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Abstract: We used Christmas Bird Count reports in conjunction with precipitation data from 9 locations in Texas, to investigate relationships between rainfall and northern bobwhite (*Colinus virginianus*) and scaled quail (*Callipepla squamata*) abundance. Regional differences in northern bobwhite abundance could not be predicted by precipitation regimes, whereas scaled quail abundance was negatively correlated with fall and winter rainfall. Differences in rainfall patterns were not significantly correlated with year-to-year changes in northern bobwhite and scaled quail abundance.

Key words: distribution, northern bobwhite, population fluctuations, regulating factors, scaled quail.

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Although most research suggests that quail distribution and abundance are regulated primarily by availability and quality of habitat (Johnsgard 1973, Goodwin and Hungerford 1977, Brown 1982, Brennan 1991, Rice 1991), quail populations periodically rise and fall even in areas with high-quality habitat. These fluctuations as well as interregional differences in abundance appear to be due primarily to differences in reproductive success (Lehmann 1953b, Parmalee 1955, Wallmo 1956, Robinson 1957, Speake and Haugen 1960, Schemnitz 1961, 1964, Campbell 1968, Campbell et al. 1973, Roseberry and Klimstra 1975).

Factors such as vitamin (Nestler 1946, Lehmann 1953*a*), mineral (Cain et al. 1982), and macronutrient deficiencies (Wood et al. 1986); increased intake of phytoestrogens (Leopold et al. 1976, Cain et al. 1987, Lien et al. 1987); and water deprivation or drought (Campbell et al. 1973, Kiel 1976, Cain and Lien 1985, Koerth and Guthery 1991) have been suggested as possible explanations for changes in reproductive success. However, only water deprivation, presumably due to annual and regional differences in rainfall expressed as differences in succulent foods and available free water, appears to have potential to induce the dramatic population fluctuations exhibited by quail populations (Koerth and Guthery 1991).

The purpose of this study was to investigate the relationship between rainfall and northern bobwhite and scaled quail abundance, and to compare effects of changing precipitation regimes between these 2 species.

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METHODS

We used Christmas Bird Count (CBC) data published in *American Birds* for 1966-91 from 9 locales in Texas to document regional and year-to-year differences in northern bobwhite and scaled quail abundance. For interspecific comparisons, we selected study areas within the area of distributional overlap of northern bobwhite and scaled quail. Location of the study areas roughly corresponds to the western edge of northern bobwhite distribution and the eastern edge of distribution of scaled quail (Johnsgard 1973). Christmas Bird Count locations included Amarillo (Potter County), Anzalduas-Bentsen (Hidalgo County), Big Spring (Howard County), Falcon Dam State Park (Starr County), Lubbock (Lubbock County), Midland (Midland County), Muleshoe National Wildlife Refuge (Bailey County), San Angelo (Tom Green County), and Stanton (Martin County). CBC's were standardized by dividing counts by person hours of observer effort.

We used both uncorrected rainfall data and rainfall corrected for evaporative loss, using Thornwaite's index of precipitation effectiveness (Critchfield 1966) for our analyses. Using simple and multiple regression ($P \leq 0.05$ needed to enter the model) analyses, proportional change in CBC's were compared to precipitation data (U.S. EDS 1966-91) collected at each CBC location, to determine year-to-year relationships between rainfall and proportional change in quail abundance. Precipitation data were grouped by month, season (winter, spring, summer, fall, breeding, nonbreeding), year, and difference from the long-term (1966-91) mean total annual rainfall for the analyses. Pearson correlation coefficients were calculated to determine correlations among precipitation classes. Christmas Bird Counts were compared to previous year's CBC and year using simple linear regression.

To investigate regional differences in quail abundance in relation to rainfall, for each study area, mean precipitation class values were compared to mean quail abundances (1966-91) using simple linear regression and stepwise multiple regression ($P \leq 0.05$ needed to enter the model). Precipitation classes were the same as those used for year-to-year analyses.

RESULTS

Year-to-year Trends

Relationships between proportional change in quail abundance and rainfall, and change in quail abundance and rainfall corrected for evaporative loss were highly correlated ($r = 0.808$, $P = 0.000$). For each variable, the corrected rainfall comparisons typically had smaller *r* and larger *P* values. For simplicity, the following results and discussion refer to analyses of uncorrected rainfall data (Table 1).

