THE RELATIONSHIP BETWEEN BLACK-CAPPED VIREO (*VIREO ATRICAPILLUS*) TERRITORY DENSITY AND PRESCRIBED BURN AND ENVIRONMENTAL VARIABLES AT THE KERR WILDLIFE MANAGEMENT AREA, KERR COUNTY, TEXAS

THESIS

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Vireo territory density may be impacted not only by prescribed burn related factors (such as intensity and time since burn), but also by other environmental variables, including vegetation, rainfall, and soil types. In this study, pastures were burned at different intensities and studied for different post burn periods. Both one day counts and territory mapping were used in collecting data to determine vireo territory density. There was little relationship between data obtained with the two methods ($r_{Pearson} = 0.32$, $P = 0.15$). Suggestions were made regarding how to evaluate and, either choose between the data collection techniques, or improve the correlation of data collected via the two methods. In general, vireo territory densities were increasing throughout the study. However, whether this was due to the effects of fire or part of the natural cycle of density change was not clear. Vireo densities were higher 0–3 years after a burn than 7–11 years after a burn. In the best general linear model ($r^2 = 0.82$, $P = 0.0001$), only year in study ($P = 0.0001$) and the dummy variable pasture identification ($P = 0.0001$) were significant in predicting vireo territory density. However, in one model there was also the suggestion that time post burn might also contribute ($P = 0.10$). The best model may be generalizable by substituting soil types for pasture identification. Suggestions regarding other data needed were made as well as how to use modeling along with a geographic information system (GIS) to better understand factors affecting Black-capped Vireo territory density.

INTRODUCTION

The Value of Birds

Birds are ubiquitous. We find them in every major habitat on earth, in polar regions and tropical rain forests, in deserts and freshwater lakes, ponds, and streams. They plant seeds, control insects, and pollinate flowers. Not only are they "useful," but they also amaze us with their adaptations and delight us with their color, flight, and song. Since the Ice Age, birds have been prominent in human magic, religion, superstition, augury, folklore, and art (Welty and Baptista 1988).

Moreover, birds have long been regarded as gauges of the health of ecosystems. Indeed, it was the avifauna that warned us of the dangers of pesticides (Carson 1962). Now, as avian populations decline, birds may be telling us yet again that something is dangerously wrong and the time for positive human intervention critical. In particular, neotropical migratory birds, with their sensitivity to changes in landscapes that compromise the spatial continuity and integrity of natural ecosystems, should be a focus for management action (Maurer 1993).

Status of the Black-capped Vireo (*Vireo atricapillus*)

The Black-capped Vireo (*Vireo atricapillus*) is a small, active, neotropical migratory songbird. Its historic breeding range extended from south central

Kansas through central Oklahoma, south through central Texas to the Edwards Plateau, then west and south to north and central Coahuila, Mexico and Big Bend National Park, Texas (Graber 1961, U. S. Fish and Wildlife 1991). However, the bird has experienced recent reduction and fragmentation of its breeding range. It has been extirpated from Kansas, is found in only limited areas in Oklahoma, and is greatly reduced in Texas (Grzybowski 1995). Although less well known than the breeding range, the bird's winter range extends along the Pacific slope of Mexico, with records primarily from extreme western Durango, southern Sinaloa, Nayarit, Jalisco, and Colima (Grzybowski 1995). The species was listed as endangered in November, 1987 (Ratzlaff 1987). Threats to the vireo include cowbird parasitism as well as loss and fragmentation of nesting habitat due to range management practices, fire suppression, urbanization, and conflicts between landowner rights and the Endangered Species Act (U. S. Fish and Wildlife 1996).

Characteristics of Vireo Habitat

Little is known about the vireo in its winter range or about its migratory routes (U. S. Fish and Wildlife Service 1991, Grzybowski 1995). However, in its breeding range, vireo habitat is usually a mosaic of open grassland and scrubby, woody vegetation with foliage within 3 m of the ground (Graber 1961, Campbell 1995, Greenman 1995). In terms of vegetational composition, a variety of species are found in vireo habitat (Graber 1961, Grzybowski 1995, Grzybowski et al. 1996), and include oaks (*Quercus* spp.), sumacs (*Rhus spp.*), Texas persimmon (*Diospyros texana*), redbud (*Cercis canadensis*), agarita (*Berberis trifoliolata*), and mountain laurel (*Sophora secudiflora*) (Campbell 1995). The variety in plant species composition is especially interesting given the small breeding range of the vireo. Although locally many plant species may comprise a significant portion of the deciduous cover in habitat occupied by vireos, oak (*Quercus*) is the most frequently encountered taxon (U. S. Fish and Wildlife 1991, Grzybowski 1995).

Vegetational structure seems to be more important than composition in determining vireo habitat. The key elements include a high density of deciduous vegetation in the 0–2 m height range (Graber 1961, Campbell 1995, Greenman 1995), at least 35-55% landscape coverage by primarily deciduous woody species (Grzybowski et al. 1996), and vegetation of irregular heights and distribution (Grzybowski et al. 1996). Also important at least in some areas is the presence of "edge" features, including roads, fence lines, and dry creekbeds (Steed et al. 1987, personal observation). These edge features represent a kind of "line" where vegetated and non-vegetated areas meet and the additional light promotes low scrubby growth (Steed et al. 1987).

The vegetational component of vireo habitat is thus described as a transitional type of vegetation - a seral stage typically occurring between the time of disturbance of a woodland or savannah (e.g., fire) and its eventual return to a wooded character, or following disturbance of a grassland (e.g., excessive grazing) and its invasion by brush (Steed 1988). Climatic, edaphic, and topographic features, in addition to frequency and extent of disturbance, are important factors which interact to produce the vegetation preferred by vireos (Graber 1961, Greenman 1995, U. S. Fish and Wildlife 1996), and which likely also determine how long habitat remains suitable for vireo use.

Vireo Habitat and Fire

The U. S. Fish and Wildlife Service issued the Black-capped Vireo

Recovery Plan in 1991. In outlining recovery actions, the plan specified that management techniques were needed to create and restore vireo habitat as well as to maintain existing habitat in a condition suitable for vireo use. The plan also noted that fire probably played a historical role in maintaining or periodically returning certain areas to vireo habitat. The largest populations in the Wichita Mountains in Oklahoma, on Fort Hood Military Reservation, the Kerr Wildlife Management Area, and in the Austin, Texas vicinity are in regions recovering from burning (U. S. Fish and Wildlife 1991).

Other investigators have also linked fire history with vireo habitat use. Graber (1957) suggested that burning done by Native Americans likely helped in the dispersal of the species. She also reported that fire could be used to return climax communities that had become unsuitable to an earlier successional stage that was once again used by the birds.

In an ecological status survey of the vireo at Fort Hood, Texas, (Tazik et al. 1993a and Tazik et al. 1993b) fire was considered to be important both in the development and maintenance of vireo habitat. On Fort Hood, vireo habitat developed within 3–5 years after a fire and stayed suitable for as long as 20–30 years (Tazik et al. 1993a and Tazik et al. 1993b). A five-year burning cycle for maintaining habitat was proposed (Tazik et al. 1993a).

Based on six field seasons of research at the Camp Bullis Training Reservation, Fort Sam Houston, Texas, Rust and Watson (1995) found that cool season burning could be used for interim maintenance of existing vireo habitat. However, these researchers further concluded that the application of aggressive clearing followed by hot fires at relatively long inter-burn intervals may more closely mimic the presumed natural disturbance events which produced and maintained suitable Black-capped Vireo habitat in the past (Rust and Watson 1995).

In 1995, biologists representing 26 agencies, organizations, universities, and companies met to participate in a Black-capped Vireo population and habitat viability assessment. Funded by the U. S. Fish and Wildlife Service, the goals of the workshop were the development of population targets and conservation recommendations for the Black-capped Vireo (U. S. Fish and Wildlife Service 1996). Among the recommendations resulting from the meeting were several related to the use of prescribed burning as a management tool for restoring and maintaining vireo habitat. As others before them, the workshop participants also concluded that the timing (cool or warm season) as well as frequency of burns should vary according to site and should depend on why existing habitat was not suitable for vireo use.

O'Neal et al. (1996) investigated the effects of prescribed burning on Black-capped Vireo habitat and territory establishment at the Kerr Wildlife Management Area in Kerr County, Texas. In this study, three pastures were burned with different intensity fires and two pastures remained unburned. The researchers concluded that winter prescribed burning in known nesting habitat, regardless of the intensity of the fire, did not sufficiently degrade the habitat to cause a post burn reduction in number of vireos.

In a regional analysis of Black-capped Vireo breeding habitats, Grzybowski et al. (1996) found that many of the deciduous species comprising vireo habitat were fire adapted, and very hot fires probably most closely simulated historical conditions that produced usable habitat. These investigators further hypothesized that cooler burns might also play a maintenance role in already occupied vireo habitat. In these areas, cooler non–breeding season burns could be used to set back succession and, thus, keep vegetation in a "vireo friendly" condition.

Fire and Avian Population Density

Fire affects not just the habitat, but also bird populations. Fire can alter the number of birds present on specific sites as well as in regions, either through direct effects on survivorship or indirectly by changing prey populations and/or acceptable habitat (Rotenberry et al. 1993). Moreover, to the extent that a species is dependent on a fire-maintained habitat, its distribution and sometimes its population size, are actually "regulated" by fire (Rotenberry et al. 1995).

Bendell (1974) noted that the size of a burn, its edges, and the mix of burned vegetation with cover types outside of the burn are structural features that may affect the response of birds to changes caused by fire. In particular, the pattern of cover created by a burn may affect where birds live and their population density. Bendell (1974) further hypothesized that the size of a burn may affect the growth of some bird populations that move into the burned area. His reasoning was that burns provide new and unlimited resources, thus releasing genotypes that will expand in numbers when free from interference of established genotypes that tend to keep a population in check (Bendell 1974).

Breininger and Smith (1992) studied the relationships between fire and bird densities in Florida coastal scrub. Among the variables they investigated were time since fire and percent burn. They found that most shrub dwelling birds preferred older or intermediate stands (those not burned within four years). Their results also included negative correlations between some species and percent burn in stands burned within one to two years. Breininger and Smith (1992) concluded that some avian populations would decline under a fire regime of extensive burns every four years or less.

Modeling as a Tool

The link between fire and vireo habitat is established well enough for researchers to recommend prescribed burning as a management technique for restoring and maintaining vireo habitat. The management questions that relate to a decision to do a prescribed burn are why? where? when? under what conditions? how? and with what frequency? If the manager also wants to limit possible adverse affects of a burn on birds, the same questions apply. However, few studies have actually addressed the specifics of these issues as they relate to avian populations (Rotenberry et al. 1995).

Modeling is one of the tools available for assessing probable effects of management action, including prescribed burning, on avian populations. Models at a very basic level depict relationships (Wasser 1986). Ranging from simple words to complex equations, there may be little relationship between a model's complexity and its fit with reality (Verner et al. 1986). Stormer and Johnson (1986) suggested that one way to model ecological reality more accurately is to incorporate statistics. Not only do statistics provide a way to quantitatively express uncertainty about natural phenomena, but statistical analysis also requires the modeler to adopt an attitude of objectivity, rigor, and healthy skepticism, all features essential to good modeling. Statistical techniques useful in the modeling process include examining assumptions (normality, randomness, independence of observations), testing hypotheses, and checking goodness of fit.

More than just mathematical abstractions of real world situations, models help researchers and managers define problems, organize thoughts, understand data, communicate and test understanding, and make predictions (Starfield and Bleloch 1986). Investigators currently use a variety of models and approaches to modeling for such tasks as biological survey and inventory, land-use planning, conservation evaluation, and protected area management (Norton and Possingham 1993). As a decision-making aid, models help researchers explore the consequences of management actions, and can be particularly helpful when managers must choose from several alternative management scenarios. In this case, models can be used to learn what is driving changes in a population, to improve data collection and analysis, to identify interactions between two alternative management policies, and to investigate whether the effectiveness of management action might depend on a particular biotic or abiotic factor (Starfield 1997).

Well documented models with rigorous biometric approaches are needed. As one manager summarized it, good field biologists can fairly accurately predict species' presence and general number patterns without biometric models. To be useful, biometric approaches need to extend existing professional knowledge and help the manager understand the ecological contexts within which the model may be used reliably (Marcot 1986). In the big picture, then, the incentive for modeling relationships between habitat and population parameters of wildlife species is based on the belief that animals respond to habitat in an adaptive fashion (Noon 1986). Theoretically, then, by altering specific components of the habitat, one might be able to influence an animal's habitat selection. In the case of the Black-capped Vireo, by creating disturbance in the form of fire, managers may be able to affect vireo density.

Purpose of this Study

The purposes of my research were to investigate the relationships between vireo territory density and environmental and burn data. As indicated above, earlier studies have shown that the frequency and intensity of burns required to create and maintain vireo habitat are probably site specific. What wildlife managers need is a practical means of evaluating individual situations. The goal of my work was to produce an easy to use model that would allow managers to do just that, while also maximizing efforts and resources.

MATERIALS AND METHODS

Study Area

My work was a continuation of O'Neal's (1996) 1993–1995 study of the effects of prescribed burning on vireo habitat, territory establishment, and production at the Kerr Wildlife Management Area (KWMA), Kerr County, Texas. The KWMA is a 2,629 ha facility owned and operated by the Texas Parks and Wildlife Department. Originally purchased in 1950 to study wildlife, including the relationships between wildlife and domestic livestock, as well as to demonstrate range improvement and wildlife management techniques, the KWMA is still used for these purposes today (Texas Parks and Wildlife Department 1986). The KWMA is located 19.3 km northwest of Hunt, Texas, in the Edwards Plateau Ecological Region, a region that receives 38–84 cm of rainfall per year.

