FORAGING ECOLOGY AND FORAGE AVAILABILITY FOR THE

BLACK-CAPPED VIREO (*VIREO ATRICAPILLA)*

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David Timothy Morgan, B.S.

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December 2012

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Committee Members Approved:

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M. Clay Green, Chair

____
Michael L. Morrison

____
Thomas R. Simpson

Approved:

____
J. Michael Willoughby
Dean of the Graduate College

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ABSTRACT

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SUPERVISING PROFESSOR: M. CLAY GREEN

An individual's survival and reproduction depends on its ability to capture prey and obtain energy. Current literature is lacking quantitative information on the foraging habitats or available foods of the federally endangered black-capped vireo (*Vireo atricapilla*). In 2010 and 2011, I monitored male black-capped vireo territories to collect foraging ecology and available foods data at the Balcones Canyonlands National Wildlife Refuge, Texas. I conducted foraging behavior, vegetative time-use, nesting productivity, and vegetation composition surveys in 30 and 58 breeding territories in 2010 and 2011, respectively. I observed 273 foraging events and recorded over 2000 minutes of time-use surveys from black-capped vireo territories in 2010 and 377 foraging events and over 3200 minutes of vegetation time-use surveys in 2011. I collected descriptive data on the

use of vegetative substrates and compared male vireo foraging mean proportion of use versus vegetative species availability between species, year, within season sampling periods, and reproductive success. I collected branch clippings to sample available arthropod foods from a subset of 16 territories in 2010 and 20 territories in 2011. I compared mean arthropod abundance, biomass, and order richness between within season sampling periods and compared mean arthropod order biomass between vegetative species. Ashe juniper (*Juniperus ashei*), shin oak (*Quercus sinuata*), and live oak (*Q. fusiformis*) were the predominant foraging and time-use substrates. There was little difference in vegetation use and territory reproductive successfulness. Sampling available foods revealed variation in arthropod communities between sample years, within season sampling periods, and vegetative species. Ashe juniper is a species of interest because it is commonly removed from vireo habitat because of its tendency to encroach if not properly managed. These data should provide managers valuable information on vegetative species composition to provide vireos optimum foraging opportunities.

CHAPTER 1

FORAGING ECOLOGY AND FORAGE AVAILABILITY FOR THE BLACK-CAPPED VIREO (*VIREO ATRICAPILLA)*

INTRODUCTION

The study of foraging ecology and food resources is critical to understanding the biology of a species (Morrison et al. 1990). An individual's survival and reproduction depends on its ability to capture prey and obtain energy (Hutto 1990a). Food availability plays an important role in the dynamics of natural populations (Wolda 1990), is an important factor in habitat selection (Moorman et al. 2007; McGrath et al. 2008), and contributes to the understanding of various life history characteristics of many bird species (Hutto 1990a). The availability and composition of food resources also affects the amount of time and energy spent for breeding (McGrath et al. 2008).

The black-capped vireo (*Vireo atricapilla*) is a small, federally endangered, insectivorous songbird whose breeding range extends from northern Mexico to Central Texas and spotted populations in Oklahoma (Graber 1961; USFWS 1991; Grzybowski 1995). The breeding range of this vireo once extended from Mexico to Kansas, but human development, fire suppression, nest parasitism, and over-grazing have caused the loss or degradation of habitat across the vireo's range (USFWS 1991). Much of the current vireo research is focused on identifying and monitoring areas of breeding habitat (Benson and Benson 1990; Pinkston et al. 2002; Farquhar et al. 2003; Cooksey and

Thompson 2005; Cimprich and Kostecke 2006) and threats to current populations (Sparkman 1996; Barber and Martin 1997; Eckrich et al. 1999; Guilfoyle 2002; Stake and Cimprich 2003; Kostecke et al. 2005; Maresh 2005). Other recent research topics include breeding habitat characteristics and nest site selection (Grzybowski et al. 1994; Greenman 1995; Dufault 2004; Bailey 2005; Noa et al. 2007) as well as the genetic variation of the species (Fazio 1994; Fazio et al. 2004; Barr et al. 2008). Current literature is lacking critical information on foraging ecology and food availability of the black-capped vireo, and surprisingly, there is little mention of this information in the 1991 federal Black-capped Vireo Recovery Plan (USFWS 1991).

Houston (2008) conducted the most comprehensive study on foraging habits of the black-capped vireo and predominantly focused on niche overlap and differences in foraging behaviors between males and females. Her results quantitatively confirmed Graber's (1961) and Grzybowski's (1995) observations that black-capped vireos are largely foliage-gleaning birds. Both males and females primarily used the foraging gleaning method over other foraging styles (91% for males, $n = 63$ and 94% for females, $n = 44$; Houston 2008). Houston (2008) also presented data on woody vegetative species used by foraging black-capped vireos (live oak, *Quercus fusiformis*, 40%, $n = 48$; Spanish oak, *Q. buckleyi*, 9%, $n = 12$; shin oak, *Q. sinuata*, 20.5%, $n = 22$; Ashe juniper, *Juniperus ashei*, 10%, $n = 11$; other species, 20.5%, $n = 23$). Houston's (2008) study did not account, however, for the vegetative species composition of the study sites, temporal changes in foraging behavior, or available foods throughout the breeding season. Therefore, the potential applicability to understanding foraging ecology of the species is minimal. Foraging ecology is important in understanding the behavioral ecology of a species. Food availability is patchy in time and space, and cyclical on a daily and seasonal basis (Pyke 1977; Orians 1980). There are many studies showing an insectivorous bird's ability to track food resources (Orians 1980; Hutto 1981, 1985; Yard et al. 2004). Tree and shrub phenology changes throughout the seasons, and available foods concentrate on certain woody vegetative species at different periods of development (McGrath et al. 2008). Pollinating arthropods are more abundant around actively flowering species, whereas folivorous arthropods follow leaf phenology (McGrath et al. 2008). Additional research needs to be conducted on the food resources and foraging ecology within black-capped vireo habitat to qualify existing data.

Foraging ecology is also important to consider for better understanding and subsequent development of management strategies for a species. An assumption about the way habitat should be managed often comes from unquantified sources, data from studies conducted in other regions, or human bias. Although black-capped vireos are known to nest in the branches of Ashe juniper, use the bark in the construction of their nests, and forage in its foliage (Graber 1961; Houston 2008), Ashe juniper is generally thought to be an unimportant species in black-capped vireo habitat (Fazik 1993; Leyva 2002; Campbell 2003). Ashe juniper does have the ability to encroach and form monocultures if not managed properly (USFWS 1991; Campbell 2003), which may negatively impact vireo breeding habitat. However, quantitative data on exactly how and to what extent Ashe juniper is used by the birds is largely unknown. Existing Texas Parks and Wildlife Department (TPWD) black-capped vireo habitat management recommendations suggest the selective removal of brush (i.e., Ashe juniper) during the non-breeding season (Campbell 2003). Grzybowski et al. (1994) suggested juniper canopy cover should be kept well below 10% except in areas with only marginal amounts of deciduous vegetation available, and then juniper may be more beneficial at higher levels. Grzybowski et al. (1994) and Tazik et al. (1993) found that vireos tend to occupy areas with lower Ashe juniper cover. However, juniper may be beneficial at certain cover levels or its spatial juxtaposition to other woody species and may be a crucial foraging resource. Many agencies, including TPWD, USFWS, and City of Austin, have extensively removed juniper from vireo habitat. To understand better the implications of juniper brush removal, the black-capped vireo's use of Ashe juniper and other relevant plant species should be examined further.

Research Objectives:

Objective 1: Conduct behavioral foraging surveys of adult black-capped vireos to quantify foraging behaviors and identify temporal shifts in the use of foraging substrates throughout the breeding season.

Objective 2: Conduct observational behavioral surveys to identify and quantify temporal changes of vegetation usage during the black-capped vireo breeding season.

Objective 3: Collect arthropod samples to document and track changes in the abundance and composition of available foods within black-capped vireo habitat throughout different periods of the breeding season.

METHODS

Study Area

I used multiple locations within the Balcones Canyonlands National Wildlife Refuge (BCNWR) as my principal study area. The BCNWR was acquired in 1992 under the authority of the Endangered Species Act of 1973 as part of a larger conservation strategy for the city of Austin, Texas. The primary goal of the refuge is preserving breeding habitat for the endangered black-capped vireo and golden-cheeked warbler (*Setophaga chrysoparia*) (USFWS 1991, 2001, 2003). Located within the Balcones Escarpment and Canyonlands eco-region, in the southeastern portion of the Edwards Plateau, the BCNWR currently contains 53 noncontiguous tracts of land encompassing >8,100 ha (USFW 2001). I focused my research effort in black-capped vireo breeding territories on the Eckhardt (approximately 413 ha), Rodgers (approximately 1494 ha), Simons (approximately 256 ha), Hiene (approximately 24 ha), Russell (approximately 39 ha), and Gainer (approximately 236 ha) tracts, which encompass ~2,460 ha across Travis, Williamson, and Burnet counties (Fig. 1). Male vireo breeding territories during this study ranged from 0.46 ha to 12.72 ha with a mean of 2.91 ha. I selected these tracks because they were known to host multiple breeding vireo territories each year (Sexton 2002, 2005), and allowed me to sample across the BCNWR.

