0.0017	-0.4067	0.34
Beef cattle population ²	40.9809	0.000051	0.489		

¹ GARCH model; ² EGARCH model

Mean annual precipitation ($\beta = 0.0963$) and mean annual temperatures ($\beta = -13.2914$) contributed significantly to variations in mean annual rang condition. And they both explained 33% and 34%, respectively, of the variation in mean annual range condition. Table 1. shows that mean annual range condition was positively linked to mean annual precipitation, whereas it negatively correlated with mean annual temperatures. Adequate precipitation can result in luxuriant plant growth (Stoddart & Smith, 1955), leading to increased mean annual range condition. However, drought can cause mortality among plant forage (Herbel et al., 1972), resulting in decreased mean annual range condition. In New Mexico, prolonged drought (4-6 years) plagues rangeland every 40 years (Holechek, 1996a). To make matters worse, high temperatures cause high rate of evaporation-reaches 250 cm in NM-resulting in a decline in the water required for plant growth (Stoddart & Smith, 1955). This could be the reason for the declining trend in mean annual range condition between 1970_s and the middle of 2010_s (Figure 2).

The findings of this study partially support the study hypotheses. As expected, crude oil prices and climatic variables were significantly correlated with changes in range condition, aligning with the

hypothesis that climate is a primary driver of rangeland dynamics. On the other hand, contrary to expectations, beef cattle population did not show a significant relationship with range condition. This may be attributed to the consistent use of conservative stocking rates in the study region, which may have mitigated grazing pressure on rangelands (Holechek, 1996b; Holechek et al., 1998). These results suggest that while climatic variables remain a dominant factor, effective rangeland management practices may buffer against some biological pressures.

Annual Range Condition Cycle: Based on the periodogram in Figure 1, the length of the mean annual range condition cycle was 10 years, which was used to decompose its timeseries. As can be seen in Figure 2, the seasonal pattern of mean annual range condition specified that mean annual range condition in each cycle began to decrease from the second year and continued through the third year and then began to increase from the fourth year and continued through the tenth year which was the peak of mean annual range condition. In general, mean annual range condition was below average for 6 years in each cycle. Zaid et al. (2021) studied the annual cycle of drought in NM, and their results were not consistent with our results, in other words, their results could not explain the behavior of mean annual range condition, especially since, when our regression model showed that mean annual precipitation and the mean annual temperatures significantly correlated with mean annual range condition, highlighting the need for further research to understand the behavior of these factors and their potential interactions.

In spite of the meaningful insights obtained, this study has several limitations. First, the analysis depended on aggregated annual data, which might hide short-term variations or localized impacts in range condition. Second, the study focused on arid and semi-arid region in NM, limiting the generalizability of findings to other ecosystems with different management practices or climatic features. Finally, it is important to highlight that rancher should be aware of the potential risks involved in relying on these predictions, as natural and social systems can behave unpredictably.

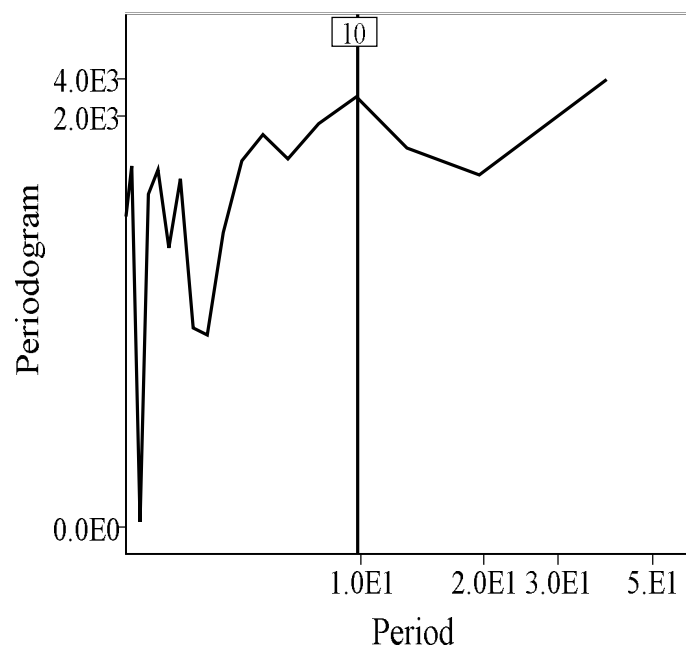


Figure: (1). The periodogram of mean annual range condition was obtained from spectral analysis in SPSS. The x-axis represented the period (years) in logarithmic scale. The y-axis represented the periodogram values (unitless). Peak value indicated the length of mean annual range condition cycle in 1958-2017 period in NM.