Elevation is about 610 m, and topography is gently rolling to very hilly. Soils may be characterized as stony, fertile, non-calcareous clay on the redland sites; shallow clay soils and clay loam soils on the low rolling hills; and shallow clay soils on the rocky uplands. The dominant woody vegetation includes several oak species (*Quercus virginiana, Quercus buckleyi*, and *Quercus sinuata*), some of which form mottes, and Ashe juniper (*Juniperus ashei*) in dense stands on some parts of the KWMA. Grasses are primarily bluestems (*Schizachyrium scoparium* and *Andropogon gerardii*) and Texas wintergrass

(*Stipa leucotricha*), while forbs are relatively abundant depending on seasonal rainfall (Texas Parks and Wildlife Department 1991).

A 2.3-m high, deer-proof fence completely encloses the KWMA, which is divided into pastures. Range and wildlife management techniques include rotational grazing, prescribed burning, brush control, and hunting (Texas Parks and Wildlife 1986). One day presence/absence counts of Black-capped Vireos have been conducted since 1986, and Brown-headed Cowbirds (*Molothrus ater*) are trapped and removed while Black-capped Vireos are present.

Pasture Selection

Since this study was the continuation of work done by O'Neal (1996), I used the same five pastures selected for the original study: North Rock (62. 3 ha), Middle Rock (86.6 ha), South Rock (79.4 ha), North Doe (50.2 ha) and South Doe (75.3 ha) (Fig. 1).

Territory Mapping Counts

To ascertain the size of the male breeding Black-capped Vireo population, I used essentially the same intensive territory mapping method as O'Neal (1996). I counted Black-capped Vireo territories from 30 April 1996 to 1 August 1996, and from 14 May 1997 to 4 August 1997 in all study pastures. I walked a survey route, the course of which was determined by topography, vegetation, and the location of previously documented vireo territories. The routes thoroughly covered each pasture, and I surveyed under acceptable weather conditions (Robbins 1981).

Whenever I saw or heard a male vireo, I followed it and marked the observation points on a topographic map. I used these points to delineate each

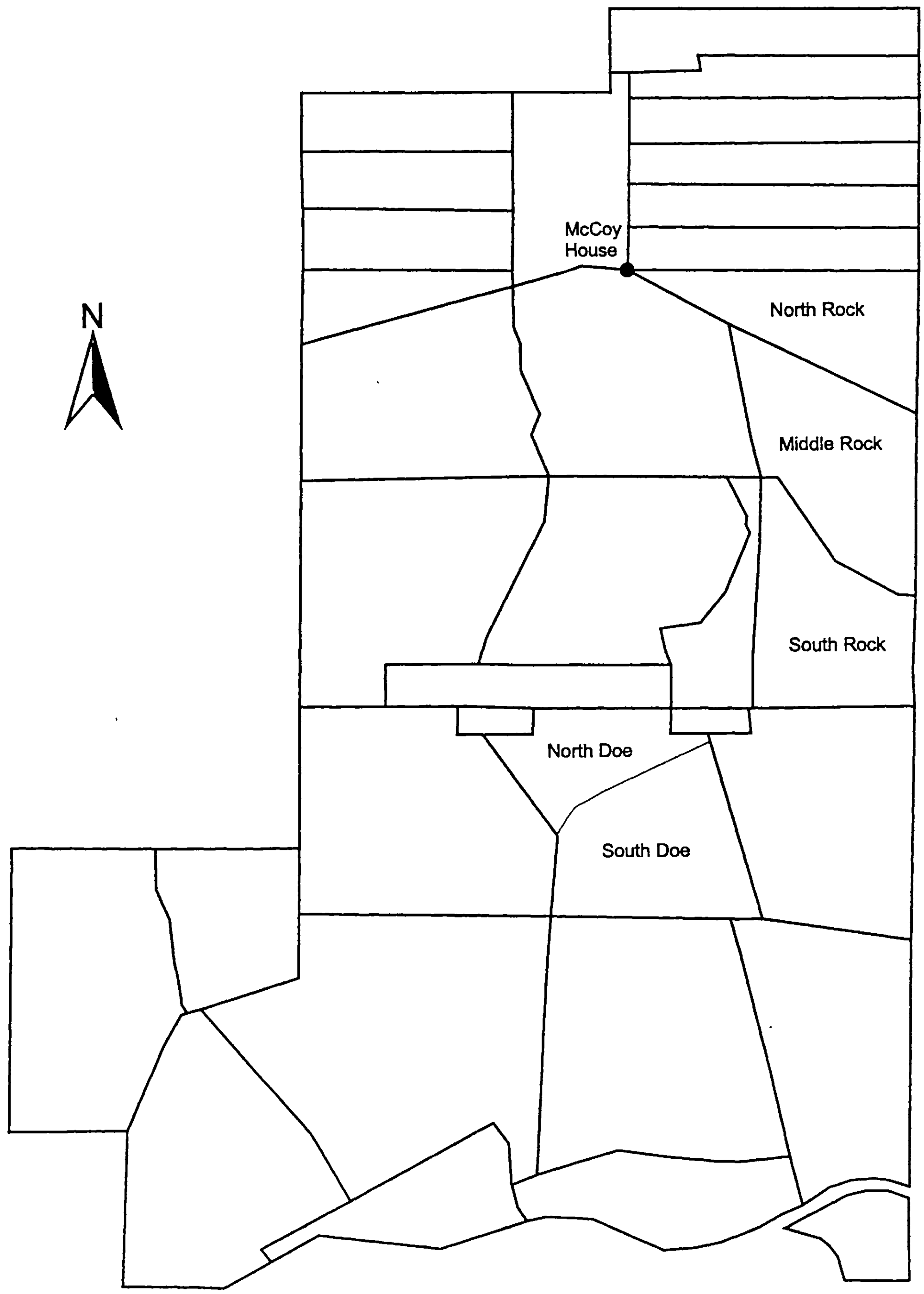

Figure 1. Locations of the study pastures at the Kerr Wildlife Management Area, Kerr County, Texas.

male bird's territory. If I was uncertain about the presence or absence of a territory or had difficulty determining the territory boundaries or location, I resurveyed the area until I resolved any questions. Although the precise locations of territories might change over the course of the breeding season, it was assumed that once all birds had arrived, the total number of adult males would remain the same.

I assigned each territory a field number and, whenever possible, observed and recorded cap-color class, presence or absence of leg bands, audible song patterns, details of behavior, and vegetation use. These additional observations were used to differentiate one bird from another and to reduce the likelihood of any bird being counted more than once. I also noted any encounters with female vireos and fledglings.

Vireo Production

Although gathering production data was not my main objective, whenever I found a nest, I recorded the nest location, substrate, and orientation in the vegetation as well as any observations of eggs (vireo as well as Brown-headed Cowbird) and nestlings. Whenever possible, I revisited the nest and collected data on bird behavior and dates of hatching and fledging. These data are not presented here, although details may be found in the annual reports filed with Texas Parks and Wildlife (Baccus et al. 1997, 1998).

Other Vireo Counts

Since my goal was to build an easy to use model to predict vireo territory density, I first wanted to see if there was a relationship between data collected by the intensive vireo territory mapping method and that gathered by the less time consuming presence/absence counts. Since O'Neal and I used comparable techniques, I combined his intensive territory mapping counts with mine for a total of five years (1993–1997) of vireo territory mapping counts in the study pastures. I also obtained the presence/absence vireo count maps from the KWMA (TPWD, unpublished data).

Conducted by TPWD personnel, the presence/absence counts were made once each year over the course of 1–2 days at the beginning of the breeding season. Counters walked a census line and stopped every 91.4 m (100 yds) and listened for singing vireos. After listening for 3 minutes, they played a tape of a vireo song for 15–30 seconds and listened another 1.5 minutes. The estimated locations of singing birds along transects were recorded on a map. Counters also walked all or part of each pasture, noted any singing vireos not detected on transects, and marked each bird's approximate location on a map. The total number of vireos believed to be in each surveyed area was reported as the "area count." Singing birds were assumed to be males.

No presence/absence counts were done in the Middle Rock Pasture in 1993, 1994, or 1995. Also, because counts from more than one pasture were often combined into one count number, I used the data collection maps to divide these totals among pastures. For example, in 1993, 1994, and 1995, data from both Doe Pastures were combined with data from a non-study pasture into one number. I verified any adjustments made with the KWMA biologist, who coordinated the counts, and used the area count numbers as the presence/absence count data.

Variables

With vireo territory density as the outcome variable, I chose pasture identification, year in the study, prescribed burn intensity, time since burn, soil type, vegetation, and rainfall as potentially important explanatory variables to analyze further. Because of data availability limits and the categorical nature of some data, and before completing statistical analysis, I organized and standardized the data as follows.

Vireo Territory Density Calculations

Since the study pastures were different sizes, I calculated vireo territory density by dividing the intensive territory counts as well as the presence/absence counts by the size (hectares) of pastures.

Pasture Identification

In each pasture, there were many biological, chemical, physical, and geologic components that might have contributed to the attractiveness of the pasture to vireos and vireo productivity. However, only limited data for any of these components were available. Therefore, I treated pasture as a categorical variable and each pasture as a different category.

Year in the Study

I created a variable called "year in study" to account for general trends over time. The study began in 1993 and ended in 1997, so year 1 of the study was 1993, 1994 year 2, and so on.

Prescribed Burn Intensity

All study pastures, except South Doe, were burned in 1994, 1995, or 1996, prior to the beginning of my data collection. In addition, all five pastures were previously control burned either in 1984 (Rock Pastures) or 1986 (Doe Pastures). KWMA personnel provided burn history for all study pastures and qualitative intensity assessments of cool, moderate, hot, or very hot (based on the effects of burns on plant succession) for all but the 1986 South Doe prescribed burn (Texas Parks and Wildlife, unpublished data). However, complete information regarding fuel loads, wind speed and direction, relative humidity, fire temperature, and ambient temperature was not available.

Time Since Burn

I treated the year in which a pasture was burned as time zero and counted the years since it was burned to calculate the time since burn. For example, Middle Rock Pasture was burned in 1984 and again in 1997. Thus, in 1993, the time since burn was 9 years. However, in 1997, the time since burn was 0 years.

Soil Type

Using the Geographic Information System (GIS) developed by Coats (1997) for management of the Black-capped Vireo on the KWMA, TPWD provided soil data. For each study pasture, I obtained the percentage of each soil type present as well as a general description of soil types.

Vegetation

Although some vegetation cover information was available, data were only collected in two of the five study pastures, and therefore could not be included in the analysis.

Rainfall

I obtained rainfall in inches by month for 1991–1997 from KWMA personnel (TPWD, unpublished data). Rainfall was collected in a gauge at the McCoy House in the northwest corner of the North Rock Pasture (see Fig. 1). I converted rainfall amounts from inches to centimeters and added monthly amounts to get January to July and burn date to 1 May rainfall totals. I chose these particular time periods based on the likely impact of rainfall on vegetation before and during vireo territory establishment.

Data Analysis

I used correlation analysis, scatter plots, and general linear models (GLM) to analyze data. With correlation analysis, I investigated the relationship between the intensive territory mapping and the presence/absence methods of measuring vireo territory density.

I used scatter plots to visually identify general trends and to inspect the data for possible "outlier points." I found one putative outlier and performed most subsequent analyses both with and without this point.

To study the relationship of vireo territory density to pasture identification, year in the study, prescribed burn intensity, time since burn, rainfall, and soil type, I used GLM. After choosing a best model on the basis of GLM analysis and biological significance, I plotted ordinary residuals as well as predicted residual error sum of squares (PRESS) residuals. I used these plots to check the fit of the model with observations. With GLM and contrast sums of squares, I compared the coefficient estimates of the independent variables in the model with the best fit.

Data analyses were performed using SAS (1989) (version 6.11, Cary, NC). The details of the methods used are given below.

Correlation Analysis

I used correlation analysis to investigate the relationship between the presence/absence counts and the vireo territory mapping counts. I calculated both Pearson and Spearman correlation coefficients, and ran the analysis both with and without the outlier point.

I also plotted vireo territory density estimated by territory mapping versus density estimated using one day presence/absence counts. I visually inspected this plot to see if there was a relationship between the vireo territory density estimated using the one day presence/absence method and the density estimated in the same pasture and year using the territory mapping method.

Scatter Plots

I made several scatter plots of vireo territory density, including vireo territory density vs. years since burn, vs. year, vs. rainfall between burn date and 1 May, vs. rainfall from January through July, vs. burn intensity, and vs. pasture identification. Using these plots, I visually examined the data and identified large scale trends and one possible outlier point.

General Linear Modeling

I used GLM to study the relationship between vireo density (as the dependent variable) and pasture identification, year in study, time since prescribed burn, burn intensity, and rainfall (as the independent variables). I included pasture identification (k = 5) as a set of 4 (k-1) dichotomous dummy variables. While treating year in study, time since burn, and rainfall as continuous variables, I coded burn intensity ordinally (1 = cool, 2 = moderate, 3 = hot, and 4 = very hot) and also treated it as a continuous variable.

There are several ways to build or prune models in order to obtain an optimal model. Using "back-ward" elimination, I started with a model including all variables and removed non-significant terms, one at a time. I performed significance testing at the alpha = 0.05 level.

There are also several ways to calculate the significance of the individual terms in models. When data are unbalanced (the number of observations is not the same for each combination of experimental conditions), the order in which variables are considered can lead to different conclusions. Because data in this study were not always balanced, I took a conservative approach, and based F ratios on type III sums of squares, which is invariant to the order in which model terms are specified (Glantz and Slinker 1990).

On the basis of P values, r^2 values, and biological significance, I identified models that best fit the observations. I then used GLM analysis to check for interaction between the independent variables in the best models.

General linear modeling: observation subset with complete data--The burn intensity assessment was missing for the 1986 South Doe burn. Therefore, following the procedures outlined above, I first conducted GLM analysis using only the subset of observations for which complete data were available. This allowed for comparing one model with another on an equal basis. I ran all analyses both with and without the suspected outlier.

General linear modeling: all observations--Based on the results of the first set of modeling analyses, I next omitted burn intensity as a predictor variable. This time, using all observations, I followed the GLM procedures outlined above and explored the relationship between vireo territory density and the remaining independent variables. I completed all analyses both with and without the outlier.

