National Quail Symposium Proceedings

Volume 6 Article 36

2009

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Recommended Citation

Lusk, Jeffrey J.; Guthery, Fred S.; Peterson, Markus J.; and DeMaso, Stephen J. (2009) "Long-Term Climate Trends and Northern Bobwhite Populations in South Texas," *National Quail Symposium Proceedings*: Vol. 6 , Article 36.
Available at: http://trace.tennessee.edu/nqsp/vol6/iss1/36

Long-Term Climate Trends and Northern Bobwhite Populations in South Texas

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Because climate change and its associated weather changes may influence population trends of birds, we analyzed northern bobwhite (*Colinus virginianus*; bobwhite hereafter) age ratios and abundance in relation to climate trends during 1908-1997 in south Texas. Weather variables included regional mean temperature maxima for June, July, and August, and precipitation totals for autumn (Sep-Nov), winter (Dec-Feb), spring (Mar-May), and summer (Jun-Aug). Long-term temporal trends for these weather variables were estimated with a linear regression. Yearly weather data were used to predict bobwhite age ratios (juv/ad in autumn and winter) and abundance between 1908 and 1997 using neural network models. We compared these predictions with data available from various bobwhite surveys in south Texas over the period 1940-1999. Means for daily maximum temperature during summer declined at rates between 1.6 and 2.3°C/century. No temporal trends were detected for seasonal precipitation (1908-1997), age ratios (1940-1999), or abundance (1977-1998). Neural models developed independently to predict bobwhite age ratios and bobwhite abundance from weather data produced predictions that were consistent with each other. Years with high age ratios tended to coincide with or precede years of high abundance.

Citation: Lusk JJ, Guthery FS, Peterson MJ, DeMaso SJ. 2009. Long-term climate trends and northern bobwhite populations in South Texas. Pages 328 - 337 in Cederbaum SB, Faircloth BC, Terhune TM, Thompson JJ, Carroll JP, eds. Gamebird 2006: Quail VI and Perdix XII. 31 May - 4 June 2006. Warnell School of Forestry and Natural Resources, Athens, GA, USA.

Key words: climate trends, *Colinus virginianus*, northern bobwhite, south Texas

Introduction

Researchers have demonstrated that global climate change may be associated with long-term trends in bird populations (Root 1993). There also is evidence that the population dynamics of some avian species, such as northern spotted owls (*Strix occidentalis caurina*), might be governed by weather patterns independent of habitat (Franklin et al. 2000). In England, 31% of bird species (n = 65) exhibited significant trends towards earlier nest-initiation over a 25-yr period (Crick et al. 1997). These changes in nest-initiation date were related to climate change for 38% of the species exhibiting long-term trends (Crick and Sparks 1999). In the United States, the mean Julian date for the initiation of the first clutch of the Mexican jay (*Aphelocoma ultramarina*) advanced by 10.1 days between 1971 and 1997 (Brown et al. 1999). Klimstra and Roseberry (1975) reported that the length of the bobwhite nesting season declined by 12 days for each 1°C increase in mean July-August maximum daily temperature. Climate change is thought to be a leading cause of the decline of capercaille (*Tetra urogallus*) in Scotland between 1975 and 1999 (Moss et al. 2001). Similarly, Guthery et al. (2000) hypothesized that global climate change could reduce the percentage of female bobwhites that attempt to lay and the number of nesting attempts per hen, which could lead to reductions in annual production.

The northern bobwhite's range extends through most of the eastern and central parts of the United States (Kaufman 1996). Because bobwhites are an important game species across their range, bobwhite demography is relatively well studied (e.g., Roseberry and Klimstra 1984) compared to other avian

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species. Bobwhite populations tend to exhibit boom-or-bust dynamics (Stoddard 1931, Roseberry and Klimstra 1984, Peterson 2001), and weather patterns may be a determining factor in such dynamics. Because they are so well studied, bobwhites offer a unique opportunity to evaluate the impacts of climate change on their life-history characteristics.