Black-capped vireo habitat on the BCNWR typically consists of an irregular composition of patchy mixed deciduous and evergreen vegetation at varying heights and dense amounts of low lying foliage. Vegetation usually consists of shin oak and/or live oak mixed with Ashe juniper and other woody species, including Spanish oak, Texas persimmon (*Diospyros texana*), Texas Hercules' club (*Zanthoxylum hirsutum*), yaupon (*Ilex vomitoria*), Texas privet (*Forestiera pubescens*), netleaf hackberry (*Celtis laevigata*), gum bumelia (*Sideroxylon lanuginosum*), Texas redbud (*Cercis canadensis*), cedar elm (*Ulmus crassifolia*), and escarpment black cherry (*Prunus serotina)* (USFWS 2001; personal observations). Historically, topography, climate, and soil conditions, as well as fire, grazing, and other disturbances, contributed to the irregular composition and

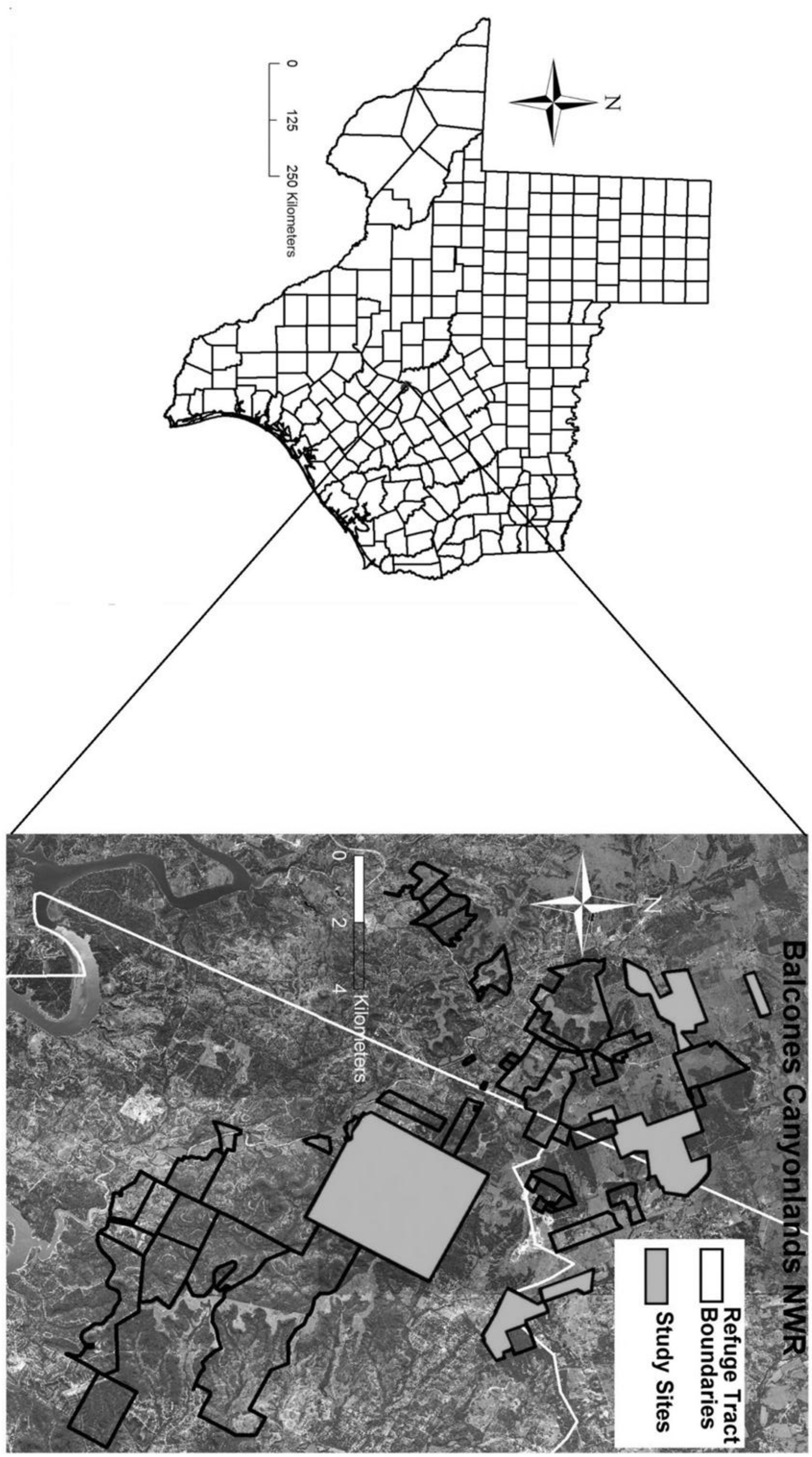

Figure 1: Map of the Balcones Canyonlands National Wildlife Refuge and study sites during the 2010 and 2011 black-capped vireo breeding seasons.

structure of black-capped vireo habitat. Staff and researchers on the BCNWR attempt to identify, protect and manage areas of occupied vireo habitat. Current management practices include prescribed burning, selective habitat manipulation, brown-headed cowbird (*Molothrus ater*) control, limitation of human disturbance, and white-tailed deer (*Odocoileus virginianus*) herd management (USFWS 2001).

Average precipitation of the BCNWR is 84 cm, with an accumulation of ~39.5 cm from March – July, during the black-capped vireo breeding season (ncda.noaa.gov). During both seasons of this study, the accumulation of precipitation from March - July was below average; with ~33.8 cm shown in 2010 and only ~12 cm precipitation in 2011 from March – July (Fig. 2). The average annual temperature of this region is 19.4°C, with an average of 22.43°C from March - July. During this study, mean temperatures were slightly above average in May and June in 2010, and all months of 2011 observed above average temperatures (Fig. 3). The Edwards Plateau, including the BCNWR, is known for its great differences in precipitation between "wet" and "dry" years, as well as intense summer thunderstorms (SCS 1974, 1979). I observed these conditions during my study. The 2010 study season experienced near average temperatures and only slightly below average precipitation, but the summer of 2011 saw severe drought conditions. Janzen and Schoener (1968) observed several effects on arthropod communities during dry seasons, including fewer insects in some sites and "a striking lack of immature insects in all of the areas sampled, and caterpillars, a favorite food for the young of many temperate insectivorous birds." These seasonal climate differences could have adverse effects on foraging capabilities of insectivores.

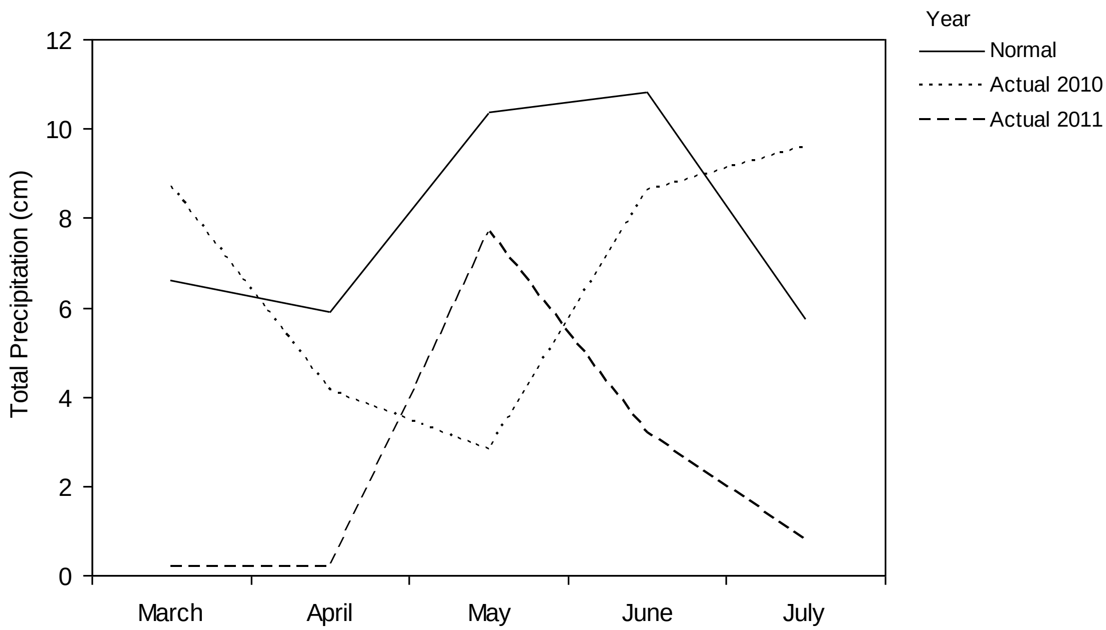

Figure 2: Total monthly precipitation accumulation (cm) with normal monthly averages at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