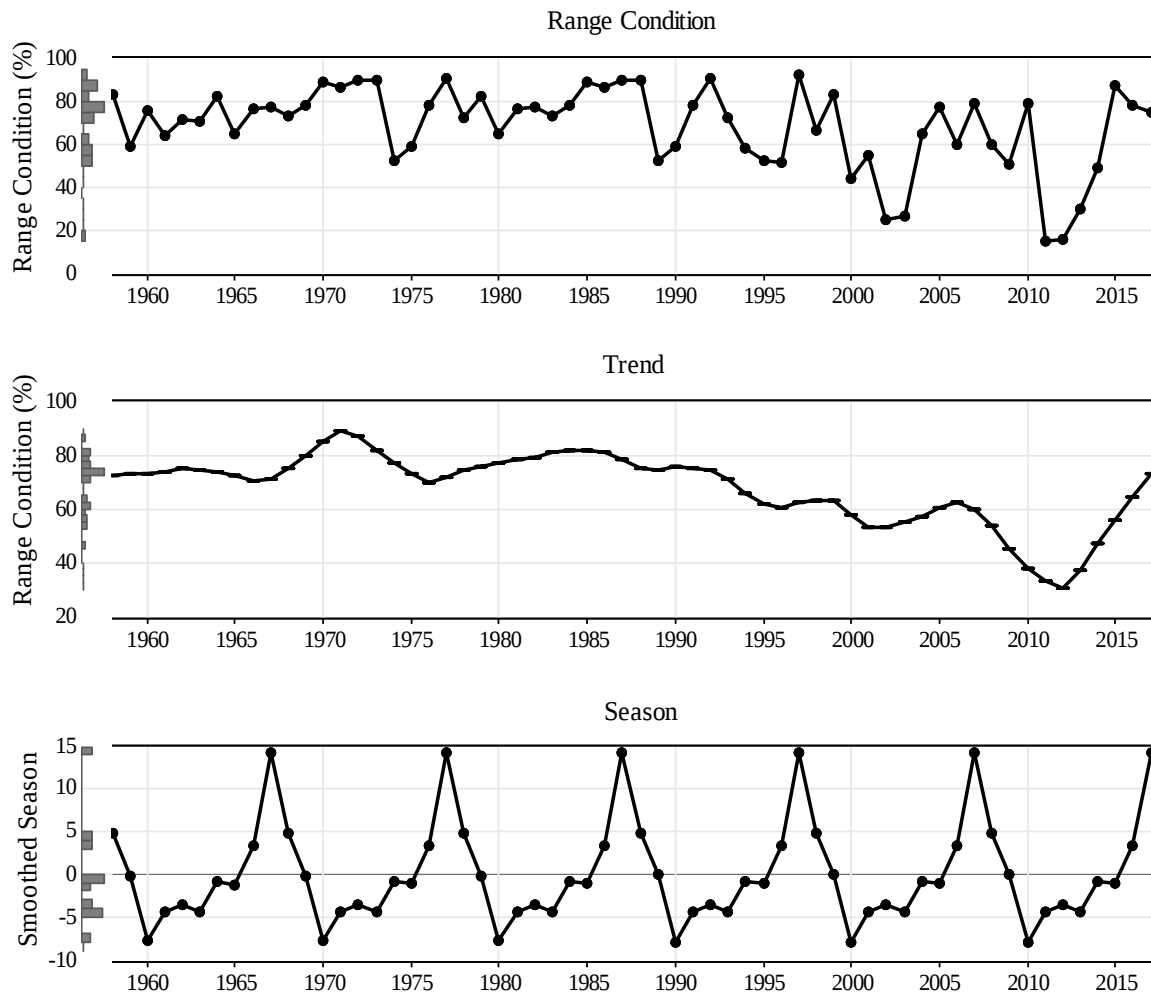


Figure: (2). The seasonal adjustment function output included 3 panels. The top panel showed actual mean annual range condition (%). The middle panel showed mean annual range condition trend. Smoothed seasonality for mean annual range condition was showed in the bottom panel. 10 years was the length of each cycle. Mean annual range condition data of 60 years (1958-2017) in NM used to conduct this analysis.

Conclusions

This study highlighted the response of range condition to crude oil production, crude oil prices, mean annual precipitation, mean annual temperatures, and beef cattle population and described the behaviour of the range condition cycle in NM. Both crude oil prices and mean annual temperatures had negative relationship with it, whereas mean annual precipitation had positive relationship with the mean annual range condition. In each cycle, range condition declined gradually from the second year through the third year and then increased from the fourth year through the tenth year. The findings of this paper can help ranchers develop effective and workable plans for the future. For instance, a rancher can reduce their herd size when a decrease in range condition is predicted for the coming years. Conversely, they can increase their herd size if an increase in range condition is anticipated. Furthermore, we emphasize that research is trying to predict the nature, but nature, sometimes, does not follow consistent behavior. Therefore, ranchers should be careful and consider the risk when using such findings.

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Duality of interest: The authors declare that they have no duality of interest associated with this manuscript.

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