Our aim was to investigate patterns in bobwhite demography with respect to weather patterns. To that end, we examined long-term trends in summer (Jun, Jul, and Aug) temperature maxima and seasonal (fall, winter, spring, and summer) rainfall in south Texas and compared these trends with bobwhite age-ratios and abundance. If climate patterns strongly influence bobwhite population dynamics, then we expected age ratios and bobwhite abundance to correlate with climate patterns within the same timeframe. Finally, we used neural network models to predict bobwhite age ratios and abundance between 1908 and 1997 based on weather records from south Texas. Previous research on bobwhites demonstrated the importance of weather conditions on abundance (Lusk et al. 2002) and production (Guthery et al. 1988, 2002). We used the predictions of the age ratio model to predict when boom years should have occurred within the historical record and corroborated these predictions using the results of the abundance model.

Study Area

Data used in these analyses were obtained from the South Texas Plains. This ecoregion has a level to rolling topography with elevation ranging from ∼305 m to sea level (Gould 1975). The South Texas Plains were originally a grassland savannah, but now contain a significant shrub component due to heavy grazing. This process is well established in desert grasslands (Bahre 1995). Age ratio data came from the Chaparral Wildlife Management Area (CWMA), a semiarid thornscrubland (Gabor et al. 2001) located in Dimmit and LaSalle counties of south Texas, and encompassing 61.5 km^2. Rainfall in the South Texas Plains varies between 40.6 and 88.9 cm annually (Gould 1975), while at the CWMA rainfall averages 64 cm annually (Hellgren et al. 1995, 2000).

Methods

We obtained data (EarthInfo, Inc. Boulder, Colorado, USA) from the weather station located in Falfurrias, Texas, which is roughly centered in the South Texas Plains. Records were available for the period 1908-1997, but were not collected continuously over this period. Whenever possible, we substituted data from the next nearest weather station (Carrizo Springs) when weather data for a particular year were unavailable from the Falfurrias station. Carrizo Springs is 224 km northwest of Falfurrias in the northwestern South Texas Plains. However, in some years, weather data were unavailable for both stations. Therefore, we had data for 79 of a possible 89 years. These data consisted of South Texas mean temperature maxima for June, July, and August, and precipitation totals for fall (Sep-Nov), winter (Dec-Feb), spring (Mar-May), and summer (Jun-Aug). We smoothed the time series for each variable with a 3-point moving average (Kendall and Ord 1990). Estimates of trend in weather variables through time were determined from the slope of the simple linear regression equation for time (year) regressed on each weather variable separately.

We also used linear regression to estimate trends in age ratio and abundance data. Age ratios were obtained from Lehmann (1984) and from records of the CWMA. These records encompassed the period 1940-1999 (n = 46 records for 60 years), but, as with the weather data, some years were missing from these data. Abundance data were obtained from Texas Parks and Wildlife Department's annual roadside quail survey (Peterson and Perez 2000). These records cover the period 1977-1998 and are continuous over the period.

Guthery et al. (2002) used a portion of the above described weather data to develop a neural model to predict bobwhite age ratios. Neural modeling is a powerful analysis tool for describing functional relationships between a set of predictors and responses. Further information on this modeling technique can

Table 1: Slope (β = point estimate) and 95% lower (LCL) and upper (UCL) confidence limits for the linear relation between weather variables and year in south Texas, 1908-1997.

	Slope		
Period	β	LCL	UCL
Mean maximum temperature (°C)			
June	-0.023	-0.037	-0.009
July	-0.016	-0.028	-0.004
August	-0.022	-0.034	-0.009
Seasonal precipitation (mm)[a]			
Fall	0.406	-0.739	1.551
Winter	0.386	-0.182	0.954
Spring	-0.015	-0.715	0.685
Summer	0.062	-0.828	0.953