Abundance of both species of quail was shown to be significantly, but weakly, influenced by changing precipitation regimes. However, the factor explaining the most variation in abundance of both species was quail abundance the previous year (northern bobwhite: $r = 0.307$, $P = 0.000$; scaled quail: $r = 0.322$, $P = 0.000$). During the past 26 years, bobwhite abundance has not shown a long-term change ($r = 0.017$, $P = 0.791$), while scaled quail abundance has shown a decline ($r = -0.217$, $P = 0.001$).

Changes in northern bobwhite populations appear to be most sensitive to changes in precipitation during the previous breeding season (Table 1). Other significant predictors of bobwhite abundance were previous year's total rainfall and precipitation during fall, June, and October (Table 1). Previous year's total and previous year's breeding season rainfall were highly correlated ($r = 0.783$), as were October and fall precipitation ($r = 0.832$).

Changes in scaled quail abundance were most sensitive to variations in precipitation during January and winter (Table 1). January and winter rainfall were highly correlated ($r = 0.652$). Using step-wise multiple regression, no multivariable model was found to be significant ($P > 0.05$) for either species.

Regional Trends

No precipitation class significantly predicted regional differences in northern bobwhite abundance. May precipitation explained the most variation ($r = 0.448$, $P = 0.227$). Differences in scaled quail abundance among regions were best predicted by winter ($r = -0.654$, $P = 0.056$) and fall ($r = -0.622$, $P = 0.074$) rainfall. Using step-wise multiple regression, no multivariable model was found to be significant ($P > 0.05$) for either species.

DISCUSSION

Year-to-year Trends

Year-to-year differences in abundance of many species of quail have been associated with varying precipitation regimes. Research on California quail (*Callipepla californica*; Leopold 1977, Botsford et al. 1988), and Gambel's quail (*Callipepla gambelii*; Swank and Gallizioli 1954, Gallizioli 1960, 1965, Raitt and Ohmart 1968) found significant relationships between the amount and timing of precipitation and reproductive success and survival.

Studies throughout the northern bobwhite range have found significant positive relationships between year-to-year quail abundance and reproductive success, and breeding season rain-

Table 1. Significant ($P \leq 0.05$) relationships between year-to-year rainfall and changes in northern bobwhite and scaled quail abundance based on Christmas Bird Counts in Texas, 1966–91.

	Northern bobwhite			Scaled quail		
Precipitation class	r	r^2	P	r	r^2	P
Winter	–0.059	0.003	0.458	0.163	0.027	0.029
Fall	–0.170	0.030	0.032	–0.029	0.001	0.702
January	–0.099	0.010	0.212	0.283	0.080	0.000
June	0.168	0.028	0.034	–0.078	0.006	0.295
October	–0.159	0.025	0.046	0.015	0.000	0.840
Previous total	0.276	0.076	0.000	–0.040	0.002	0.593
Previous breeding season	0.292	0.085	0.000	0.061	0.004	0.414

fall (Lehmann 1953b, Parmalee 1955, Robinson 1957, Wunz 1959, Speake and Haugen 1960, Rosene 1969, Roseberry and Klimstra 1975, Kiel 1976). Other studies suggest that during the northern bobwhite breeding season, May and June are most important to quail productivity (Lehmann 1946, Klimstra 1950, Durrell 1958, Wallmo and Uzzell 1958). Our study found similar relationships for northern bobwhite in Texas (Table 1). We also noted a significant positive relationship between previous year's total annual rainfall and northern bobwhite abundance, as well as a negative relationship between fall and October rainfall and northern bobwhite abundance.

Our analyses indicated that the best predictor of northern bobwhite abundance was abundance the previous year, as did Roseberry and Klimstra's (1984) Illinois bobwhite study. Therefore, we believe that rainfall during the breeding season is important to northern bobwhite nesting success and production, and fall rainfall is also of importance as it affects the condition and quantity of breeding stock.

Much controversy exists over the importance of seasonal rainfall to year-to-year scaled quail abundance. Campbell (1968) and Campbell et al. (1973) working with scaled quail in eastern New Mexico, and Brown (1970) in Arizona, found significant positive relationships between scaled quail abundance and spring-summer rainfall. They also noted a lack of significant correlations between scaled quail abundance and October-March rainfall. Wallmo (1956) and Wallmo and Uzzell (1958) found that scaled quail in west Texas were affected by seasonal rainfall, with spring being of particular importance. These studies contrasted Schemnitz's (1961, 1964) findings that scaled quail in the Oklahoma panhandle were not affected by breeding season drought.