Analysis of Residuals

To examine the data more closely for evidence of outliers, I plotted both ordinary and predicted residual error sum of squares (PRESS) residuals. Predicted residual error sum of squares (PRESS) analysis is a way to approximate an independent test of a model (Glantz and Slinker 1990). In PRESS analysis, several regression lines are generated by systematically removing one data point at a time before calculating the regression coefficients. The removed data point is then used to test how well the regression equation, generated without that point, predicts its value. The predicted residual is thus equal to the difference between the observed value of the dependent variable and the predicted value.

There are two uses for PRESS; one as a way to compare several models. The other, and the one for which I used PRESS, was to measure the fit of a model for individual observations. I plotted PRESS residuals against actual density observations and visually identified outliers, i.e., observations for which the relationships seen in the rest of the data were not apparent.

Contrasts

In experiments in which the effects of more than one treatment are being measured, and statistical analysis shows there is a difference in treatment means, contrasts and contrast sums of squares may be used to determine which treatment means differ (Hicks 1973). In my study, I used contrast sums of squares to compare the coefficient estimates of the variables in the model with the best fit. I performed significance testing at the alpha = 0.05 level. If some variables, or combinations of variables, had equal coefficients, it might have been possible to further simplify the model.

Increasing the Generalizability of the Model

One way to make the model generalizable beyond the boundaries of the study area was to substitute other more widely applicable variables for one or more of the variables in the model with the best fit. Because of its general availability and biological significance, I substituted percent soil type for pasture identification and again did general linear modeling. There were five soil types in the study pastures. Since all the soil percentages summed to a constant (100%), once percentages for four of the soil types were specified, the fifth percentage was determined and thus did not represent independent information. Therefore, I used a slightly different procedure in modeling than was used with the other independent variables.

Using all observations except the visually determined outlier, I generated a new model substituting all five soil types for pasture identification in the model with the best fit. However, no estimate was made for the intercept (as was done in all other general linear modeling). By making this modification to the procedure, I avoided the problem of overspecifying the model. I performed significance testing at the alpha = 0.05 and removed non-significant terms. To calculate the significance of the individual terms in the model, I again used type III sums of squares.

I then generated a final soil model, substituting only the statistically significant soil types for pasture identification. This time I calculated an intercept estimate so that this model could be compared on an equal basis with the best pasture identification model. My goal was to see if there was any difference in the way the two models fit the data.

RESULTS

Data Structure and Content

Complete data on territory counts, year of burn, rainfall, and soil type were available for five pastures over five years (n = 25) (Table 1-A, Appendix). In addition, one day vireo counts were available for all pastures in each year of the study, except the Middle Rock Pasture in 1993, 1994, and 1995. The burn intensity was missing for the 1986 South Doe prescribed burn. A scatter plot (Fig. 2) and preliminary regression analysis using density as determined by territory mapping as the outcome of interest identified one observation (North Doe,1997) as a potential statistical outlier. Most analyses were performed both with and without this point.

Relationship between Territory Mapping and One Day Count Data

Ideally, there should be a relationship between data collected by the intensive vireo territory mapping method and data obtained by the one day presence/absence counts. Had this been the case, it might have been possible, using the appropriate conversion factor(s), to use both sets of data interchangeably. However, there was very little relationship between vireo territory densities determined by intensive mapping and those estimated via one day presence/absence counts (see Fig. 2). Correlational analysis yielded

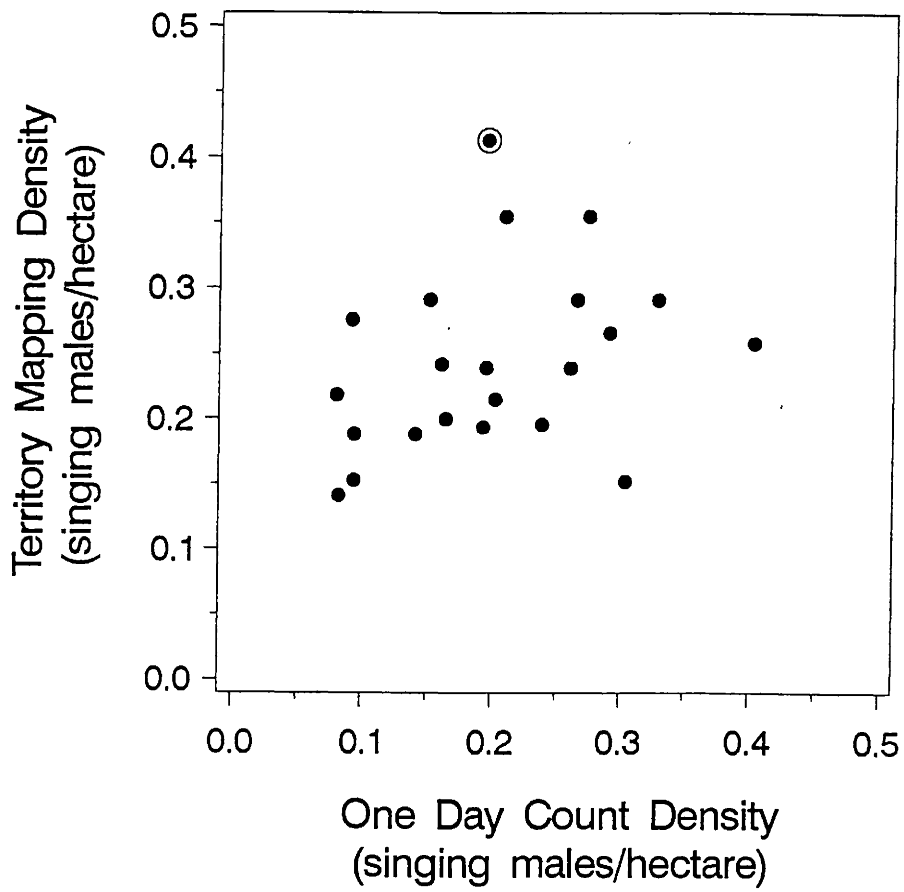

Figure 2. Scatter plot of Black-capped Vireo territory density estimated by territory mapping versus density in the same pasture and year estimated using one day presence/absence counts at the Kerr Wildlife Management Area, Kerr County, Texas, 1993–1997. The putative outlier (North Doe, 1997) is circled. $r = 0.32$ ($P = 0.15$), $r_{sp} = 0.38$ ($P = 0.08$).

an r (Pearson) value of 0.32 (P = 0.15), with the outlier. Eliminating the outlier improved the relationship slightly (r = 0.38, P = 0.08). Due to the lack of agreement, I used only territory based data in the remainder of the analysis.

General Trends

Starting territory densities in Middle Rock, North Doe, and South Doe were about the same as were those in North Rock and South Rock (Fig. 3). By visual inspection of the data, territory densities increased in all pastures from the beginning as compared to the end of the study (see Fig. 3). However, the details of year to year changes varied. For example, while territory density in Middle Rock increased each year, the densities in all other pastures had years of decrease or no change (Fig. 4, 5). Also visually apparent were similar patterns of increasing density in Middle Rock and North Doe from 1993–1995 (Fig. 4, 5).

Trends and Prescribed Burns

All pastures were prescribe burned at least once since 1984 (see Table A-1, Appendix). Thus, I noted another set of trends, this time considering the history of prescribed burning in the study pastures. I first present trends noted exclusively in the 1993–1997 study years, followed by patterns which also took into account the earlier prescribed burn histories.

Because pastures were burned in three different years during the 1993–1997 study period, not all pastures were studied for the same duration post burn. By the end of the study, all burned pasture territory densities were higher than the density in the one pasture (South Doe) that was not burned between 1993 and 1997 (see Fig. 4). South Doe also had the smallest

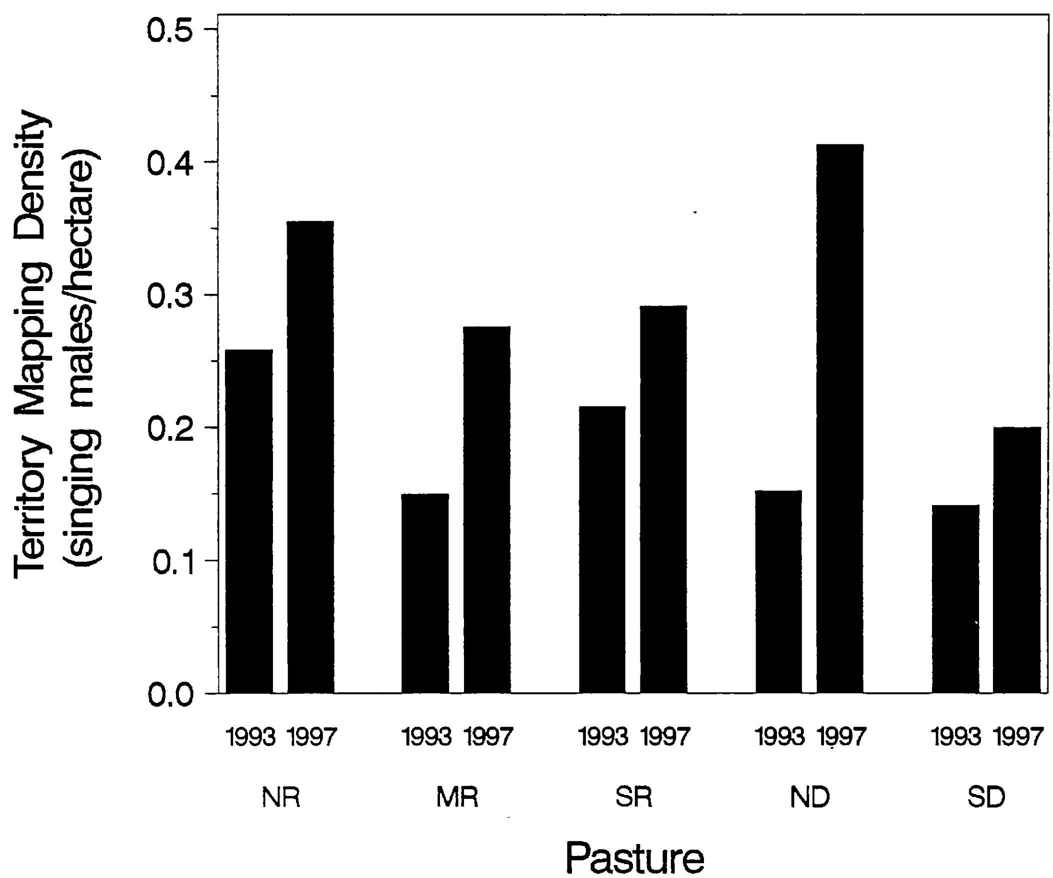

Figure 3. Bar graph showing increases in Black-capped Vireo territory densities in study pastures at the Kerr Wildlife Management Area, Kerr County, Texas, 1993–1997. NR = North Rock, MR = Middle Rock, SR = South Rock, ND = North Doe, SD = South Doe.

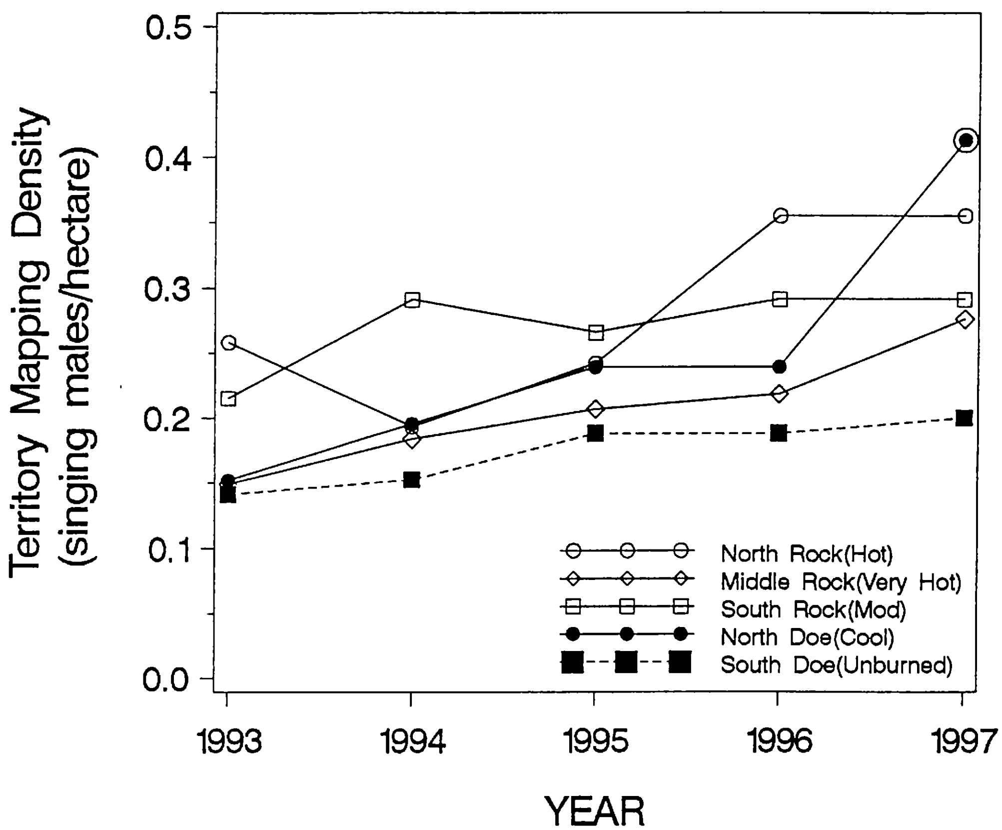

Figure 4. Black-capped Vireo territory mapping density by year for each of the study pastures at the Kerr Wildlife Management Area, Kerr County, Texas. Also indicated are the intensities of the most recent prescribed burns in each pasture. Putative outlier is circled.