[a] Fall = Sep-Nov, winter = Dec-Feb, spring = Mar-May, and summer = Jun-Aug

be found in Smith (1996) and a discussion of ecological applications of this method can be found in (Fielding 1999). Specifically, the neural model was developed using age ratio data from Lehmann (1984, :133; 1940-1972) and CWMA records (1973-1997) and the appropriate years of weather data (1940-1997), and contained 7 inputs (independent variables), 2 hidden nodes, and 1 output (age ratio). The model (Guthery et al. 2002) was developed using 80% of the data (n = 28) and the remaining 20% were used for model testing (n = 7). We used this model to predict age ratios over the period 1908-1999, and the accuracy of these predictions was determined by comparing predicted age ratios with population abundance estimated from roadside counts (Peterson and Perez 2000). If the models performed acceptably, we would expect a crude correlation between age ratios and abundance because juveniles normally make up 50% of the autumn population. Such comparison allowed us to examine patterns of population booms based on production.

Bobwhite abundance was estimated from the above weather data in an analogous manner using a neural model developed for Texas Parks and Wildlife Department to predict fall abundance from weather and land-use data (Lusk et al. 2002). We used the predictions of this second neural model to examine population booms based on production as estimated from the age ratio model and to assess the overall performance of the two models. We did this by comparing the agreement with regard to increases and decreases in bobwhite productivity between the two models. Because the dependent variables used in the two models were different (abundance vs. age ratios), and were gathered at different times and in different locations within the South Texas Plains, this comparison represents a true validation of the model (Conroy 1993, Oreskes et al. 1994, Conroy et al. 1995). However, the neural model developed by Lusk et al. (2002) had 3 variables in addition to those used in the model of age ratios (Guthery et al. 2002): 1) proportion of county area in cultivation, 2) head of cattle per ha of non-cultivated land, and 3) previous year's bob-

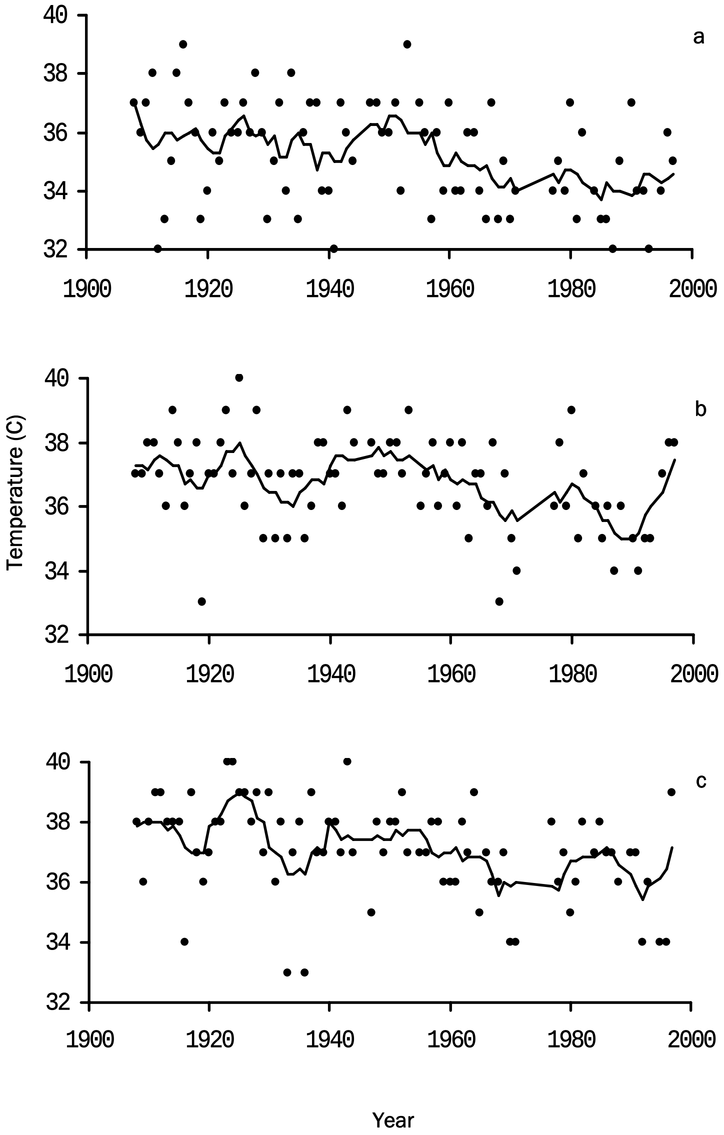

Figure 1: Mean of daily temperature maxima and smoothed trends (3-point moving average) for (a) June, (b) July, and (c) August in south Texas (Falfurrias station), 1908-1997.