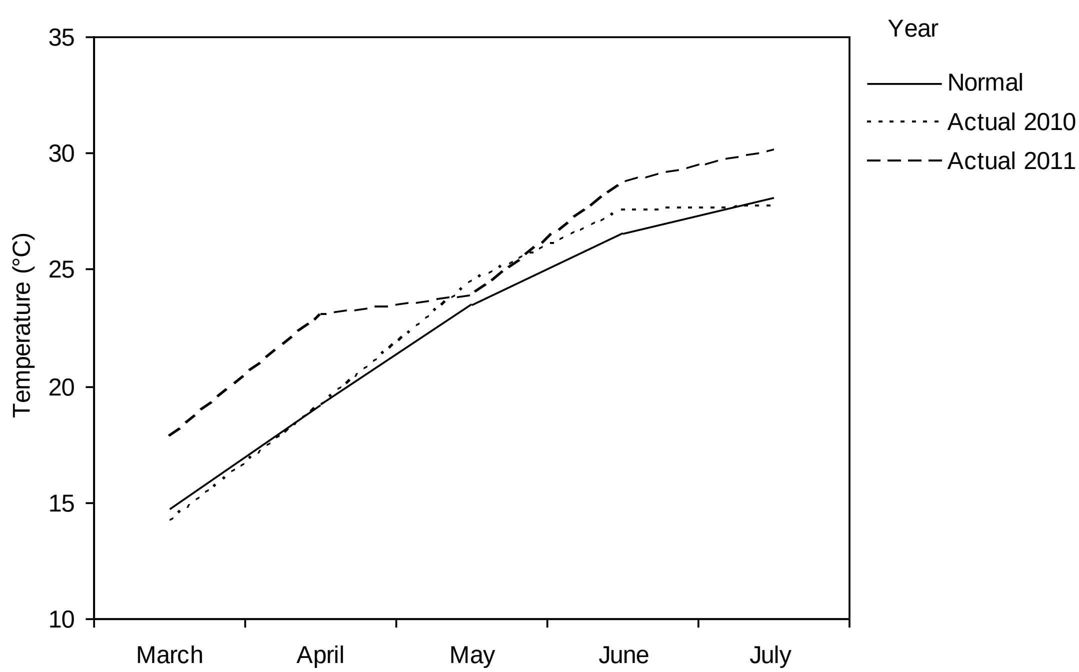

Figure 3: Mean monthly temperature (°C) with normal monthly averages at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

Territory Mapping

I mapped breeding territories of adult male vireos to determine the spatial location that the male or breeding pair inhabits. I located vireos by entering areas of potential habitat and walking transects approximately 50 m to 100 m apart while listening and watching for individuals. Spacing between transects varied depending on habitat patch size. Male vireos are usually vocal through portions of the breeding season, and females can often be found nearby if there is an active mating pair (Graber 1961). Once I located a vireo, I spent a maximum of 60 minutes observing the individual to comply with USFWS endangered species permit regulations. I revisited territories every 3-10 days, with a minimum of 3 territory points being marked during each visit. At the vireo's location I marked a Global Positioning System (GPS) waypoint and continued to follow the bird's movements, keeping a minimum distance of 20 m from the individual, and recording additional waypoints each time the bird traveled 20 m or more from its last location. I designated a unique territory ID for territorial waypoints and uploaded them into an ArcGIS (ESRI 2009) point shapefile and plotted accordingly. I recorded waypoints using the Universal Transverse Mercator (UTM) grid system (NAD 1983, UTM Zone 14N*)*. Territory points were taken throughout the breeding season to adequately identify the area being occupied. I used these vireo territories as my study areas to conduct my foraging ecology and food abundance research. My goal was to map and observe at least 25 male breeding territories in 2010 and at least 40 breeding territories in 2011.

Nesting Behavior and Breeding Productivity

The abundance and composition of available forage affects the amount of time an individual spends foraging, which can affect the amount of time and energy spent for breeding (McGrath et al. 2008). Comparing the foraging habits and available foods of reproductively successful versus unsuccessful vireos may give insight to woody plant species that provide optimum foraging opportunities for nesting vireos. I defined successful vireo territories as those in which fledge at least one young during the breeding season, as opposed to unsuccessful in which no young fledge.

I monitored black-capped vireo pairs for nesting activity. I entered a known vireo territory and attempted to locate a male or female. Once I located a vireo, I spent a maximum of 60 minutes observing the individual for nesting activity and/or searching for nests. If I did not detect the target vireo within 30 minutes, I moved to another vireo territory. I revisited known vireo territories every 3-10 days to monitor nesting behavior and productivity. Once I located a nest, I placed a strip of flagging tape on a tree branch a minimum distance of 10 m away and marked the location with a GPS waypoint. On the flagging tape I recorded the date, unique nest ID, surveyor's initials, nesting substrate, nest direction from flag (degrees), nest distance from the flag (m), nest height (m), and any other information to help locate the nest on return visits. I visually checked active nests every 2-3 days to observe status of the nest. I recorded the nesting stage (building, laying, incubating, nestling, abandoned, failed, or fledged), and if applicable, number of eggs or nestlings and approximate age (days) of nestlings. Nest observations continued until the nest failed, was abandoned, or all chicks fledged.

Vegetation Composition

I conducted point sampling vegetation surveys to examine the vegetation composition of woody plant species in black-capped vireo territories. Starting in late June, once all vireo territories were established and thoroughly mapped, I created minimum convex polygons around the outer boundaries of known established vireo territories using ArcGIS. I then created and overlaid a 20 m x 20 m sampling point grid over territory polygons using Hawth's tools extension in ArcGIS. I then surveyed each sampling point within each territory and determined if woody cover was present (Y/N) at the point, and if applicable, I recorded the 3 most prevalent woody plant species. For each woody species, I recorded the minimum and maximum height of foliage cover to the nearest 0.5 m.

Foraging Behavior and Vegetation Use

I simultaneously used 2 types of behavioral observation surveys during my study. (1) Observational foraging surveys to observe sequential foraging events and record foraging behavior and use of foraging substrates by black-capped vireos throughout the breeding seasons. (2) Vegetation time-use surveys to record time spent in woody plant species during behaviors when the vireo could be foraging. I repeatedly conducted both surveys during the black-capped vireo breeding season from April to July 2010 and 2011, dividing the breeding seasons into three sampling periods (Early, Middle, and Late). The early sampling period (Period 1) occurred from mid-April to mid-May (12 Apr to 10 May 2010; 12 Apr to 11 May 2011) and consisted of vireos establishing territories, searching for mates, and early season nesting attempts and incubation. The middle sampling period occurred from mid-May to early June (11 May to 01 Jun 2010; 12 May to 12 Jun 2011) during the peak periods of nest incubation/nestling activity and mid-season nesting attempts. The late period occurred from mid-June to the early July (02 Jun to 29 Jun 2010; 13 Jun to 11 Jul 2011), after nests had fledged young and late season nesting attempts. Vireos had further late season nesting attempts which extended sample periods 2 and 3 in 2011. I conducted surveys during the peak hours of black-capped vireo activity, which was approximately the first six hours after local sunrise (Hutto 1981).

I entered a known vireo territory and systematically surveyed using visual and aural means to detect adult black-capped vireos. If no detection occurred within 30 minutes of entering the territory, I abandoned the survey and moved to the next vireo territory. I visited and attempted to survey each territory every 3-10 days. Once I detected a vireo, I maneuvered to locate the vireo visually without disturbing the individual. I waited a minimum of 10 seconds before recording data to ensure the bird resumed normal activity to minimize bias (Hejl and Verner 1990); I spent the next 30-60 minutes monitoring the vireo visually, with the aid of binoculars, and recording data on behavioral observations. I differentiated sexes using sexual dichromatism, behavior, and vocalizations. In 2010, my goal was to survey a minimum of 25 vireo territories, distributed evenly between all refuge study areas, throughout each breeding season tracts. In 2011, my goal was increased to 40 breeding territories.

Observational Foraging Surveys — I recorded data for each foraging event I observed while surveying. A foraging event was classified as any instance where a vireo was observed attempting to capture prey. I recorded foraging maneuver (Tables 1), foraging surface (Table 2), and species of vegetative foraging substrate. I also recorded the estimated height of each foraging event and minimum/maximum height of foliage cover in the foraging substrate, all in 0.5 m increments. I also recorded any identifiable prey (size and/or ID to order), sex of the foraging bird (M/F/UN), territory ID, and start time and end times.