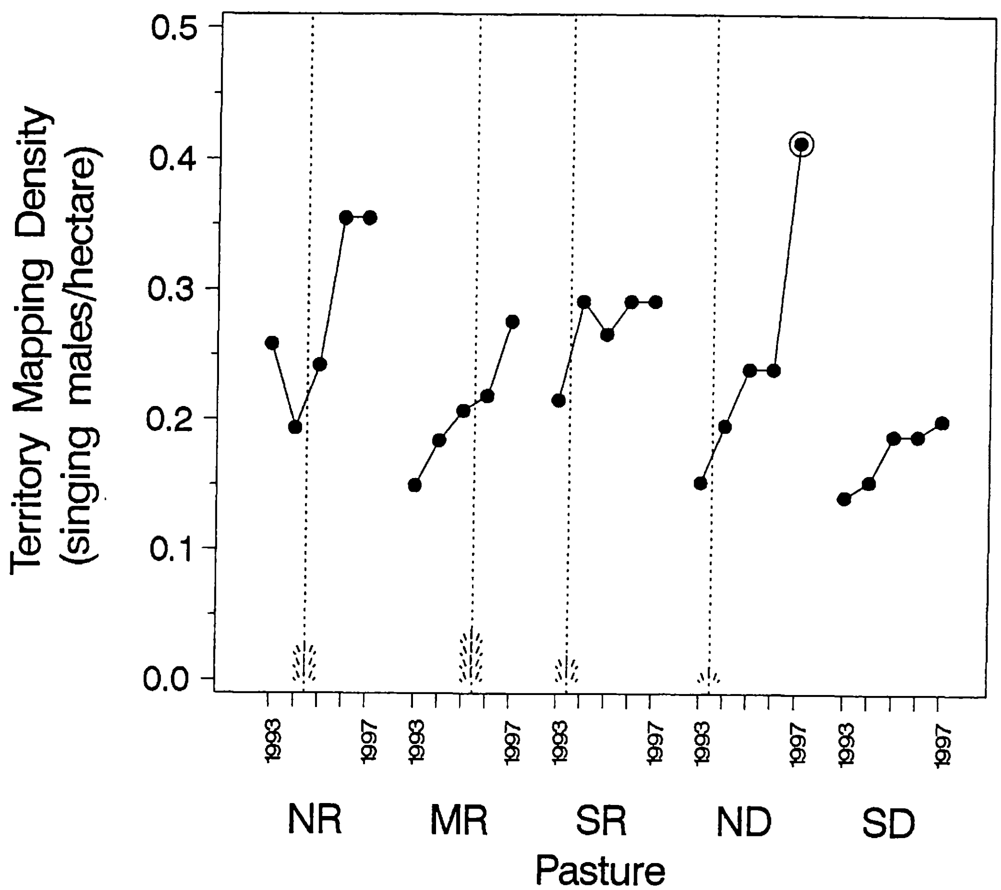

Figure 5. Black-capped Vireo territory mapping density by pasture and year at the Kerr Wildlife Management Area, Kerr County, Texas. Dotted lines indicate when each pasture was burned. Fire symbols designate the intensity of the burn with more symbols representing progressively hotter burns. Putative outlier is circled. NR = North Rock, MR = Middle Rock, SR = South Rock, ND = North Doe, SD = South Doe.

increase in territory density, while the pasture with the hottest burn (Middle Rock) had the largest increase, if the North Doe 1997 density was left out as an outlier (see Fig. 5). However, it should be noted that part of the density increase in Middle Rock occurred before the burn.

One year post burn, all pastures (except South Rock) had higher densities than they did in the year they were burned (Fig. 5, 6). Two years post burn the cool and moderately burned pastures had only slight changes in density as compared to their burn year densities, while the hot burned pasture had a more marked increase in vireo density from 0.24 vireos/hectare to 0.35 vireos/hectare (see Fig. 5). Note, no territory density data for two years post burn were available for the very hot burned pasture.

Since all Rock Pastures were burned, I could not compare territory density trends in burned vs. unburned Rock Pastures. However, both the burned and unburned Doe Pastures had similar patterns of increasing vireo territory densities, until the third year post burn. At this point the density in North Doe (burned with a cool fire) increased sharply, while density in South Doe (not burned) increased only slightly (see Fig. 5). However, this North Doe high point was identified in the statistical analyses as a possible outlier.

I also identified trends potentially related to both the most recent burn histories as well as to the earlier prescribed burns which occurred in 1984 (Rock Pastures) and 1986 (Doe Pastures). In general, vireo territory densities were higher 0-3 years following a burn than 7-11 years post burn (see Fig. 6). However, no data were available for the period between 4 and 6 years following a burn.

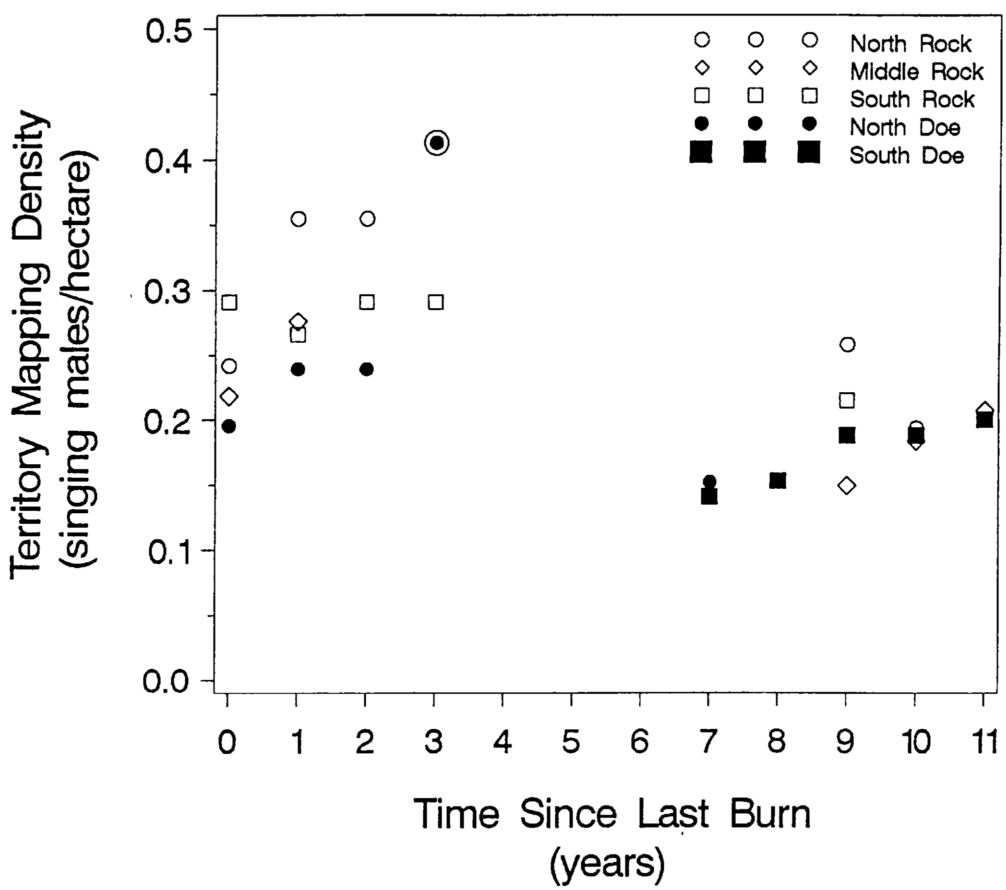

Figure 6. Black-capped Vireo territory densities, 0–11 years post prescribed burn at the Kerr Wildlife Management Area, Kerr County, Texas, 1984–1997. No data available for 4, 5, or 6 years post burn. Putative outlier is circled.

Trends and Rainfall

Rainfall directly contributes to vegetative growth, and thus might potentially be an indirect factor affecting vireo territory densities. However, during the study years and the three years prior to the most recent prescribed burns, rainfall amounts were not sufficiently different on an annual basis to be useful in identifying any overall rainfall related trends (Table 1). Moreover, since there were only four data points for rainfall amounts from burn date to bird arrival date, there were not enough data to describe a trend relating vireo territory density and rainfall since burn.

General Linear Modeling: Observation Subset with Complete Data

Based on P values, the order of elimination of explanatory variables was different depending on whether I did the analysis with or without the outlier. However, in both sets of analyses, only pasture identification and year in study were significant (Tables 2, 3). The pasture identification P value of 0.063 in the best model (outlier included) was slightly higher than the chosen significance testing level (0.05). However, the corresponding P value for pasture identification with the outlier excluded was 0.0047. Year in study with a P value of 0.0001 in the best model (with and without the outlier) was highly significant. There was no interaction between pasture identification and year in the study $P = 0.17$ with the outlier and 0.56 without the outlier) (Table 4).

The r^2 value of 0.81 was highest for the model with all variables included and the outlier omitted. However, eliminating variables did not appreciably change the r^2 values (see Tables 2, 3).

Table 1. Rainfall totals for study years in which pastures were prescribe burned at the Kerr Wildlife Management Area, Kerr County, Texas. Also included are rainfall totals for each of the three years prior to years in which prescribed burns occurred.

Year	Jan–July (cm)	Burn Date–1 May (cm)	Total (cm)
1991	5.11	a	13.12
1992	8.55	a	12.17
1993	4.86	a	6.35
1994	6.37	2.54, 2.09 b	12.45
1995	6.51	1.95	10.62
1996	3.59	0.83	11.59
1997	8.94	a	14.37

a No burn conducted in study pasture this year.

b 2.54 South Rock, 2.09 North Doe. Totals different because South Doe burned 16 February 1994 and North Doe burned 10 March 1994.

Table 2. Results of general linear model analysis relating Black-capped Vireo territory mapping density to pasture identification, year in study, burn intensity, time since burn, and January–July rainfall at the Kerr Wildlife Management Area, Kerr County, Texas, 1993–1997 for observations with complete data (n = 20, putative outlier included).

	P value*			
Source	Step 0	Step 1	Step 2	Step 3
Pasture	0.14	0.10	0.074	0.063**
Year	0.0099	0.0013	0.0008	0.0001
Burn intensity	0.94	0.94	—	—
Time since burn	0.99	—	—	—
Jan–July rain	0.61	0.59	0.57	—
r^2	0.71	0.71	0.71	0.70

* P values obtained by backwards stepwise elimination of variables. At Step 0, all variables were included in the model. At each step, the variable with the highest P value was eliminated until at Step 3 only statistically significant (alpha = 0.05) variables remained.

** This value exceeds the chosen significance level.

Table 3. Results of general linear model analysis relating Black-capped Vireo territory mapping density to pasture identification, year in study, burn intensity, time since burn, and January–July rainfall at the Kerr Wildlife Management Area, Kerr County, Texas, 1993–1997 for observations with complete data (n = 19, putative outlier omitted).

	P value *			
Source	Step 0	Step 1	Step 2	Step 3
Pasture	0.015	0.0101	0.0060	0.0047
Year	0.018	0.011	0.0078	0.0001
Burn intensity	0.78	0.79	—	—
Time since burn	0.31	0.28	0.27	—
Jan–July rain	0.86	—	—	—
r^2	0.81	0.81	0.80	0.78

* P values obtained by backwards stepwise elimination of variables. At Step 0, all variables were included in the model. At each step, the variable with the highest P value was eliminated until at Step 3 only statistically significant (alpha = 0.05) variables remained.

Table 4. Results of analysis of variance for general linear model relating Black-capped Vireo territory mapping density to pasture identification, year in study, and the pasture identification X year in study interaction at the Kerr Wildlife Management Area, Kerr County, Texas, 1993–1997 for observations with complete data.*

Source	Degrees of freedom	Sums of squares**	Mean square	F	P
Error	12	0.02	0.0015	—	—
Pasture	3	0.011	0.0037	2.5	0.11
Year	1	0.05	0.05	31	0.0001
Pasture X Year	3	0.0089	0.0030	2	0.17
Error	11	0.011	0.0010	—	—
Pasture	3	0.0060	0.0020	2.1	0.18
Year	1	0.024	0.024	23	0.0005
Pasture X Year	3	0.0022	0.00073	0.7	0.56

* Top of the table shows results of analysis including the outlier (n = 20, r^2 = 0.80, P = 0.0020); bottom of the table shows results of analysis without the outlier (n = 19, r^2 = 0.82, P = 0.0022).

** For model effects, the sums of squares are type III.

General Linear Modeling: All Observations

Once again, the order of elimination of explanatory variables, based on P values, was different depending on whether I did the analysis with or without the outlier. However, again in both sets of analyses only pasture identification and year in study contributed significantly to determining vireo territory density. In the best models, the P values were 0.0020 (outlier included) and 0.0001 (outlier excluded) and 0.0001 (outlier included and outlier excluded) for pasture identification and year in study, respectively (Tables 5, 6). Also, there was no interaction between pasture identification and year in study in the best model (P = 0.095 with the outlier and 0.44 without the outlier) (Table 7).

From the analysis of the observations without the outlier, there is the suggestion that, although not statistically significant, time since burn might have contributed slightly to predicting vireo territory density. For example, in the model with year in study, pasture identification, and time since burn included, the P value for time since burn was 0.10 (see Table 6).

The model with all variables included and the outlier omitted had the highest r^2 value (0.85). However, eliminating variables did not appreciably change the r^2 values (see Tables 5, 6).

General Linear Modeling: Best Model

I analyzed the residuals generated by the pasture identification and year in study model and also used predicted residual error sum of squares (PRESS) analysis to study the fit of the model with all the observations. Plots of the general linear model residuals versus observed territory densities (Fig. 7) and the PRESS residuals versus the territory densities (Fig. 8) provided visual

Table 5. Results of general linear model analysis relating Black-capped Vireo territory mapping density to pasture identification, year in study, time since burn, and January–July rainfall at the Kerr Wildlife Management Area, Kerr County, Texas, 1993–1997 (n = 25, putative outlier included).*

	P value		
Source	Step 0	Step 1	Step 2
Pasture	0.026	0.0027	0.0020
Year	0.0020	0.0002	0.0001
Time since burn	0.55	—	—
Jan–July rain	0.53	0.59	—
r^2	0.75	0.75	0.74

* P values obtained by backwards stepwise elimination of variables. At Step 0, all variables were included in the model. At each step, the variable with the highest P value was eliminated until at Step 2 only statistically significant (alpha = 0.05) variables remained.