white count. We used long-term weather data from south Texas to predict annual bobwhite abundance from 1908 until 1997 using this model (Lusk et al. 2002). Since we were interested only in the effects of weather, we held the values of the other three variables constant at their long-term means, and, therefore, the results we obtained are due to variation in weather only. By holding these variables constant at their mean, we assumed that this would not influence the overall dynamics of the bobwhite population response to weather variables. We tested this assumption by varying the value used for these variables. In all cases, the subsequent dynamics were similar and only changes in magnitude were observed. Therefore, we report results only for the analysis in which cultivated land, livestock density, and previous year's counts were held at their long-term means.

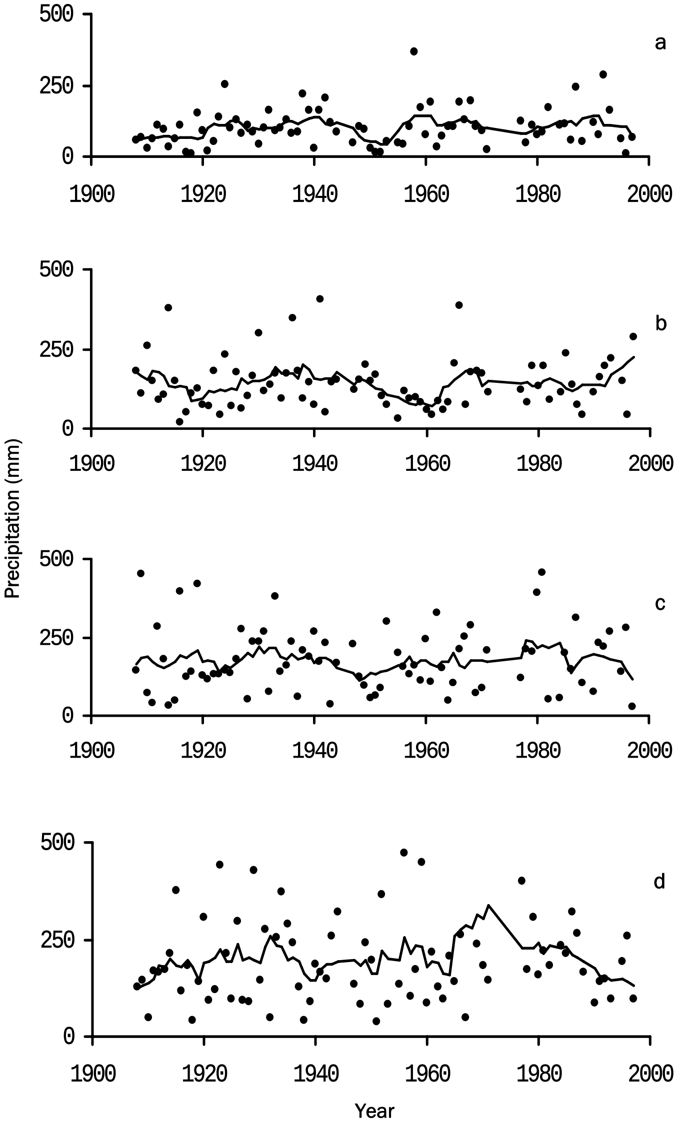

Figure 2: Seasonal precipitation and smoothed trends (3-point moving average) for (a) winter, (b) spring, (c) summer, and (d) fall in south Texas (Falfurrias station), 1908-1997.