Similarly, our study found no correlation between spring-summer rainfall and scaled quail abundance. We did, however, find a positive relationship between changes in scaled quail abundance and January and winter rainfall (Table 1).

Due to low correlation coefficients ($r < 0.3$), we believe our year-to-year comparisons to be inconclusive, probably lacking biological significance. This was probably the result of inherent biases and imprecision associated with CBC's (Butcher 1990). A delayed response of quail to changing precipitation could also result in low correlation coefficients.

Regional Trends

This study found that regional differences in northern bobwhite abundance could not be predicted based on differences in rainfall. Speake and Haugen (1960) also noted no effect of breeding season rainfall on regional northern bobwhite abundance in Alabama. However, Guthery et al. (1988) found significant differences in reproductive performance between 2 populations of northern bobwhite in south Texas, existing in areas with different amounts of annual precipitation. Therefore, rainfall may have some effect on quail production and ultimately on abundance, but habitat quality is of more importance to the distribution of northern bobwhite in Texas (Johnsgard 1973, Goodwin and Hungerford 1977, Brennan 1991, Rice 1991).

Winter and fall precipitation were found to be the best predictors of regional differences in scaled quail abundance. However, these were all negative relationships, which was in contrast to several studies of scaled quail in New Mexico (Campbell 1968, Campbell et al. 1973), Arizona (Brown 1970), and west Texas (Wallmo 1956, Wallmo and Uzzell 1958) that suggest positive relationships between scaled quail abundance and rainfall. These discrepancies may be explained by differences in the climatography of the study areas.

Our study areas were situated on the eastern edge of the scaled quail's distribution in Texas (Johnsgard 1973), and had a mean October-March rainfall of 22.81 cm (range: 16.83-31.64). Our analyses indicated that as fall and winter (nonbreeding season) precipitation increased among study areas, scaled quail abundance declined. In Texas, precipitation increases during all seasons from west to east (Larkin and Bomar 1983), which coincides with a decline and ultimately an absence of scaled quail as one moves from west to east (Johnsgard 1973). Therefore, in this part of central Texas, scaled quail have more than enough rainfall to survive and reproduce; abundance and distribution are more likely limited by increasing fall, winter (nonbreeding season), and total precipitation that may alter or eliminate preferred habitats, such as open grasslands and bare ground (Schemnitz 1964, Campbell et al. 1973, Johnsgard 1973, Goodwin and Hungerford 1977, Eng 1986, Wilson and Crawford 1987). Other studies concerning scaled quail abundance in relation to rainfall (Wallmo 1956, Wallmo and Uzzell 1958, Campbell 1968, Brown 1970, Campbell et al. 1973) were conducted in regions with less than 10.0 cm of October-March precipitation. In these low precipitation areas, scaled quail may respond directly to rainfall. This is in contrast to our areas in central Texas where we believe birds responded to the influence of precipitation on habitat, at least on a regional level.

Interspecific Comparisons

Our data indicate that within the area of distributional overlap of northern bobwhite and scaled quail in Texas, rainfall influences the 2 species in very different ways. We are puzzled by the weak relationship between northern bobwhite and rainfall in a dry portion of their range. In contrast, rainfall appears to be ample for reproduction and survival of scaled quail. Additional precipitation, at least on a regional level, may be detrimental to their existence by eliminating preferred habitat components such as bare ground and open grasslands and providing more mesic and dense habitats that favor potential competitors such as the northern bobwhite (Schemnitz 1964, Campbell et al. 1973, Goodwin and Hungerford 1977, Eng 1986, Wilson and Crawford 1987).

Northern bobwhite abundance on our study areas has not shown a long-term change over the past 26 years. This coincides with the finding of Brennan (1991), who examined statewide trends in northern bobwhite abundance in Texas for 1960-90. Scaled quail abundance exhibited a decline over the same period.

Based on our findings, it is apparent that rainfall significantly influences scaled quail regional abundance, while it may not be a limiting factor of northern bobwhite in this part of their range. Although we believe our results represent actual quail-rainfall relationships, due to small *r* values for our year-to-year comparisons, we regard the findings as inconclusive, warranting further study. We suggest that research be initiated into the mechanisms of relationships between rainfall and quail abundance.

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