Table 1: Descriptions of foraging attack maneuvers used by black-capped vireos during observational foraging surveys to identify physical foraging events at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

Maneuver Type [a]	*Description*
Glean	Picking food off of available substrates without the use of wing power
Hover-Glean	Hover to attack prey with the use of the wings
Sally	Attack from a perch and then return to perch with the use of the wings
Jump-Glean	Attack from a perch and then return to perch without use of the wings
Food Carry	Individual seen gathering prey or seen carrying prey to mate or young
Unknown	Unknown or unlisted behavior

[a] Adapted from Robinson and Homes (1982) and Personal Observations

Table 2: Descriptions and codes used to describe surface substrates of observed black-capped vireo foraging events during observational foraging surveys at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

Surface [a]	*Description*
Foliage	Leaf, seed, flower, gall, or moss
Branch	Limb or offshoot from main stem
Trunk	Main stem visibly distinct from branches or roots
Ground	Bare soil, grass, leaf litter, or exposed root

[a] Adapted from Robinson and Homes (1982) and Personal Observations

Vegetation Time-Use Surveys — Due to visibility constraints of the dense shrub vegetation, I was not able to continuously observe foraging events; however, I was able to track individual vireos' movements using audible vocalizations and intermittent visual sightings. Vegetation time-use surveys reduced the bias of only recording visual observations of foraging since visual observations may be biased towards more open vegetation types. I often conducted both surveys simultaneously, recording foraging events while recording vegetation time-use. As I followed individual vireos, I recorded the amount of time spent (min) in different woody plant species for observed main behaviors (Table 3). I also recorded the estimated minimum/maximum heights of foliage being used to the nearest 0.5 m. Behaviors such as preening, perching, incubation, or behaviors when the vireo could not be foraging were recorded but omitted from any statistical analysis. In 2010, I attempted to record vegetation time-use data for each territory visit for the full 30-60 minutes and found I was able to record behavioral data for only about half the survey time, the other half of the visit I was unable to locate the vireo. So for each sample period in 2011 I attempted to record 24 - 30 minutes of observation over the course of 3 visits (8 to 10 min each) for each territory. This allowed me to gain a greater number of surveys per territory in 2011.

Table 3: Descriptions and codes used to categorize black-capped vireo behaviors observed during vegetation time-use surveys at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

Behavior [a]	*Description*
Vocal	Mobile individual vocally singing or calling
Non-Vocal	Mobile individual without vocalizations
Territorial	Interaction between same species, <10m
Nest Building	Material carry, material collection, or nest construct
Courtship	Male-female interaction <10 m, or display
Grooming	Grooming or preening feathers
Foraging	Attempting to catch prey or seen with food in beak
Incubating	Male or female sitting on eggs or nestlings within a nest
Perching	Perched or inactive individual
Unknown	Mobile Unknown or unlisted behavior

[a] Adapted from behaviors observed in Graber (1961) and Personal Observations
[b] Behaviors recorded but not included in the analysis of vegetation time-use surveys.

Abundance of Potentially Available Foods

I conducted branch clipping arthropod surveys to document available foods in black-capped vireo territories during each breeding season. Branch clipping is a cost-effective and efficient method of sampling for available foods for insectivorous foliage-gleaning birds (Cooper and Whitmore 1990; Johnson 2000). Majer et al. (1990) found few arthropods escaped when using this sampling method. I conducted arthropod surveys during three sampling periods to coincide with the forging surveys; Early, Middle, and Late. Samples were obtained over a 3-10 day period during the last half of each foraging sampling period. I sampled arthropods during the same daylight hours as foraging surveys, the first six hours after local sunrise. I sampled potential black-capped vireo foraging substrates, specifically the outer foliage of available trees and shrubs given that black-capped vireos are primarily foliage gleaning birds (Graber 1961; Wolda 1990; Grzybowski 1995; Houston 2008).

Branch Clipping Arthropod Surveys —Using ArcGIS, I created minimum convex polygons around the outer boundaries of a random subset of established vireo territories. Using Hawth's tool extension in ArcGIS, I created random sample points within each territory boundary. In 2010, I sampled 80 total points within 16 randomly selected vireo territories (5 each). In 2011, I sampled 60 total points within each of 20 randomly selected territories (3 each). I sampled these same points once during each of the 3 sampling periods. I clipped branches from the most dominant tree/shrub species within a 2 m radius of the random sampling point and repeatedly sampled those same species each sampling period from that point. I alternated sampling heights ranging from 0-1 m and 1-2 m, depending on available sampling substrates at sampling locations. For each branch clipping taken, I recorded plant species and height range of branch taken (0-1 m or 1-2 m), time of day (24:00), date, and unique branch ID.

I quickly enclosed the sample branch in a heavy-duty plastic sack and cut it off with hand shears. I then placed a cotton ball soaked with ethyl acetate or acetone into the sack with the branch to kill or stun arthropods inside and prevent predatory arthropods from feeding on other captured prey. The sacks were sealed immediately and within 1 hour were placed into cooler with ice packs to reduce decomposition. Within 4 hours of collection, sealed sample branches were put in a chest style deep freezer and kept at a temperature of 0°C for a minimum of 72 hours to kill all arthropods. Within 2 hours after branch samples were removed from the freezer, each sample was individually removed from its plastic sack and examined on a white surface to separate and collect arthropods. Arthropods from each branch clipping were counted and identified (Table 4) (Wolda 1990). Arthropods from each branch sample were then sealed in a new small bag, labeled with unique branch ID, and put back in the freezer. After arthropods were removed, the branch clipping was labeled and put into a plant press to dry. Later each arthropod sample and branch clipping was dried in an oven to obtain dry biomass. Each arthropod sample was dried at 50°C for 72 hours then weighed to nearest 0.001 g and each branch was dried at 50°C for 120 hours then weighed to nearest 0.01 g.

Available foods for the vireo can be defined as, “the abundance of potential prey items in microhabitats used by an insectivore when searching for food” (Wolda 1990). There is little information available about the diets of black-capped vireos. Graber (1961) examined the stomach contents of 11 black-capped vireos and found their diet to be similar to other vireo species. Comparing stomach content analysis of similar vireo

Table 4: Classification used to identify arthropods and arthropod orders within black-capped vireo breeding territories at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

Order/Classification	Sub-Classification	Order/Classification	Sub-Classification
Acari	N/A	Lepidoptera	Adult
Aranea	N/A	Lepidoptera	Larvae
Blattaria	N/A	Mantodea	N/A
Coleoptera	Adult	Neuroptera	N/A
Coleoptera	Larvae	Non-Prey	N/A
Collembola	N/A	Nothing/Null	N/A
Diptera	N/A	Odonta	N/A
Egg Sac	N/A	Opiliones	N/A
Hemiptera	Auchenorryncha	Orthoptera	N/A
Hemiptera	Heteroptera	Phasmida	N/A
Hemiptera	Sternorrhyncha	Psocoptera	N/A
Hymenoptera	Formicidae	Thysanoptera	N/A
Hymenoptera	Other		

[a] Adapted from Wolda (1990)

species (Beal 1907; Chapin 1925; Nolan and Wooldridge 1962; Yard et al. 2004) I was unable to classify any particular arthropod order as non-potential prey. However, Sherry and McDade (1982) stated “the largest non-crushable prey in a bird’s diet should closely correspond to gape size, and be smaller than the largest crushable prey in the diet.” Rohwer and Spaw (1988) found the average gape width of the black-capped vireo to be ~5.6 mm, so I classified potential prey as any hard bodied (with a hardened sclerotized sheath) arthropods <5.6 mm in width and all soft bodied (crushable) arthropods. I classified any arthropods >5.6 mm wide as non-potential prey items and omitted them from analysis.

Data Analysis

I conducted no detailed statistical analysis on female data, due to the low sample size of female observations. For all foraging and vegetation time-use data, I focused statistical analysis on 3 vegetative species (Ashe juniper, shin oak, and live oak). These 3 focal species were observed to be the most commonly used by black-capped vireos. Information on other vegetative species is only presented as a proportion or percentage observed.

Analysis and Predictions: Nesting Success — I calculated daily probability of nest survival using the Mayfield Method (Mayfield 1961, 1975) and the nest survival module in Program MARK to estimate nesting success (Dinsmore et al. 2002; Rotella 2012). I analyzed data from active nests which contained eggs or nestlings and remained active for at least two nest visits. I ran separate analysis in program MARK for each year using the sin link function and viewing the real parameter estimates output. Each encounter occasion was represented by an individual nests' observations and included five pieces of information (1) first day of incubation, (2) last day eggs/nestlings were observed in the nest, (3) day the nest fledged or last day the nest was checked, (4) nest fate (successful/failed), and (5) number of nests with the same encounter history (Dinsmore et al. 2002; Rotella 2012). The before mentioned days refers to standardized days within the breeding season. Each year I designated the first observed date of incubation as day 1 and then sequentially numbered all days after. Successful nests were considered nests which fledged at least one young and failed nests included all forms of nest loss (i.e., depredation, parasitism, abandonment, destroyed nests, etc.).