Table 6. Results of general linear model analysis relating Black-capped Vireo territory mapping density to pasture identification, year in study, time since burn, and January–July rainfall at the Kerr Wildlife Management Area, Kerr County, Texas, 1993–1997 (n = 24, putative outlier omitted).*

	P value		
Source	Step 0	Step 1	Step 2
Pasture	0.0007	0.0004	0.0001
Year	0.0009	0.0004	0.0001
Time since burn	0.12	0.10	—
Jan–July rain	0.86	—	—
r^2	0.85	0.85	0.82

* P values obtained by backwards stepwise elimination of variables. At Step 0, all variables were included in the model. At each step, the variable with the highest P value was eliminated until at Step 2 only statistically significant (alpha = 0.05) variables remained.

Table 7. Results of analysis of variance for general linear model relating Black-capped Vireo territory mapping density to pasture identification, year in study, and the pasture identification X year in study interaction at the Kerr Wildlife Management Area, Kerr County, Texas, 1993–1997.*

Source	Degrees of freedom	Sums of squares**	Mean square	F	P
Error	15	0.018	0.0012	—	—
Pasture	1	0.011	0.0029	2.4	0.10
Year	4	0.046	0.046	38	0.0001
Pasture X Year	4	0.011	0.0029	2.4	0.095
Error	14	0.011	0.00081	—	—
Pasture	1	0.0069	0.0017	2.1	0.13
Year	4	0.026	0.026	32	0.0001
Pasture X Year	4	0.0033	0.00080	1.0	0.44

* Top of the table shows results of analysis including the outlier (n = 25, r^2 = 0.84, P = 0.0001); bottom of the table shows results of analysis without the outlier (n = 24, r^2 = 0.86, P = 0.0001).

** For model effects, the sums of squares are type III.

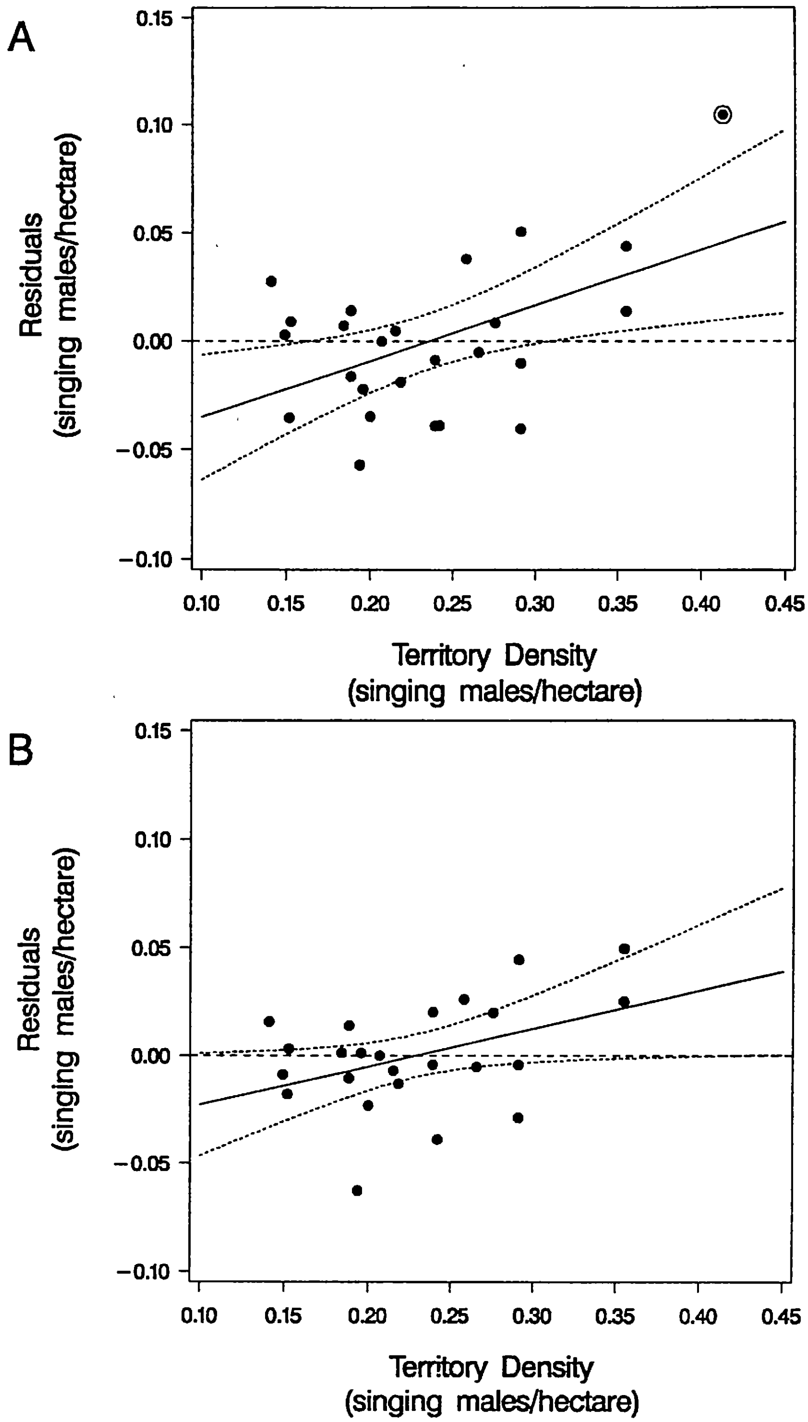

Figure 7. Scatter plot of ordinary residuals versus observed Black-capped Vireo territory densities at the Kerr Wildlife Management Area, Kerr County, Texas, 1993–1997. The solid lines show the regression of the residuals on observed territory density. The closely dotted lines show the 95% confidence region, while the more widely spaced dotted lines shows residuals equal to zero. Panel A is the model with the outlier (circled); panel B is the same plot without the outlier.

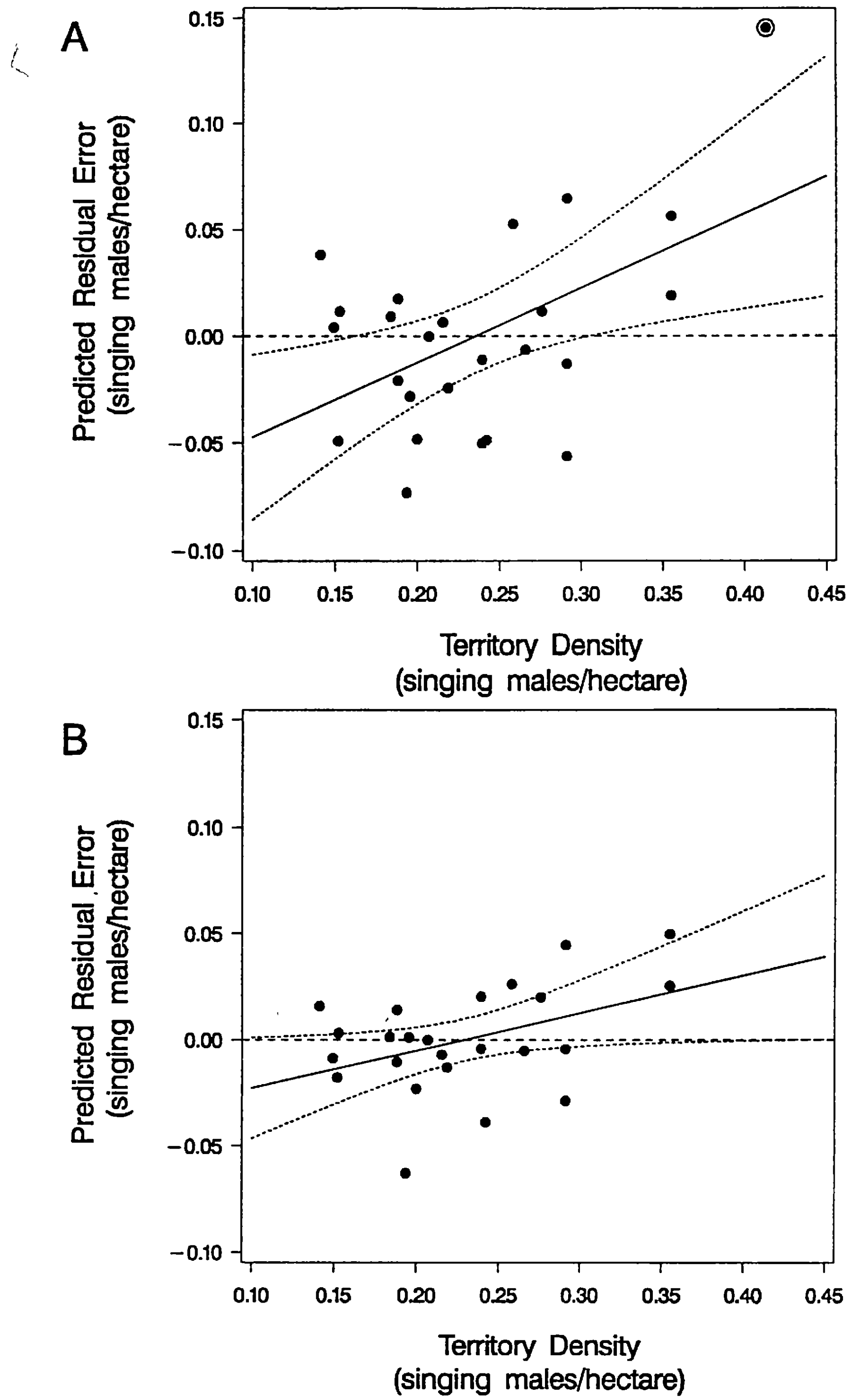

Figure 8. Scatter plot of predicted error sum of squares (PRESS) residuals versus observed Black-capped Vireo territory densities at the Kerr Wildlife Management Area, Kerr County, Texas, 1993–1997. The solid lines show the regression of the residuals on observed territory density. The closely dotted lines show the 95% confidence region, while the more widely spaced dotted lines shows residuals equal to zero. Panel A is the model with the outlier (circled); panel B is the same plot without the outlier.

evidence that the North Doe 1997 observed density point was an outlier. Note, that in both sets of plots, when the putative outlier was included, the line where residuals equal zero did not fall within the 95% confidence region for the regression of residuals on the observed territory densities (Figures 7A, 8A). However, when I held the outlier out, the residuals equal to zero line was included in the 95% confidence region (Fig. 7B, 8B). Thus, omitting this point resulted in the following best general linear model ($r^2 = 0.82$, $P = 0.0001$) for predicting vireo territory mapping density (Tables 8, 9):

$$VTD = 0.0098\,(NR) - 0.064\,(MR) + 0.00\,(SR) - 0.052\,(ND) - 0.097\,(SD) + 0.024\,(YR) + 0.20$$

where:

VTD	=	Vireo territory density (singing males/hectare)
NR	=	North Rock
MR	=	Middle Rock
SR	=	South Rock
ND	=	North Doe
SD	=	South Doe
YR	=	Year in the study (1993 = 1, 1994 = 2, etc.)

Each pasture was coded 1 if it was the pasture density being predicted and 0 if it was not the pasture density being predicted. Thus, for example, the predicted value for vireo territory density in North Rock for 1993 was calculated as follows:

$$VTD = 0.0098\,(1) - 0.064\,(0) + 0.00\,(0) - 0.052\,(0) - 0.097\,(0) + 0.024\,(1) + 0.20 = 0.23 \text{ singing males/hectare.}$$

With the best model, predicted values were not consistently higher or lower than observed values overall (Fig. 9), nor were predicted values consistently higher or lower in any one pasture (Fig. 10) or for any one year (Fig. 11).

Table 8. Parameter estimates, P values, and standard errors for best general linear model relating Black-capped Vireo territory mapping density to pasture and year in study at the Kerr Wildlife Management Area, Kerr County, Texas, 1993–1997 ($n = 24$, putative outlier omitted, $r^2 = 0.82$, $P = 0.0001$).

Parameter	Estimate	P	Std error of estimate
North Rock (NR)	0.0098	0.60	0.018
Middle Rock (MR)	- 0.064	0.0023	0.018
South Rock (SR)	0.00	—	—
North Doe (ND)	- 0.052	0.014	0.019
South Doe (SD)	- 0.097	0.0001	0.018
Year (YR)	0.024	0.0001	0.0043
Intercept	0.20	0.0001	0.018

Table 9. Results of analysis of variance for best general linear model relating Black-capped Vireo territory mapping density to pasture identification and year in study at the Kerr Wildlife Management Area, Kerr County, Texas, 1993–1997 (n = 24, outlier omitted; $r^2 = 0.82$, P = 0.0001).

Source	Degrees of freedom	Sums of squares*	Mean square	F	P
Error	18	0.015	0.00081	—	—
Pasture	4	0.040	0.0010	12.3	0.0001
Year	1	0.027	0.027	33.0	0.0001

* For model effects, the sums of squares are type III.