Results

Long-term weather patterns

The means of maximum daily temperatures for the summer months (June, July, and August) exhibited a long-term, but highly variable, decline between 1908 and 1997 ($P < 0.05$; Table 1, Figure 1). The rate of decline ranged between 1.6 and 2.3°C/century (Table 1). However, there was no apparent long-term trend in seasonal precipitation ($P > 0.10$; Table 1, Figure 2). Regression coefficients for all seasons indicated a change in magnitude of precipitation of only a fraction of a millimeter per century (Table 1). Further, the 95% CLs for precipitation in all seasons overlapped zero.

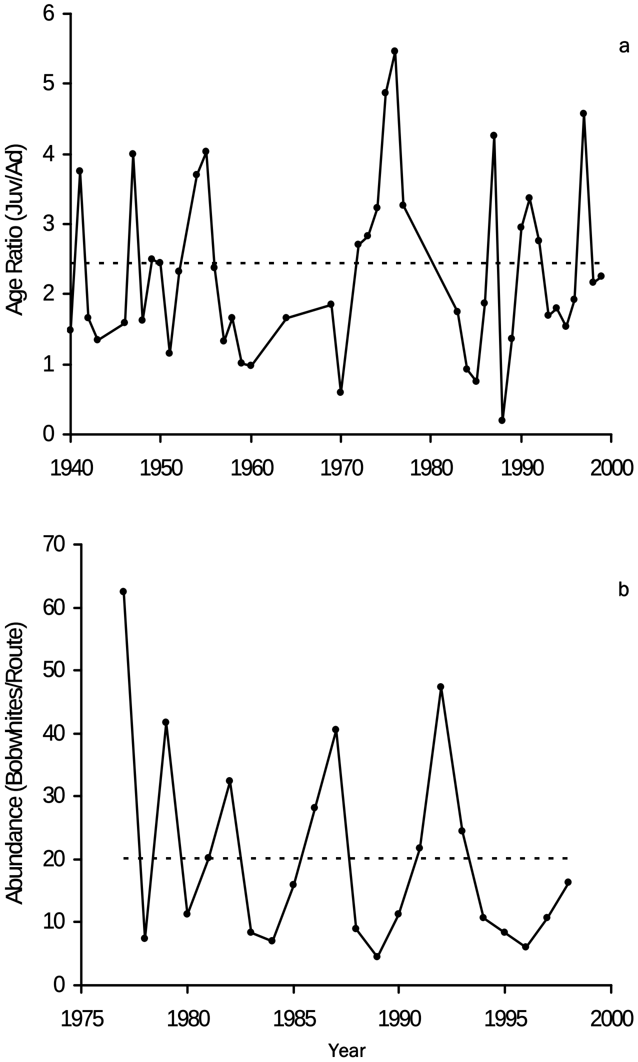

Figure 3: Empirically observed (a) age ratios and (b) abundance of northern bobwhites in south Texas. Dashed line in (a) indicates the mean age ratio of 2.45 juv/ad (1940-1999), and in (b) indicates the mean abundance of 20.22 bobwhites/route (1977-1998).

Bobwhite population trends

During 1940-1999, bobwhite age ratios at CWMA exhibited considerable variability through time (CV = 52.7%; Figure 3a). Further, the linear functional relationship was y = 2.1 + 0.003x (P = 0.753), indicated no temporal trend in age ratios. The intercept was close to the mean for the dataset (2.45 juv/ad) and the 95% CLs encompassed zero. Similarly, bobwhite abundance in the South Texas Plains between 1977 and 1998 exhibited considerable variability through time (CV = 71.0%; Figure 3b) and no temporal trends evident in the time series (y = 29.5 - 0.809x; P = 0.129). The intercept was higher than the mean abundance (20.2 bobwhites/route) for the South Texas Plains over the same period.