Analysis and Predictions: Vegetation Composition — To estimate percentage cover of available woody species I took the sum of all woody species found at each sampling point in a territory and divided the total for all species by each individual species in that territory. I then averaged means across all territories to find percentage species cover for each species. For vegetation heights, in each territory, I took the sum of all minimum and maximum heights, separately, for each species and divided by the total number of points taken for that species. I then averaged these minimum/maximum means for all territories to estimate mean minimum and maximum foliage vegetative species heights. I used Analysis of Variance (ANOVA) to examine if there were differences in mean percentage cover of common plant species between reproductively successful and unsuccessful territories.

Analysis and Predictions: Foraging Observations— I calculated total proportion of each foraging attack maneuver (no. each maneuver observed / total no. foraging maneuvers observed) and I calculated total proportion of each foraging surface (no. each surface observed / total no. foraging surfaces observed). Foraging heights, for each vegetative species, were summed and then divided by total number of foraging events within each territory. These vegetation height means were then averaged across all territories to calculate mean and standard error for foraging heights of observed foraging events. I calculated the total proportion of foraging effort (no. observed foraging events in vegetative species / total observed foraging events) for each year and sampling period. To compare the proportion of vegetative foraging effort with the amount of vegetative species available in each territory for each focal species (Ashe juniper, shin oak, and live oak), I calculated a use vs. availability ratio (% foraging effort in vegetative species / %

of vegetative species cover available) for each territory during each year, then calculated the 95 % confidence intervals. The ratio gave me a quantitative estimate of the amount of use of a vegetative species compared to how much was available, for example, a 2:1 ratio would suggest a substrate was used proportionally twice as much as the percentage vegetative cover available. I then used Pearson's correlation coefficient to estimate correlation between territory total observation time and territory proportion of use and use vs. vegetation availability ratio of observed foraging events for each year, to ensure total amount of observation time did not influence the proportion or ratios each year. I then ran a series of ANOVAs to compare mean territory proportion foraging effort and use vs. availability ratios between focal vegetative species, sample years, and reproductively successful and unsuccessful breeding territories and then calculated 95% confidence intervals for each analysis. I did not compare between sampling periods due to the low sample size of observed foraging events.

Analysis and Predictions: Behavioral Observations — For each observed behavior, during each year and sample period, I calculated the proportion (no. min observed behavior / total observation time) of time I observed each behavior. For focal vegetative species (Ashe juniper, shin oak, and live oak) I calculated proportion of vegetation time-use (mean time in each vegetation species / mean territory total observation time) for each territory during each year and sample period, and then calculated 95% confidence intervals. To compare proportion of time-use with the amount of that vegetative species available in each territory, I again calculated a use vs. availability ratio (% time-use in vegetative species / % of vegetative species cover available) for each territory during each year and sample period, along with the 95 %

confidence intervals. I then used Pearson's correlation coefficient to estimate correlation between territory total observation time and territory proportion of time-use and use vs. availability ratios for each year and sample periods. This was to ensure differing amounts of observation time did not influence the proportion or ratio for each species. Using an ANOVA, I examined mean territory proportion of time-use and use vs. availability ratios within vegetative species versus species availability, comparing the ratio of use versus availability between years, sample periods, and reproductively successful and unsuccessful breeding territories, and calculated 95% confidence intervals for each.

Analysis and Predictions: Available Foods — For each of the 10 most commonly observed arthropod orders, I calculated vegetative species mean branch clipping arthropod abundance (no. of individuals collected) and mean branch clipping biomass (milligrams of arthropods collected). For each of the 3 focal vegetative species, I then calculated mean branch clipping order richness (no. of orders observed), arthropod abundance, and arthropod biomass for each year and sample period. I used Pearson's correlation coefficient to estimate correlation between branch clipping biomass and order richness and arthropod abundance and biomass, to ensure branch samples were taken consistently (the mass of branch collected did not influence diversity, abundance, or biomass of arthropods collected). For the 10 most common arthropod orders, I used ANOVAs to compare mean branch clipping abundance and biomass between the 3 focal vegetative species. I used ANOVAs to compare vegetative species' mean branch clipping order richness, abundance, and biomass to compare between sample periods, and year. I also used ANOVAs to compare vegetative species mean branch clipping arthropod abundance and biomass between territory reproductive success for each year. I conducted all statistical analysis using program R (R Development Core Team 2009).

RESULTS

Territory Mapping & Nesting Productivity

In 2010, I mapped and identified 49 breeding territories and repeatedly surveyed 30 territories for foraging behavior throughout the breeding season. Mean (± SE) territory size was 2.46 ha ± 2.71 in 2010. Pairing success (proportion of territories observed with females or active nests) was 100% while only 4 of 30 territories (13.3%) fledged young. In 2011, I mapped and identified 63 territories and repeatedly surveyed 58 territories for foraging behavior. Mean (± SE) territory size was 3.10 ha ± 2.12 in 2011. Pairing success was 89.66% (52 of 58 territories) and 22 of 58 territories (37.9%) fledged young. Mayfield estimates of daily nest survival rate (mean ± SE) were 0.901 ± 0.021 (95% CI = 0.851-0.935) in 2010 and 0.961 ± 0.008 (95% CI = 0.943-0.974) in 2011. The lower daily nest survival rate in 2010 was due to mainly to high depredation rates compared to 2011 (personal observations).

Vegetation Composition

In 2010 and 2011, I conducted vegetation surveys in 30 and 58 male breeding territories respectively. Territory mean (± SE) woody cover was 85.98 % ± 9.37 in 2010 and 78.53 % ± 15.61 in 2011. The composition of woody vegetation varied greatly between territories in both 2010 and 2011 (Tables 5 & 6).

Table 5: Observed woody vegetative species composition (mean ± SE, minimum and maximum percentage cover) within male black-capped vireo breeding territories at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

	2010 (*n* = 30 Territories)		
Species	Mean % ± SE	Min. %	Max. %
Shin Oak	24.78 ± 13.64	0.00	48.78
Ashe Juniper	14.79 ± 11.71	1.41	47.46
Dead Vegetation	11.74 ± 9.51	0.00	29.17
Green Briar	8.80 ± 8.39	0.00	29.63
Prickly Pear Cactus	5.39 ± 5.67	0.00	16.90
Elbowbush	4.69 ± 4.12	0.00	16.95
Hackberry	4.39 ± 5.54	0.00	20.83
Flame-leaf Sumac	3.59 ± 4.43	0.00	15.24
Texas Oak	3.34 ± 5.03	0.00	24.29
Live Oak	3.30 ± 5.71	0.00	22.06
26 other spp.	15.19		
	2011 (*n* = 58 Territories)		
Species	Mean % ± SE	Min. %	Max. %
Shin Oak	24.04 ± 17.27	0.00	56.67
Ashe Juniper	21.82 ± 13.50	1.56	50.00
Dead Vegetation	7.96 ± 7.33	0.00	28.57
Prickly Pear Cactus	7.84 ± 10.23	0.00	38.24
Live Oak	6.65 ± 10.09	0.00	52.59
Flame-leaf Sumac	4.68 ± 8.17	0.00	33.78
Green Briar	4.50 ± 6.51	0.00	22.22
Texas Oak	2.99 ± 3.70	0.00	16.67
Grape Vine	2.99 ± 3.09	0.00	13.04
Elbowbush	2.92 ± 5.08	0.00	22.58
25 other spp.	13.61		

Table 6: Observed available vegetative species minimum (mean ± SE) and maximum (mean ± SE) foliage heights within male black-capped vireo breeding territories at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

2010 Mean Available Foliage Heights (*n* = 30 territories)		
Vegetation	Min. (m)	Max. (m)
Ashe Juniper	0.66 ± 0.72	3.75 ± 1.23
Shin Oak	0.10 ± 0.36	2.17 ± 1.03
Live Oak	0.75 ± 0.83	4.69 ± 1.87
All Vegetation spp.	0.27 ± 0.55	2.31 ± 1.54
2011 Mean Available Foliage Heights (*n* = 58 territories)		
Vegetation	Min. (m)	Max. (m)
Ashe Juniper	0.74 ± 1.00	3.95 ± 1.45
Shin Oak	0.29 ± 0.79	2.30 ± 1.28
Live Oak	1.27 ± 1.26	4.69 ± 1.84
All Vegetation spp.	0.45 ± 0.88	2.63 ± 1.73

Foraging Observations

Gleaning was the primary foraging attack maneuver in both 2010 and 2011 (Table 7). Vegetative foliage was the primary foraging surface in both 2010 and 2011 (Table 8). In 2010, mean (± SE) height of observed foraging event for all vegetation species was 2.59 m ± 1.38 (*n* = 283) with a mean minimum foliage height of 0.40 m (± 0.63 SE) and a mean (± SE) maximum foliage height of 3.8 m ± 1.50. In 2011, mean (± SE) height of observed foraging event for all vegetation species was 2.72 m ± 1.55 (*n* = 378) with a minimum foliage height of 0.60 m ± 0.78 and a maximum foliage height of 4.2 m ± 1.63 SE.