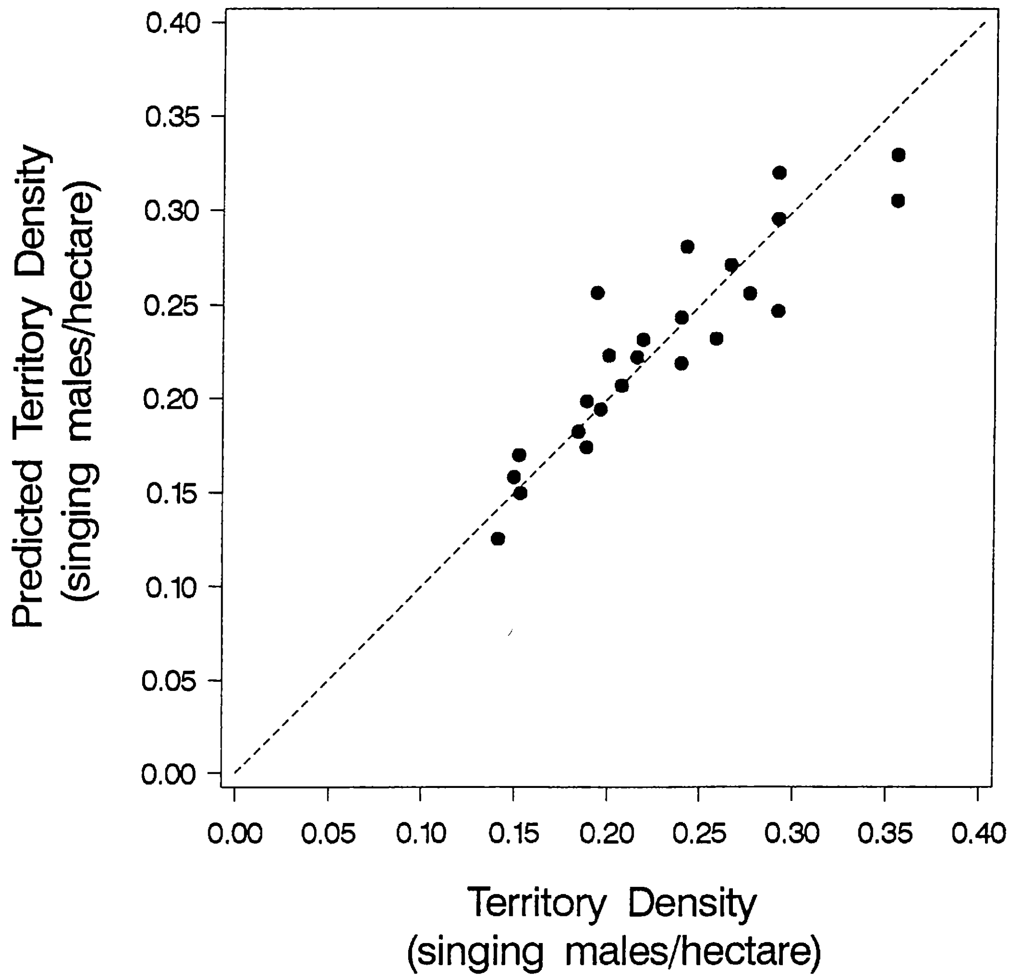

Figure 9. Scatter plot of the relationship between Black-capped Vireo densities predicted by the best general linear model ($r^2 = 0.82$, $P = 0.0001$) and densities observed by territory mapping at the Kerr Wildlife Management Area, Kerr County, Texas, 1993–1997. Dotted line indicates model predicted density equal to observed density.

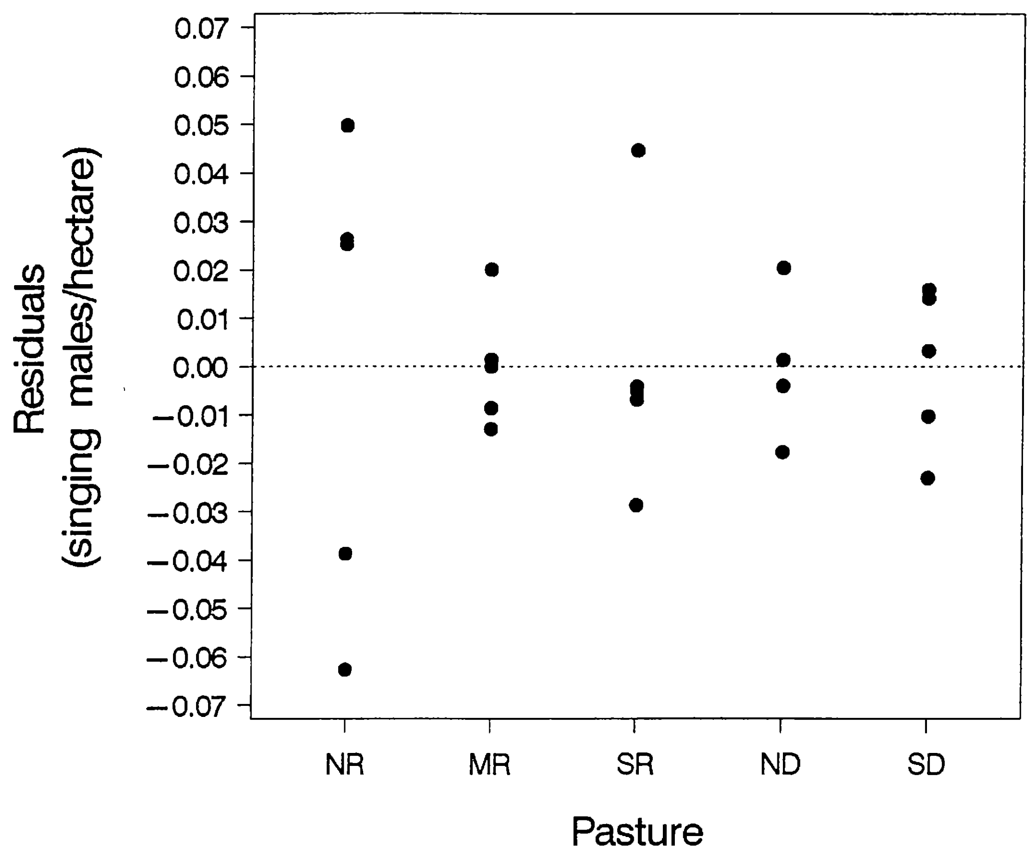

Figure 10. Scatter plot of ordinary residuals versus observed Black-capped Vireo territory mapping densities by pasture at the Kerr Wildlife Management Area, Kerr County, Texas, 1993–1997. Dotted line shows residuals equal to zero. Outlier is omitted. NR = North Rock, MR = Middle Rock, SR = South Rock, ND = North Doe, SD = South Doe.

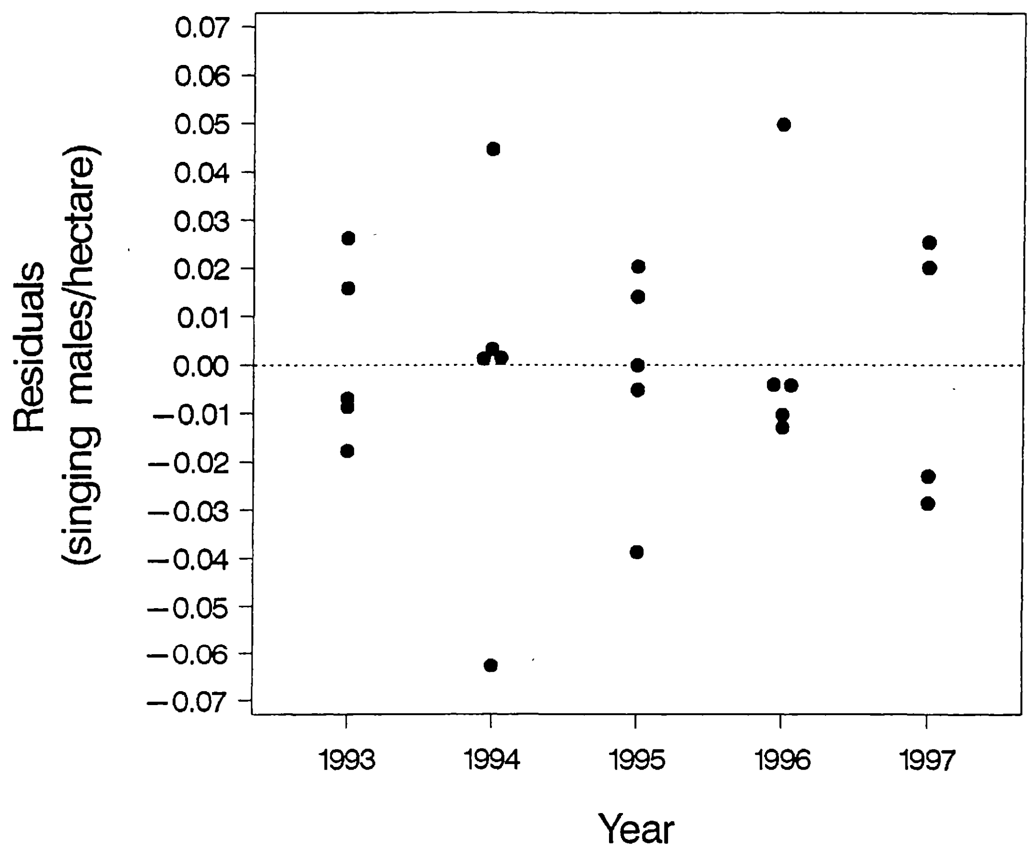

Figure 11. Scatter plot of ordinary residuals versus year in study for all study pastures combined at the Kerr Wildlife Management Area, Kerr County, Texas. Dotted line shows residuals equal to zero. Outlier is omitted.

Visually, the model fits all the data (except the North Doe outlier point) well (Fig. 12).

General Linear Modeling: Contrast Sums of Squares

In the model that best fit the data (for all observations except the outlier), estimates for the North Rock and South Rock Pasture coefficients were very close in value, as were the estimates for the Middle Rock and North Doe Pasture coefficients (see Table 8). Therefore, I used general linear modeling and contrast sums of squares to test the null hypotheses that the North Rock coefficient was equal to the South Rock coefficient or that the Middle Rock coefficient was equal to the North Doe coefficient. With P values of 0.60 and 0.55 for the contrast between North Rock and South Rock and between Middle Rock and North Doe, respectively, the null hypotheses were not rejected. Thus, I concluded that there was insufficient evidence to deduce that the North Rock and South Rock coefficients were different or that the Middle Rock and North Doe coefficients were different (Table 10).

I also used contrast sums of squares to test whether the average of the North Rock and South Rock coefficients was different from the average of the Middle Rock and North Doe coefficients, as well as to see if either coefficient average was equal to the South Doe coefficient. Based on P values, the averages were not equal, nor was either average equal to the South Doe coefficient (see Table 10).

General Linear Modeling: Increasing the Generalizability of the Model

One way to make the model generalizable beyond the boundaries of the study area was to substitute other more widely applicable variables for the pasture identification variable. Because of its general availability and biological

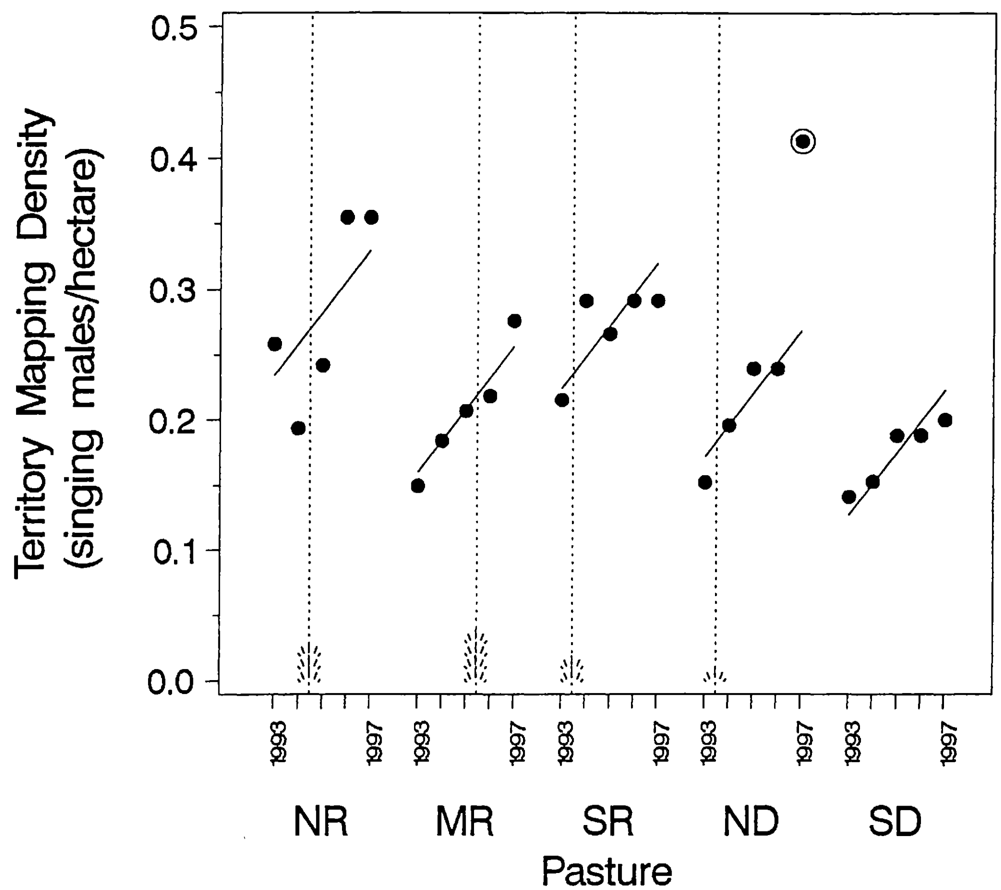

Figure 12. Observed and predicted Black-capped Vireo territory mapping density by pasture and year at the Kerr Wildlife Management Area, Kerr County, Texas. Solid lines indicate best model predicted density ($r^2 = 0.82$, $P = 0.0001$). Dotted lines indicate when each pasture was burned. Fire symbols designate the intensity of the burn with more symbols representing progressively hotter burns. Putative outlier is circled. NR = North Rock, MR = Middle Rock, SR = South Rock, ND = North Doe, SD = South Doe.

Table 10. Results of analysis of variance for contrasts investigating equivalence of pasture coefficient estimates in the best general linear model ($r^2 = 0.82$, $P = 0.0001$) relating Black-capped Vireo territory density to pasture identification and year in study at the Kerr Wildlife Management Area, Kerr County, Texas, 1993—1997 for all observations except the outlier (n = 24).