Neural model projections

Assessments of model performance are provided in Guthery et al. (2002) and Lusk et al. (2002). Neural model predictions of age ratios based on weather

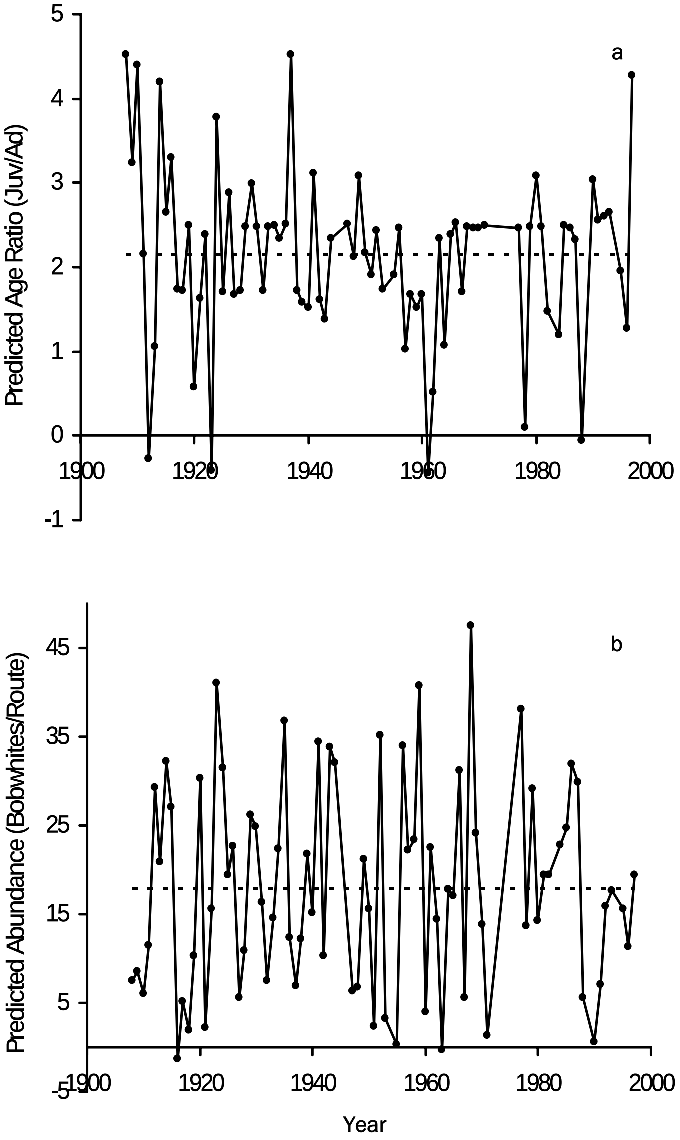

Figure 4: Neural model predictions of northern bobwhite (a) age ratios and (b) abundance in south Texas based on weather variables. The horizontal line in (a) indicates the mean age ratio of 2.15 juv/ad and in (b) indicates the mean predicted abundance of 17.88 bobwhites/route.

variables showed no apparent trend through time (P = 0.41) but were characterized by high variability (CV = 47.7%; Figure 4a). An analysis based on abundances from roadside counts (Peterson and Perez 2000) indicated that population booms were associated with 3-4 years of above-average bobwhite production. Therefore, we expected population booms to occur with $\geq$3 years of above-average age ratios, as predicted by the neural model. Based on this criterion and the neural model projections, boom years were expected in 1910, 1916, 1931, 1970, 1981, 1992, and 1993. However, abundances predicted from the neural model indicated boom years (2 mean abundance, or $\sim$40 bobwhites/route) in 1923, 1959, and 1968 (Figure 4b). Further, except for 2 cases, all of the years expected to have population booms based on age ratios were below mean predicted abundance (20.2 bobwhites/route; Figure 4b). That is, the years for which booms occurred in south Texas generally had lower than average predicted abundance. Although our expectations of the occurrences of boom years were not borne out by the abundance predictions, our subjective observation of the 3-4 years of predicted above-average production preceding a boom year may have been spurious. Further, years of high abundance tended to co-occur or follow years of above-average production, and trends tended to change in the same direction (i.e., when age ratios increased from one year to the next, abundance also tended to increase from the previous year) (Figure 4b).