Table 7: Observed number and proportion (no. observed for each maneuver / total observed) of foraging attack maneuvers by male and female black-capped vireos at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

	2010				2011			
	Male		Female		Male		Female	
Maneuver	Events	%	Events	%	Events	%	Events	%
Glean	206	75.46	33	78.57	244	64.72	14	66.67
Hover-Glean	52	19.05	5	11.90	82	21.75	4	19.05
Jump-Glean	4	1.47	1	2.38	31	8.22	2	9.52
Sally	11	4.03	3	7.14	20	5.31	1	4.76
Total	273	100.00	42	100.00	377	100.00	21	100.00

Table 8: Observed number and proportion (no. observed for each surface / total observed) of vegetative foraging surfaces by male and female black-capped vireos at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

	2010				2011			
	Male		Female		Male		Female	
Surface	Events	%	Events	%	Events	%	Events	%
Foliage	169	80.09	28	75.68	259	77.31%	11	68.75
Branch	38	18.01	9	24.32	71	21.19%	4	25.00
Ground	4	1.90	0	0.00	2	0.60%	1	6.25
Trunk	0	0.00	0	0.00	3	0.90%	0	0.00
Total	211	100.00	37	100.00	335	100.00	16	100.00

Ashe juniper, shin oak, and live oak made up the 3 most commonly used foraging substrates during 2010 and 2011 (Table 9). Ashe juniper, shin oak, live oak alone made up 78.8 % of total proportion of foraging events in 2010 and 83.6% in 2011 (Table 9). There were significant differences in mean use vs. availability ratios between the 3 focal vegetative species in 2010 ($F_{2,70}$ = 3.527; P = 0.035) and 2011 ($F_{2,141}$ = 6.643; P = 0.002).

Ashe juniper — Ashe juniper had the highest proportion of foraging effort in both 2010 and 2011 and all but one sampling period both years (Table 9). Using Pearson's correlation coefficient, I found no significant correlation between total observation time and proportion of foraging events or use versus availability ratio during sample years or sampling periods. Mean foraging use versus available vegetation ratios were not significantly different between years (Table 10) or between reproductively successful and unsuccessful territories in 2010 ($F_{1,27}$ = 0.047; P = 0.831), but there was significant difference between successful and unsuccessful territories in 2011 ($F_{1,53}$ = 4.855; P = 0.032). Territories that fledged young (n = 22) had a mean ratio of 1.548, while unsuccessful territories (n = 36) had a mean ratio of 3.481. Alternatively, mean vegetative cover of juniper did not differ between successful and unsuccessful territories in 2010 ($F_{1,28}$ = 0.360; P = 0.553) or 2011 ($F_{1,56}$ = 0.712; P = 0.403).

Ashe juniper mean (± SE) foraging height was 2.63 m ± 1.11 (n = 98) with a minimum foliage height of 0.49 m ± 0.67 and maximum foliage height of 3.91 m ± 0.90. In 2011, Ashe juniper mean (± SE) foraging height was 2.56 m ± 1.27 (n = 152) with the minimum foliage height of 0.50 m ± 0.82 and maximum foliage height of 4.5 m ± 1.15 SE.

Table 9: Observed number and proportion (no. observed in each veg. spp. / total observed) of vegetative foraging substrates used by male black-capped vireos at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

	2010		
Sample Period	Vegetation	No. Foraging Events	%
1	Ashe Juniper	33	29.20
	Shin Oak	31	27.43
	Live Oak	22	19.47
	All spp.	113	
2	Ashe Juniper	39	48.75
	Shin Oak	11	13.75
	Live Oak	12	15.00
	All spp.	80	
3	Ashe Juniper	26	28.89
	Shin Oak	23	25.56
	Live Oak	26	28.89
	All spp.	90	
	2011		
Sample Period	Vegetation	No. Foraging Events	%
1	Ashe Juniper	27	38.57
	Shin Oak	19	27.14
	Live Oak	10	14.29
	All spp.	70	
2	Ashe Juniper	85	51.20
	Shin Oak	23	13.86
	Live Oak	35	21.08
	All spp.	166	
3	Ashe Juniper	40	28.17
	Shin Oak	28	19.72
	Live Oak	49	34.51
	All spp.	142	

Shin oak — Using Pearson's correlation coefficient, I found no significant correlation between total observation time and proportion of foraging events or use versus availability ratio during sample years or sampling periods. Mean use versus available vegetative cover ratios were not significantly different between years (Table 10) or territory reproductive success in 2010 ($F_{1,26}$ = 0.091; P = 0.765) or 2011 ($F_{1,49}$ = 1.480; P = 0.230). Mean shin oak vegetative cover did not differ between successful and unsuccessful territories in 2010 ($F_{1,28}$ = 1.465; P = 0.236) or 2011 ($F_{1,56}$ = 1.755; df = 1; P = 0.191)

In 2010, mean (± SE) observed foraging height in shin oak was 1.91 m ± 1.03 (n = 65) with a minimum foliage height of 0.18 m ± 0.41 and maximum foliage height of 2.82 m ± 1.09. In 2011, mean (± SE) observed foraging event height in shin oak was 1.63 m ± 1.18 (n = 70) with a minimum foliage height of 0.20 m ± 0.51 and maximum foliage height of 2.60 m ± 1.30.

Live oak — Using Pearson's correlation coefficient, I found no significant correlation between total observation time and proportion of foraging events or use versus availability ratio during sample years or sampling periods on live oak. Mean use versus available vegetative cover ratios were not significantly different between years (Table 10) or territory reproductive success in 2010 ($F_{1,14}$ = 0.225; P = 0.643) or 2011 ($F_{1,36}$ = 0.040; P = 0.842). There were no significant differences between mean live oak vegetative cover and reproductive success in 2010 ($F_{1,28}$ = 0.410; P = 0.527), but means did differ in 2011 ($F_{1,56}$ = 4.863; P = 0.032). In 2011, unsuccessful territories (n = 36) mean (± 95% CI) was 4.54% ± 2.00 live oak cover, while successful territories (n = 22) averaged 10.40 % ± 6.62 live oak cover.

In 2010, mean (± SE) observed foraging height in live oak was 3.92 m ± 1.18 (n = 60) with a minimum foliage height of 0.60 m ± 0.73 and maximum foliage height of 5.57 m ± 0.92. In 2010, mean (± SE) observed foraging height in live oak was 4.18 m ± 1.18

(n = 94) with a minimum foliage height of 1.0 m ± 0.74 and maximum foliage height of 5.56 m ± 0.76.

Table 10: Comparison of focal vegetative species mean (± 95% CI) foraging use vs. vegetation cover available ratios (mean % foraging effort / mean % vegetation cover) by male black-capped vireos at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

	2010	2011			
Vegetation	Ratio ± 95% CI	Ratio ± 95% CI	F	*Df,res*	P-value
Ashe Juniper	1.80 ± 0.61	2.71 ± 0.89	1.94	1,82	0.167
Shin Oak	1.21 ± 0.71	0.79 ± 0.34	1.568	1,77	0.214
Live Oak	4.64 ± 4.57	2.26 ± 1.14	2.155	1,52	0.148

Behavioral Observations

In 2010, I recorded a total of 2,415.25 minutes of behavioral observations from 30 repeatedly sampled territories (mean ± SE = 80.51 ± 36.43). I recorded 2,035.80 minutes of male, 229.2 minutes of female observation. In 2011, I recorded a total of 3,388.00 minutes (mean ± SE = 58.41 ± 28.21) of behavioral observations from 58 repeatedly sampled territories. I recorded 3,232.495 minutes of male and 155.5 minutes of female observation. In both 2010 and 2011, only male observation time was used for further analysis. I broke down active/mobile behaviors into 4 categories; vocal, non-vocal, courtship, and territorial. I observed vireos foraging during all of these behaviors. I never observed foraging during immobile behaviors, such as, grooming, incubating, or perching so these behaviors were not included in further analysis. Vocal was the most common mobile behavior recorded for male black-capped vireos during 2010 to 2011, ranging from 65.40 % to 79.67 % proportion of total use (Table 11). Vocal behaviors were highest during Period 2. Courtship behaviors ranged from 3.74 % to 15.36 % and were highest during Period 1 in both 2010 and 2011. Non-vocal behaviors ranged from

4.15 % to 15.71 % and were not consistent between sample years. Territorial behaviors ranged from 2.32 % to 14.62 % and were not consistent between sample years.