Source	Degrees of freedom	Sums of squares*	Mean square	F	P
Error	18	0.015	0.00081	—	—
N. Rock vs S. Rock	1	0.00024	0.00024	0.29	0.60
Mid. Rock vs N. Doe	1	0.00031	0.00031	0.38	0.55
(N. Rock+S. Rock)/2 vs (Mid.Rock+N.Doe)/2	1	0.019	0.019	23	0.0002
(Mid. Rock+N. Doe)/2 vs S.Doe	1	0.0048	0.0048	5.9	0.026
S. Doe vs (N.Rock+S.Rock)/2	1	0.034	0.034	42	0.0001

* For comparisons of pasture coefficients, the sums of squares are contrast sums of squares.

significance, I substituted soil type for pasture identification and again did general linear modeling.

There were five soil types in the study pastures (Table 11). Since all soil percentages summed to a constant (100%), once the percentages for four of the soil types were specified, the fifth percentage was determined and thus did not represent independent information. Therefore, I used a slightly different procedure in modeling than was used with the other independent variables.

In the first soil model, I included all soil types and used this analysis to identify the soil types that contributed significantly to determining vireo territory density (Table 12). The two soil types that were significant were the Tarrant-Eckrant association (TTC) and the Eckrant-Rock outcrop association (ERG), both with P values of 0.0001. Year in study was also significant (P = 0.0001).

I then generated a final soil type model incorporating the two significant soil types and year in study. This time I calculated an intercept estimate so that this model could be compared on an equal basis with the best pasture identification and year in study model (Tables 13, 14). The best soil data model for estimating vireo territory density was as follows:

$$VTD = 0.0017\,(\%TTC) + 0.0022\,(\%ERG) + 0.024\,(YR) + 0.026$$

where:	VTD	=	Vireo territory density (singing males/hectare)
	TTC	=	Tarrant-Eckrant association soil type
	ERG	=	Eckrant-Rock outcrop association soil type
	YR	=	Year in the study (1993 = 1, 1994 = 2, etc.)

Table 11. Soil profiles of study pastures at the Kerr Wildlife Management Area, Kerr County, Texas.

Soil type	Soil code	Percentage				
		North Rock	Middle Rock	South Rock	North Doe	South Doe
Tarrant-Eckrant	TTC	25.825	60.962	98.575	68.812	19.951
Eckrant-Rock outcrop	ERG	62.740	12.652	1.425	0.000	17.308
Denton silty clay	DnB	11.435	26.386	0.000	0.000	0.000
Eckrant-Comfort	ECC	0.000	0.000	0.000	0.000	2.778
Spires-Tarpley	STC	0.000	0.000	0.000	31.188	59.963

Table 12. Results of analysis of variance for general linear model relating Black-capped Vireo territory mapping density to year in study and all five soil types represented in the study pastures at the Kerr Wildlife Management Area, Kerr County, Texas, 1993—1997 (n = 24, outlier omitted; $r^2 = 0.82$, $P = 0.0001$), no intercept estimate.

Source*	Degrees of freedom	Sums of square**	Mean square	F	P
Error	18	0.015	0.00081	—	—
Year	1	0.027	0.027	33	0.0001
TTC	1	0.095	0.095	117	0.0001
DnB	1	0.0011	0.0011	1.4	0.25
ERG	1	0.075	0.075	92.1	0.0001
ECC	1	0.000081	0.000081	0.01	0.92
STC	1	0.00029	0.00029	0.36	0.56

* TTC = Tarrant-Eckrant association, DnB = Denton silty clay, ERG = Eckrant-Rock outcrop, ECC = Eckrant-Comfort association, STC = Spires-Tarpley association

** For model effects, the sums of squares are type III.

Table 13. Parameter estimates, P values, and standard errors for best general linear model relating Black-capped Vireo territory mapping density to year in study and significant (alpha = 0.05) soil types at the Kerr Wildlife Management Area, Kerr County, Texas, 1993–1997 (n = 24, putative outlier omitted, $r^2 = 0.79$, P = 0.0001).

Parameter	Estimate	P	Std error of estimate
%Tarrant-Eckrant (TTC)	0.0017	0.0001	0.0003
%Eckrant-Rock outcrop (ERG)	0.0022	0.0001	0.0004
Year (YR)	0.024	0.0001	0.0043
Intercept	0.026	0.31	0.025

Table 14. Results of analysis of variance for best general linear model relating Black-capped Vireo territory mapping density to significant (alpha = 0.05) soil types and year in study at the Kerr Wildlife Management Area, Kerr County, Texas, 1993—1997 (n = 24, outlier omitted; $r^2 = 0.79$, $P = 0.0001$).

Source	Degrees of freedom	Sums of squares*	Mean square	F	P
Error	20	0.017	0.00086	—	—
%Tarrant-Eckrant (TTC)	1	0.030	0.030	35.4	0.0001
%Eckrant-Rock outcrop (ERG)	1	0.033	0.033	38.0	0.0001
Year (YR)	1	0.027	0.027	31.0	0.0001

* For model effects, the sums of squares are type III.

So, for example, the predicted value for vireo territory density in North Rock for 1993 was calculated as follows:

VTD = 0.0017 (%TTC) + 0.0022 (%ERG) + 0.024 (YR) + 0.026

VTD = 0.0017 (25.83) + 0.0022 (62.74) + 0.024 (1) + 0.026

VTD = 0.23 singing males/hectare

Calculated using the pasture and year in study, the vireo territory density for North Rock was also 0.23 singing males/hectare.

Comparing the Soil Model with Pasture Identification Model

Since one goal of generating the soil model was to increase the generalizability of the results, it was important to compare the soil and pasture identification models to see if there was any difference in the way they fit the data. The r^2 value (0.79) for the model in which soil types were substituted for pasture identification was only slightly less than for the model with pasture identification ($r^2 = 0.82$) (see Tables 9, 14). Essentially, the soil type variable partitioned the amount of vireo territory density that was predicted by pasture type into two other variables, percentage Tarrant-Eckrant (TTC) and percentage Eckrant-Rock outcrop (ERG).

Considering just the statistically significant soil associations, Tarrant Eckrant (TTC) and Eckrant-Rock outcrop (ERG), North Rock and South Rock had about the same percentage of the two soil types combined. Middle Rock and North Doe likewise were similar in the total percentage of soils of these two types, while the South Doe TTC plus ERG composition was unique (Fig. 13). Interestingly, in the pasture identification model, North Rock and South Rock had similar coefficients as did Middle Rock and North Doe, while again the

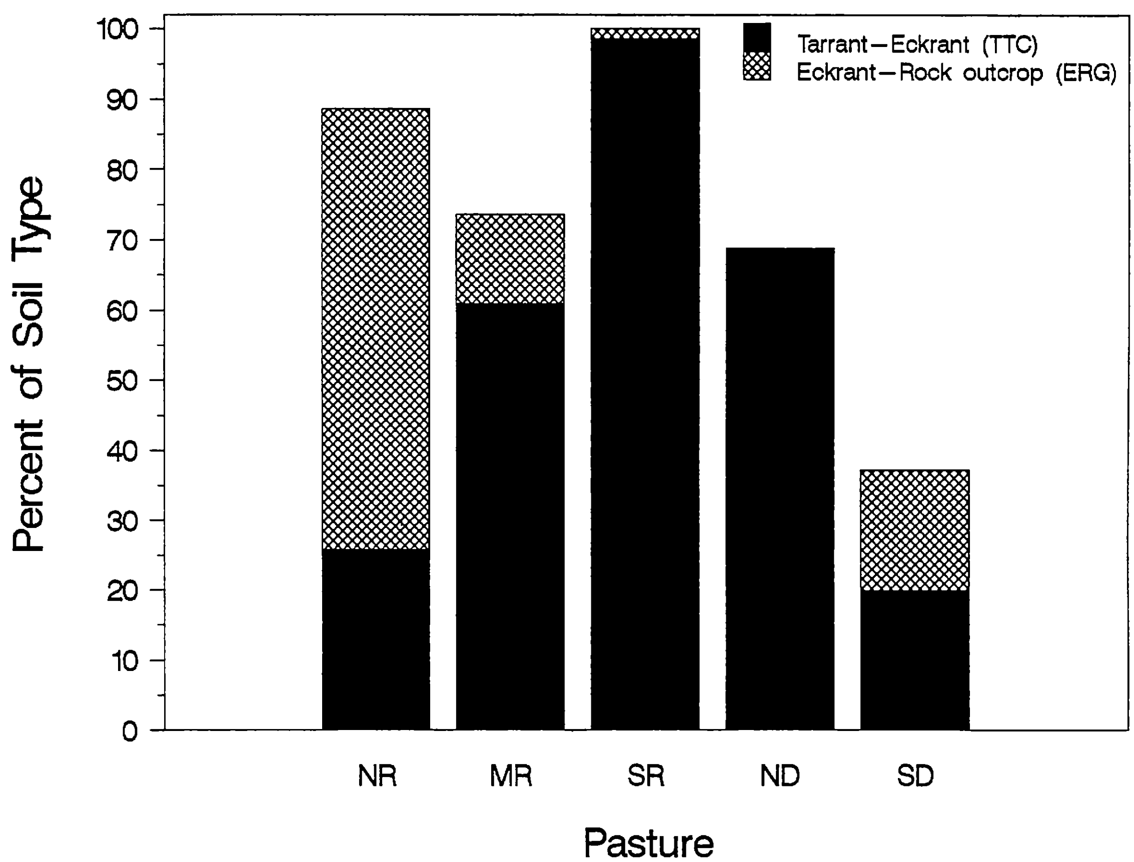

Figure 13. Bar graph of soil profiles of study pastures at the Kerr Wildlife Management Area, Kerr County, Texas. Only soil associations with statistical significance (alpha = 0.05) in predicting Black-capped Vireo territory density through general linear modeling are shown. NR = North Rock, MR = Middle Rock, SR = South Rock, ND = North Doe, SD = South Doe.

South Doe coefficient was different (see Table 8).

DISCUSSION

Habitats for migratory birds should be viewed as ecosystems capable of sustaining complex processes of disturbance, regeneration, and seral development in various ways (Sherry and Holmes 1995). Theoretically, the ecosystem approach to management is holistic and has a goal of sustaining natural resources by ensuring that ecosystem processes and functions operate within natural ranges of variation (Block et al. 1995). With a holistic approach, management plans for endangered species protection should be in concert with other natural resource goals, including biodiversity conservation, watershed protection, and soil maintenance (Rust and Watson 1995). Such an approach, which is motivated by an appreciation for the natural potential of the land, should produce the most benefit at the lowest cost over the longest time (Rust and Watson 1995).

In the case of management practices at the KWMA, the questions are, Does prescribed burning used to control Ashe juniper affect the other components of the ecosystem, in particular the Black-capped Vireo? and How can management strategies be optimized? Moreover, because the KWMA is part of a larger ecosystem, the value of individual site-focused management will depend on the matrix of vireo numbers and available habitat in which the sites are found and may also depend on certain dimensions of population structure (Grzybowski 1991).

Assessing Management Activities: One Day Counts and Territory Mapping

Monitoring is one way to assess the consequences of management action (Droege 1993). Since there is geographic variation in the habitats available and used by the Black-capped Vireo, different techniques may be needed to create and maintain vireo habitat (Grzybowski et al. 1996). Monitoring is essential to determine commonalities and differences in successful site by site management for vireos.

To be effective, local monitoring programs should be determined by goals and should consider priorities, regional monitoring, the kind of feedback required, and available resources (Droege 1993). Monitoring techniques ideally are accurate and precise and introduce a minimum of disturbance into the population being assessed. Formal monitoring of the Black-capped Vireo at the KWMA has been done by one day presence/absence transect counts and, in selected study pastures, by intense territory mapping. Since the results of this study showed a lack of correlation between the one day counts and those obtained by intensive mapping, choices must be made considering the goals of the monitoring as well as the strengths and weaknesses of each method.

One Day Counts

The one day presence/absence counts do not appear to be adequate for estimating territory density, and thus currently are not adequate for making density-based evaluations or decisions. With the transect method, the relationship between the number of cues counted along the transect and the absolute density of the birds appears to depend on two variables: (1) cue attenuation with lateral distance from the transect line and, (2) the frequency with which birds produce visual or audible cues detectable at any range

(Emlen 1977). The one day count transect method in use at the KWMA does not seem to control for either of these variables.

Other limits of the one day count method include the conducting of the counts only once each year and only early in the breeding season at a time when weather conditions are often influenced by late spring cold fronts. Since only one run of each transect is made, it is especially difficult to determine if a bird was missed or simply not present at the time the transect was walked when comparing transect counts with other monitoring counts. The fact that tapes are used to "call" the birds introduces an element of disturbance and potentially skews the results. Another limitation of the one day transect method is the way data are combined for some pastures and recorded on hard to interpret maps.

Because of the limitations of the one day count methods, rather than considering the data as a measure of density of singing males/ha, it might be more appropriate to report the transect counts (without the addition of birds picked up in the general walk of each pasture and added to the transect numbers) as singing males/km of transect. Then the transect data would be useful as an index of relative abundance to compare year to year changes (Caughley and Sinclair 1994) and to note general trends .

If one goal of monitoring is to obtain better correlation between transect and intensive mapping data, it might be useful to map vireo territories in relationship to transect lines. For example, a map could be made showing the locations of the transect line(s) and territories in each pasture. An acoustical band could be drawn around each territory in order to see at what stop each bird might be detected from the transect line. Detailed information regarding birds recorded at each transect stop would obviously be necessary and the use of the KWMA Black-capped Vireo management geographical information system (GIS) developed by Coats (1997) might be helpful in accurately mapping the data.

Intense Territory Mapping Counts

Although the territory mapping counts are labor and time intensive, they must be regarded as the gold standard by which to measure density of singing male vireos/ha. Advantages of this method for estimating density include the fact that whole pastures are surveyed over most of the breeding season. The method is also less disturbing to birds (to the extent that birds are not driven around their territories) and more detailed information is gathered regarding territory locations.