Discussion

Our analysis of bobwhite demography relative to weather variables in south Texas was subject to sources of uncertainty and bias that require explanation. First, the weather variables used in modeling exert variable influence on quail demographics in semiarid environments. Precipitation occurring in association with reproduction has a more powerful influence on productivity than precipitation occurring in seasons that precede reproduction (Heffelfinger et al. 1999, Guthery et al. 2002). Thus, spring precipitation was the most meaningful and fall precipitation the least meaningful precipitation variable in our study; Kiel (1976) also found a strong correlation between spring precipitation and bobwhite productivity in south Texas. Guthery et al. (2002) observed a positive influence of June temperature maxima on the age ratio. They also observed that the age ratio was insensitive to July temperature maxima up to a threshold value of about 36°C; production collapsed above this temperature. August temperature maxima were relatively inconsequential because the reproductive season either had ended or was in sharp decline during August in south Texas (Guthery et al. 1988). We note, also, that temperatures and seasonal precipitation apparently interact in a complex, nonlinear manner in modulating the production of Gambel's quail (*Callipepla gambelii*) (Heffelfinger et al. 1999) and bobwhites (Guthery et al. 2002) in semiarid environments.

Second, the neural model predictions of age ratios and population trends were subject to several problems. The use of data from the Falfurrias or Carrizo Springs stations operated under the strong assumption that data from these stations were representative of the conditions throughout south Texas. Moreover, the weather variables used, though empirically supported in some cases, were arbitrary. Our modeling on means (temperature maxima) and seasonal totals (precipitation) did not account for any catastrophic events such as deluges or severe heat waves, or for the lag effects of rainfall on vegetation.

Third, the dependent variables (age ratio, counts) were themselves subject to uncertainty and bias. The age ratio is a function of reproduction phenology, the proportion of hens that lays, nest success, survival rates for chicks and adults, propensity to renest and multiple-brood, and length of the laying season (Guthery and Kuvlesky 1998). Weather undoubtedly influences these demographic variables in a complex manner. Counts of bobwhites from roadsides, the index used to judge population trends, also are suspected of bias (Lusk et al. 2002). For example, drought may force bobwhites to roadsides that have cover, thus biasing counts upward in drought years. Conversely, periods of precipitation may permit the general use of habitat space away from roadsides, thus biasing counts downward in rainy years. The comparative quantity of vegetation in rainy and drought years also would influence the visibility of coveys and individuals (Lusk et al. 2002).

Despite the problems mentioned above, the neural models revealed apparent patterns in the data (see Guthery et al. 2002). Model predictions reflected the high variability in production and abundance that characterizes quail populations in semiarid environments. The models also provided an approximation of historical trends in production and abundance. As such, we can conclude that the model captures the dynamics of bobwhite populations in this region of their range.

In conclusion, our analysis contained weather variables (spring precipitation, June and July temperature maxima) that have empirical support as correlates of bobwhite production in semiarid environments. Whereas there was evidence of declining temperature maxima during 1908-1998, the rate of decline and the total decline over the period of record were small and probably not biologically significant for bobwhites. There was no trend in spring precipitation. Therefore, in accordance with the models in Kiel (1976), there was no trend in production or abundance of bobwhites, whether these trends were based on empirical data (1940-1997 for age ratios, 1977-1998 for populations) or on neural model predictions before and during the period of empirical record. Global climate change did not appear to be influencing bobwhites in south Texas during 1908-1998. However, as climate change progresses, this assessment will have to be reevaluated.

Acknowledgments

This research was supported by the Texas Parks and Wildlife Department, the Department of Forestry at Oklahoma State University (OSU), the Oklahoma Agricultural Experiment Station, the Game Bird Research Fund, the Bollenbach Endowment, and the Noble Foundation. We thank S. Fuhlendorf for commenting on an early draft of this paper. This research was approved for publication by the Oklahoma Agricultural Experiment Station.

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