Table 11: Observed minutes and proportion (no. min of observed behavior / total observed time) of behavior time-use by male black-capped vireos at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

			2010			
	Period 1		Period 2		Period 3	
Behavior	Min	%	Min	%	Min	%
Courtship	90.00	15.36	49.75	8.94	31.45	3.74
Non-Vocal	56.25	9.60	48.00	8.62	131.90	15.71
Territorial	56.50	9.64	15.45	2.78	19.50	2.32
Vocal	383.25	65.40	443.55	79.67	656.95	78.23
Total	586.00	100	556.75	100	839.80	100
			2011			
	Period 1		Period 2		Period 3	
Behavior	Min	%	Min	%	Min	%
Courtship	96.5	10.39	65.75	5.93	87.75	7.37
Non-Vocal	100	10.76	46	4.15	76.25	6.41
Territorial	38	4.09	139.75	12.60	174	14.62
Vocal	694.5	74.76	858.05	77.33	852.45	71.61
Total	929	100	1109.55	100	1190.45	100

Ashe juniper, shin oak, live oak, Texas oak, dead vegetation, and hackberry made up the majority proportion of time (time in species/total time) within vegetative species in 2010 (92.68%) and 2011 (88.38%; Table 12). Ashe juniper, shin oak, and live oak, alone, made up 68.67% of total proportion of time-usage in 2010 and 76.69% in 2011 (Table 12). Means differed in time-use vs. availability ratios between the 3 focal plant species in 2010 ($F_{2,74} = 8.417$; $P < 0.001$) and 2011 ($F_{2,156} = 6.463$; $P = 0.002$). Table 13 compares observed mean minimum (m) and maximum (m) vegetation foliage heights of Ashe juniper, shin oak, and live oak.

Table 12: Observed minutes and proportion (no. observed vegetation min / total min) of vegetation time-use by male black-capped vireos at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

	2010	
Species	Min Observed	%
Shin Oak	607.45	29.84
Ashe Juniper	517.95	25.44
Live Oak	272.75	13.40
Texas Oak	245.15	12.04
Dead Vegetation	140.40	6.90
Hackberry	103.20	5.07
Flameleaf Sumac	28.45	1.40
Elbowbush	27.50	1.35
19 other spp.	92.95	4.56
Total	2035.80	100
	2011	
Species	Min Observed	%
Ashe Juniper	1052.35	32.56
Shin Oak	874.895	27.07
Live Oak	551.60	17.06
Texas Oak	221.30	6.85
Dead Vegetation	93.75	2.90
Hackberry	63.00	1.95
Flameleaf Sumac	55.75	1.72
Cedar Elm	53.75	1.66
Elbowbush	43.00	1.33
17 other spp.	223.10	6.90
Total	3232.50	100

Table 13: Observed behavioral vegetative species time-use mean (± SE) minimum (m) and maximum (m) foliage heights observed within male black-capped vireo breeding territories at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

	2010	
Vegetation	Min. (m) ± SE	Max. (m) ± SE
Ashe Juniper	0.56 ± 0.65	4.14 ± 0.91
Shin Oak	0.15 ± 0.41	2.94 ± 0.98
Live Oak	0.53 ± 0.69	5.39 ± 1.05
All Vegetation spp.	0.46 ± 0.71	4.10 ± 1.45
	2011	
Vegetation	Min. (m) ± SE	Max. (m) ± SE
Ashe Juniper	0.65 ± 0.74	4.55 ± 1.11
Shin Oak	0.23 ± 0.53	2.78 ± 1.07
Live Oak	0.82 ± 0.83	5.48 ± 1.00
All Vegetation spp.	0.60 ± 0.76	4.10 ± 1.55

Ashe juniper — Pearson's correlation coefficient showed no significant correlation between total observation time and proportion of time-use or use versus availability ratios during 2010 or 2011 or during any sample period. Mean time-use vs. availability ratios did not differ between years, sample periods in 2010 or sample periods in 2011 (Table14). There was no difference in mean Ashe juniper time-use vs. availability ratios comparing territory reproductive success in 2010 ($F_{1,28}$ = .0002; P = 0.988), but there were differences in mean use vs. availability ratios in 2011 ($F_{1,56}$ = 10.524; P =0.002). Successful territories in 2011 (n = 22) averaged a ratio (± 95% CI) of 1.304 ± 0.32, while unsuccessful territories (n = 36) averaged 2.273 ± 0.43.

Shin oak — Pearson's correlation coefficient showed no significant correlation between total observation time and proportion of time-use or use versus availability ratios during 2010 or 2011 or during any sample period. There were no differences in mean ratio between sample years (Table 14). There were differences between sample periods in 2010, but no differences between sample periods in 2011 (Table 14). There were no significant differences in mean time-use vs. availability ratios between territory reproductive success in 2010 ($F_{1,27}$ = 0.660; P = 0.424) or 2011 ($F_{1,52}$ = 2.722; P = 0.105).

Live oak — Pearson's correlation coefficient showed no significant correlation between total observation time and proportion of time-use or use versus availability ratios during 2010 or 2011 or during any sample period. Mean time-use vs. availability ratios did not differ between sample years, or sample periods in 2010 or 2011 (Table 14). There were no significant differences in time-use vs. availability ratios between territory reproductive success in 2010 ($F_{1,16}$ = 0.071; P = 0.793) or 2011 ($F_{1,45}$ = 0.514; P = 0.477).

Table 14: Comparison of focal vegetative species sample period and year mean (± 95 % CI) time-use vs. availability ratios (proportion of time use / vegetative cover available) by male black-capped vireos at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

			2010			
	Period 1	Period 2	Period 3	*F*	*D,res*	*P*
Ashe Juniper	2.10 ± 1.04	2.03 ± 0.84	1.90 ± 0.71	0.054	2,65	0.947
Shin Oak	1.88 ± 0.76	0.88 ± 0.31	0.83 ± 0.26	5.985	2,64	0.004 *
Live Oak	3.06 ± 2.35	4.02 ± 2.34	1.44 ± 1.92	1.652	2,46	0.203
			2011			
	Period 1	Period 2	Period 3	*F*	*Df,res*	*P*
Ashe Juniper	1.62 ± 0.54	2.37 ± 0.58	1.84 ± 0.42	2.252	2,133	0.109
Shin Oak	1.40 ± 0.40	1.22 ± 0.44	1.45 ± 0.68	0.215	2,126	0.807
Live Oak	5.49 ± 3.90	4.69 ± 2.51	4.26 ± 2.17	0.200	2,98	0.819
			Season Totals			
	2010	2011	*F*	*Df,res*	*P*	
Ashe Juniper	2.13 ± 0.79	1.91 ± 0.31	0.428	1,86	0.515	
Shin Oak	1.15 ± 0.29	1.35 ± 0.35	0.586	1,81	0.446	
Live Oak	4.18 ± 2.1	4.23 ± 2.22	0.001	1,63	0.977	

*Significance (P < 0.05)

Arthropod Sampling

In 2010, I collected branch clippings from 16 territories. Four arthropod orders in 2010 and 6 orders in 2011 had significant differences in mean arthropod biomass between the 3 focal vegetative species; Ashe juniper, shin oak, and live oak (Table 15).

Table 15: Focal vegetative species comparison of mean arthropod order biomass (mg) per branch clipping collected of the 10 most common arthropod orders within black-capped vireo breeding territories at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

		2010 Mean Biomass (mg)				
Order	Ashe Juniper (*n* = 96)	Shin Oak (*n* = 168)	Live Oak (*n* = 54)	*F*	*df*	*P*
Acari	0.625	0.179	0.000	3.195	2	0.042*
Araneae	18.333	14.464	7.037	1.351	2	0.260
Coleoptera	5.729	6.548	16.481	1.530	2	0.218
Diptera	2.188	1.548	1.667	0.396	2	0.673
Hemiptera	14.792	7.262	8.889	0.841	2	0.432
Hymenoptera	1.979	3.274	4.259	0.570	2	0.556
Lepidoptera	20.625	6.310	49.440	2.622	2	0.074
Neuroptera	0.313	0.119	0.000	0.891	2	0.411
Orthoptera	32.917	13.929	0.000	0.929	2	0.396
Thysanoptera	0.104	0.595	0.000	3.412	2	0.034*
All Orders	10.469	5.530	13.815	2.041	2	0.131
		2011 Mean Biomass (mg)				
Order	Ashe Juniper (*n* = 78)	Shin Oak (*n* = 99)	Live Oak (*n* = 48)	*F*	*df*	*P*
Acari	3.846	0.202	0.208	17.228	2	< 0.001*
Araneae	10.380	12.929	16.667	0.234	2	0.791
Coleoptera	1.795	0.303	3.958	1.719	2	0.182
Diptera	5.897	0.101	0.000	1.104	2	0.333
Hemiptera	6.282	7.172	11.458	0.495	2	0.610
Hymenoptera	1.154	8.586	4.167	4.507	2	0.012*
Lepidoptera	1.282	0.606	2.500	2.746	2	0.066
Neuroptera	0.000	0.000	0.000	NA	-	NA
Orthoptera	1.026	0.202	1.458	1.470	2	0.232
Thysanoptera	0.128	0.303	0.000	0.929	2	0.396
All Orders	3.333	3.242	4.167	0.267	2	0.766