Limitations of the method include the reality that vireo territories do not always fit completely within the boundaries of one pasture, and so decisions have to be made regarding whether a particular territory is actually in one pasture or another. Terrain and vegetation make it hard to accurately map territories and unless males are counter-singing during one observation period, it is sometimes hard to tell if there are one or two birds in an area. Males may also change singing and conspicuousness as the breeding season progresses. Also, although the territory numbers can be expressed as a density for the whole pasture, the territories are not necessarily uniformly distributed within a pasture.

The bottomline is that there are always tradeoffs between methods used and data obtained. What is important is that the results be adequate for the purpose of the study.

General Trends in Vireo Densities

Monitoring vireo densities via the intense territory mapping method revealed several general trends which may give some insight into the usefulness and desirability of the habitat for the vireos as well as the effects of prescribed burns. For example, the observation that the starting densities of birds in the study pastures were at one of two different levels may be an indication that not all habitat is equal.

Because one of the pastures chosen to be a control (left unburned) was inadvertently burned, it is difficult to interpret the results as they relate to the effects of prescribed burns on vireo density. Initially, the Middle Rock Pasture was not scheduled to be burned during the 1993–1997 study period. According to the original experimental design, Middle Rock was to be the control for the Rock Pastures, while South Doe was the control for the Doe Pastures. However, the starting density in Middle Rock was more similar to that in North Doe and South Doe, while South Rock and North Rock beginning densities were similar. Also, vegetation data (such as species, density, dominance, frequency, importance, and richness) were not collected throughout the study in all pastures. Thus, more data would be needed to choose (and then maintain) the best control(s).

With the caveat of the limitations imposed by having no clear control, it is still worth looking closely at the trends and the questions they raise. Densities in general were increasing (although there were some annual increases and decreases), but were densities in "better quality" pastures growing at a rate different from that in lower quality pastures? What about the effect of fire? The ending density in all burned pastures was higher than the ending density in the one unburned pasture. Does fire somehow equalize the attractiveness and usefulness of habitat so that, once burned, lesser quality habitat becomes more like better quality? The study time period was too short to answer these questions. Perhaps this study only captured the natural cycle of density change and does not show a response of the birds to fire disturbance. Diehl (1986) found a sawtooth pattern of regular increases and decreases in alternating years, superimposed on the otherwise steady upward trend in numbers of breeding passerines in her 21 year study of bird community dynamics in a heterogeneous and changing habitat. In the case of my work, a longer study period might help discriminate between random variation in density and response to disturbance.

Looking at the trends considering years post burn raises even more questions. At one year post burn, all but one pasture showed an increase in density. In South Rock after an initial decline, density increased and finally plateaued. Was the decline related to the burn at all? Or was something else happening in the region (densities in other study pastures were not declining in 1995)? Perhaps the plateau reflects saturated habitat so that even with a burn, effects on density are limited even in the short term.

At two years post burn, the cool and moderately burned pastures showed only slight changes in density (as compared to burn year densities), while the hot burned pasture had a more marked increase. However, that there were no data two years post burn for the very hot burned pasture makes it hard to say how intensity of burn might affect vireo territory density.

Vireo territory densities in general were higher 0–3 years following a burn as compared to 7–11 years following a burn. This seems to support the findings of others that burns do not seem to have a negative effect on vireo territory density (O'Neal et al. 1996), and that periodic burning may be necessary to keep habitat in a condition suitable for vireo use (Graber 1957, U. S. Fish and Wildlife 1991, Grzybowski et al. 1993, Tazik et al. 1993a, Rust and Watson 1995, Grzybowski et al. 1996). Since no data were available for 4–6 years following a burn, interpretation is limited and these are data worth pursuing.

Modeling to Study Vireo Territory Density Relationships

The most common questions asked by wildlife managers concern where and in what abundance a species occurs and what will happen when a particular management action is taken. Thus, research is needed to refine models that can best inform these questions (Norton and Possingham 1993). This study addressed both issues by using modeling to look at the factors that affect vireo territory density and the consequences of prescribed burning.

Part of the value of a model to applied management is measured in its usefulness for making wise decisions (Norton and Possingham 1993, Starfield 1997). Sometimes the decisions needed are not about what to do or not to do, but about what information is needed and what is the best way to get that information. Modeling in this context can be a tool to investigate how effective it is to collect and use data in one way rather than another (Starfield 1997). My model, while providing information regarding the factors affecting vireo territory density, may be most useful in enlightening the data collection and analysis processes.

Factors Affecting Vireo Territory Density: Year in Study and Pasture Identification

Of the variables studied, only year in study and pasture identification were significant in predicting vireo territory density. The significance of year in the study fits with the general trend of densities increasing with time. Pasture identification as a dummy variable essentially held a place for many variables. Although there were five different pasture categories (because there were five study pastures), considering just starting density there were only two pasture types, the North Rock and South Rock type (with starting density of about 0.21 singling males/ha) and the Middle Rock, North Doe, and South Doe type (with starting density of about 0.15 singing males/ha). Contrast sums of squares analysis as well as the best soil model suggested there were three pasture categories, the North Rock and South Rock type, the Middle Rock and North Doe type, and the South Doe type (probably most similar to the Middle Rock and North Doe category). Thus, maybe there really are only two or three different pasture types. Simplifying the model by reducing the number of pasture categories could provide additional understanding regarding the factors important to vireo habitat selection and productivity, while also making the model more generalizable.

Factors Affecting Vireo Territory Density: Soil Type

While more data are necessary to characterize pastures more completely, some insight into what part edaphic features might play in affecting vireo territory density can be obtained by a closer look at the soil data. Others (Sexton et al. 1989, Sexton 1990, Rust and Watson 1995, Grzybowski et al. 1996) have suggested a correlation between the occurrence of Black-capped Vireos in Texas and the location of particular soils and/or geologic strata. Not considering the Eckrant-Comfort association (ECC) because it was present in only one study pasture (2.778% of the soil composition), comparing the range site descriptions for the other soil types show some interesting patterns. For example, although the four soil types are similar in many ways, the Tarrant-Eckrant (TTC) and Eckrant-Rock outcrop (ERG) associations are shallow to very shallow and have shallow or very shallow rooting zones, while the Denton silty clay (DNB) and Spires-Tarpley association (STC) are deep or moderately deep to shallow and have deep or shallow to moderately deep rooting zones (Soil Conservation Service 1986).

In the soil model, it was the TTC and ERG types that contributed significantly to predicting vireo territory density. Perhaps differences in soil and rooting zone depths are reflected in the vegetational composition of the landscape and in this way affect vireo territory density. Just how soils affect vegetation depends on a whole matrix of variables, including topography, climate, past use of the land, disturbance, and management strategies. In my study, soil analysis was exploratory and primarily done to increase the generalizability of the pasture identification and year model. Additional research is needed to further investigate the role of soils in relationship to vireo territory density.

Factors Affecting Vireo Territory Density: Time Since Burn

Although not statistically significant in this relatively small data set, there was some indication that time since burn might have contributed to predicting vireo territory density. This would seem to be in agreement with the idea that vireo habitat is found at a particular point in succession following disturbance (Steed 1988). Whether time since burn exerted a weak effect only barely detectable in the small sample size or whether the effect was just due to random variation is not clear. Collecting data over a longer length of time, especially covering the period of 4–6 years after a burn, might further elucidate the contribution of time since burn.

Interaction between Factors Affecting Vireo Territory Density

In the best models, there was no interaction between pasture identification and year in study or between soil types and year in study. In these models, then, each predictor variable acts independently of the others. In other words, the effect of a given change in one independent variable (year in study, pasture identification, or soil type percentage), was always the same no matter what the values of the other independent variable (Glantz and Slinker 1990).

Measuring the Variation in Vireo Territory Density Explained by the Models

The coefficient of determination (r^2) is used to describe how much of the variance is explained by the regression plane. In stepwise regression, r^2 can also be used as an indication of the additional information gained by including more independent variables in a regression model (Glantz and Slinker 1990). Because r^2 values for both the pasture and soil models were relatively high and comparable, both models seem to explain a significant amount of variability in vireo territory density. The models also achieved the goal of parsimony in that they had reasonably high r^2 values without including a large number of independent variables.

The Outlier Dilemma

The North Doe 1997 observed density outlier point adds interest to the study results. Although there were not enough data to calculate an outlier test statistic, the visual evidence provided by the plots of both the ordinary residuals and the PRESS residuals demonstrated that the relationships seen in the rest of the data did not fit this one point. Because of the small sample size, some of the effects of the outlier were likely magnified. However, although holding the outlier out of the analysis improved the fit of the model, it did not change which variables contributed significantly to predicting vireo territory density.

As neither the result of a data entry nor field counting error, the outlier stimulates several questions. Among them are the following. Would the steep increase in density in North Doe continue if data were collected for a longer period? What would using the GIS show about the locations of the additional vireos in comparison with prior year North Doe territory locations? What was the history of fire in the nearby pastures as well as in the nearby region off the KWMA?

The last two questions raise the whole issue of landscape level effects. Freemark et al. (1995) suggest that the distribution and population dynamics of neotropical migratory birds cannot be understood solely from processes occurring within individual habitat patches. In particular they suggest that metapopulation dynamics may confuse interpretations of monitoring data based solely on abundance. One way to explore landscape (and even larger scale effects) is to do banding. Banding studies could show whether essentially the same birds are returning year after year while also providing important demographic information.

Adding to the Model: Other Data to Explore

As the outlier dilemma makes clear, it is apparent that more data are needed to explore the variables affecting Black-capped Vireo territory density.

Factors to consider include collecting data for a longer period of time, assessing vegetation, and obtaining more specific prescribed burn information.

Extending the study period would not only increase the amount of data for analysis, but as discussed previously, would also help fill in the gap regarding changes in vireo territory density four to six years following a prescribed burn. Moreover, collecting data over a longer period of time might also improve the chance of seeing the effects of climate on territory density. Other researchers (Gaud et al. 1986, Hejl and Beedy 1986) have found relationships between climatological variables, including precipitation, and bird abundance. In my study, the finding that January–July rainfall was not significant in predicting vireo territory density may be because it takes a particular pattern of alternating wet and dry periods or a long drought before vireo territory densities are affected.

Besides collecting data over a longer period of time, another important factor to consider is vegetation. Fonteyn et al. (1988) found that the effect of fire on the community structure of vegetation on the Edwards Plateau depends to a great extent on species-specific and individual responses of the vegetation. They also noted that the community structure that develops after a fire may be the result of microhabitat variations in fire-generated temperatures. Since one component of the vireo habitat selection template seems to be vegetation structure, it would be important in future studies to collect vegetation data (such as species, density, dominance, frequency, importance, and richness), both before prescribed burns and throughout the monitoring period.

The finding by Fonteyn et al. (1988) that fire-generated temperatures can affect the vegetative community after a burn also illustrates the need to collect detailed information on prescribed burn conditions. This would include parameters such as fuel load, fire-generated temperature, ambient temperature, relative humidity, and wind speed and direction. Although in this study burn intensity was not significant in vireo territory density prediction, perhaps including the individual prescribed burn variables (instead of just a qualitative assessment of the effects of the fire on vegetation succession) would yield different results.

Conclusions

Even if one believes that eventually a detailed process model will be necessary, it is makes sense to start simple (Starfield 1997). Although the model produced in this study is simple, it does shed some light on the variables affecting vireo territory density at the KWMA. The soil model might even be worth testing with an independent data set either collected at the KWMA or at another area (perhaps Kickapoo Caverns State Natural Area, depending on soils). At a minimum the modeling process used in this study suggests what data are important and how to do meaningful analysis.

APPENDIX

Table 1A. Data collected at Kerr Wildlife Management Area, Kerr County, Texas, 1984–1997.

		Singing males				Rainfall (cm)		Soil Percentage				
Year	Pasture	One day count	Territory count	Yrs. since burn	Burn intensity	Jan-Jul	Jan-Dec	Tarrant-Eckrant	Eckrant-Rock	Denton silty clay	Eckrant-Comfort	Spires-Tarpley
1993	N. Rock	25	16	9	Hot	31.34	41.00	25.825	62.740	11.435	0	0
1993	M. Rock	—	13	9	Hot	31.34	41.00	60.962	12.652	26.386	0	0
1993	S. Rock	16	17	9	Hot	31.34	41.00	98.575	1.425	0	0	0
1993	N. Doe	14	7	7	Cool	31.34	41.00	68.812	0	0	0	31.188
1993	S. Doe	7	12	7	Unknown	31.34	41.00	19.951	17.308	0	2.778	59.963
1994	N. Rock	12	12	10	Hot	41.12	80.31					
1994	M. Rock	—	16	10	Hot	41.12	80.31					
1994	S. Rock	12	23	0	Moderate	41.12	80.31					
1994	N. Doe	11	9	0	Cool	41.12	80.31					
1994	S. Doe	8	13	8	Unknown	41.12	80.31					
1995	N. Rock	10	15	0	Hot	42.01	68.50					
1995	M.Rock	—	18	11	Very hot	42.01	68.50					
1995	S. Rock	23	21	1	Moderate	42.01	68.50					
1995	N. Doe	12	11	1	Cool	42.01	68.50					
1995	S. Doe	8	16	9	Unknown	42.01	68.50					
1996	N. Rock	13	22	1	Hot	23.14	74.75					
1996	M. Rock	7	19	0	Very hot	23.14	74.75					
1996	S. Rock	21	23	2	Moderate	23.14	74.75					
1996	N. Doe	9	11	2	Cool	23.14	74.75					
1996	S. Doe	12	16	10	Unknown	23.14	74.75					
1997	N. Rock	17	22	2	Hot	57.71	77.19					
1997	M. Rock	8	24	1	Very hot	57.71	77.19					
1997	S. Rock	26	23	3	Moderate	57.71	77.19					
1997	N. Doe	9	19	3	Cool	57.71	77.19					
1997	S. Doe	14	17	11	Unknown	57.71	77.19					

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