*Significance ($P < 0.05$)

Ashe juniper — Using Pearson's correlation coefficient, I found no significant correlations between sample branch weight and arthropod abundance or biomass. I found significant differences in mean order richness between sample periods in 2010 and 2011 (Table 16), but no significant differences between territory reproductive success in 2010 ($F_{1,94}$ = 0.607; P = 0.438) or 2011 ($F_{1,76}$ = 2.648; P = 0.108). I found no significant differences in mean arthropod abundance between sample periods in 2010 (Table 16). Although in 2010 there were no differences in mean arthropod abundance between territory success in 2010 ($F_{1,94}$ = 0.004; P = 0.953), there were significant differences in 2011 ($F_{1,76}$ = 5.422; P = 0.023). Successful territories averaged 3.31 arthropods per branch clipping; while unsuccessful territories only averaged 1.81 arthropods per clipping. I found no differences in mean arthropod biomass between sampling periods in 2010 or 2011 (Table 16). There were no differences in mean arthropod biomass between territory reproductive success in 2010 ($F_{1,94}$ = 2.006; P = 0.160) or 2011 ($F_{1,76}$ = 0.069; P = 0.793).

Table 16: Comparison of sample period mean arthropod order richness, total abundance, and total biomass (mg) of Ashe juniper branch clippings taken within black-capped vireo breeding territories at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

	Ashe Juniper 2010					
	Period 1 (n = 32)	Period 2 (n = 32)	Period 3 (n = 32)	F	df	P
Richness	2.03	1.44	1.28	2.720	2	0.071
Abundance	3.28	2.56	1.91	1.910	2	0.154
Biomass (mg)	5.40	12.30	13.80	0.778	2	0.463
	Ashe Juniper 2011					
	Period 1 (n = 26)	Period 2 (n = 26)	Period 3 (n = 26)	F	df	P
Richness	1.62	0.77	1.04	5.718	2	0.005*
Abundance	2.85	2.00	2.65	0.598	2	0.552
Biomass (mg)	4.20	4.00	1.90	0.871	2	0.423

Table 16 - Continued

	Season Totals 2010 (n = 96)	Season Totals 2011 (n = 78)	F	df	P
Richness	1.58	1.14	6.018	1	0.015*
Abundance	2.55	2.49	0.022	1	0.882
Biomass (mg)	10.47	3.33	4.644	1	0.036*

*Significance (P < 0.05)

Shin oak — Using Pearson's correlation coefficient, I found no significant correlations between sample branch weight and arthropod abundance or biomass. I found no significant differences in mean order richness between sample periods in 2010 or 2011 (Table 18). I found no differences in mean richness between territory reproductive success in 2010 ($F_{1,166}$ = 1.535; P = 0.217), but did find differences between reproductive success in 2011 ($F_{1,97}$ = 3.300; P = 0.072). Successful territories averaged 1.21 orders per branch clipping, while unsuccessful territories averaged only 0.85 orders. I found significant differences in mean arthropod abundance between sample periods in 2010, but no differences in 2011 (Table 18). There were no differences in mean abundance between territory success in 2010 ($F_{1,166}$ = 2.239; P = 0.137) or 2011 ($F_{1,97}$ = 0.333; P = 0.565). I found no differences in mean arthropod biomass between sampling periods in 2010 or 2011 (Table 18). There were also no differences in mean arthropod biomass between territory reproductive success in 2010 ($F_{1,166}$ = 0.589; P = 0.444) or 2011($F_{1,97}$ = 0.091; P = 0.764).

Table 17: Ashe juniper, shin oak, and live oak sample periods mean arthropod order biomass (mg) per branch clipping collected within black-capped vireo breeding territories at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

	2010 Mean biomass (mg) per branch clipping								
	Ashe Juniper			Shin Oak			Live Oak		
Order	Period 1 (*n* = 32)	Period 2 (*n* = 32)	Period 3 (*n* = 32)	Period 1 (*n* = 56)	Period 2 (*n* = 56)	Period 3 (*n* = 56)	Period 1 (*n* = 18)	Period 2 (*n* = 18)	Period 3 (*n* = 18)
Acari	0.938	0.625	0.313	0.000	0.536	0.000	0.000	0.000	0.000
Araneae	3.750	15.000	36.250	3.929	11.429	28.036	2.778	11.111	7.222
Coleoptera	6.250	10.625	0.313	7.143	4.464	8.036	3.333	45.000	1.111
Diptera	4.063	1.875	0.625	1.429	2.679	0.536	4.444	0.556	0.000
Hemiptera	6.250	10.313	27.813	6.607	11.071	4.107	9.444	1.667	15.556
Hymenoptera	1.875	0.625	3.438	1.964	6.607	1.250	2.778	3.889	6.111
Lepidoptera	16.250	43.750	1.875	11.964	3.214	3.750	18.889	96.111	33.333
Neuroptera	0.000	0.938	0.000	0.357	0.000	0.000	0.000	0.000	0.000
Orthoptera	0.313	33.750	64.688	1.071	39.821	0.893	0.000	0.000	0.000
Thysanoptera	0.000	0.313	0.000	0.000	0.714	1.071	0.000	0.000	0.000
All Orders	5.406	12.250	13.750	3.518	8.125	4.946	4.167	25.778	11.500

	2011 Mean biomass (mg) per branch clipping								
	Ashe Juniper			Shin Oak			Live Oak		
Order	Period 1 (*n* = 26)	Period 2 (*n* = 26)	Period 3 (*n* = 26)	Period 1 (*n* = 33)	Period 2 (*n* = 33)	Period 3 (*n* = 33)	Period 1 (*n* = 16)	Period 2 (*n* = 16)	Period 3 (*n* = 16)
Acari	3.077	2.308	6.154	0.303	0.303	0.000	0.000	0.625	0.000
Araneae	11.538	12.269	6.923	4.545	28.182	6.061	32.500	12.500	5.000
Coleoptera	0.000	4.615	0.769	0.303	0.303	0.303	0.000	5.625	6.250
Diptera	1.154	16.538	0.000	0.303	0.000	0.000	0.000	0.000	0.000
Hemiptera	13.846	2.692	2.308	11.212	2.727	7.576	3.125	25.000	6.250
Con’t									

Table 17 - Continued

	2011 Mean biomass (mg) per branch clipping								
	Ashe Juniper			Shin Oak			Live Oak		
Order	Period 1 (*n* = 26)	Period 2 (*n* = 26)	Period 3 (*n* = 26)	Period 1 (*n* = 33)	Period 2 (*n* = 33)	Period 3 (*n* = 33)	Period 1 (*n* = 16)	Period 2 (*n* = 16)	Period 3 (*n* = 16)
Hymenoptera	2.308	0.385	0.769	11.515	10.303	3.939	1.875	7.500	3.125
Lepidoptera	0.385	0.000	0.000	1.515	0.303	0.000	4.375	0.000	3.125
Neuroptera	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Orthoptera	1.154	0.000	1.923	0.606	0.000	0.000	1.875	2.500	0.000
Thysanoptera	0.000	0.385	0.000	0.909	0.000	0.000	0.000	0.000	0.000
All Orders	4.154	3.962	1.885	3.121	4.545	2.061	4.688	5.438	2.375

Table 18: Comparison of sample period mean arthropod order richness, total abundance, and total biomass (mg) of shin oak branch clippings taken within black-capped vireo breeding territories at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

	Shin Oak 2010					
	Period 1 (*n* = 56)	Period 2 (*n* = 56)	Period 3 (*n* = 56)	*F*	*df*	*P*
Order Richness	1.36	1.55	1.25	0.939	2	0.393
Abundance	1.93	2.98	1.82	2.578	2	0.079
Biomass (mg)	3.50	8.10	4.90	1.664	2	0.193
	Shin Oak 2011					
	Period 1 (*n* = 33)	Period 2 (*n* = 33)	Period 3 (*n* = 33)	*F*	*df*	*P*
Order Richness	1.03	0.94	0.85	0.380	2	0.686
Abundance	1.79	2.15	1.09	1.116	2	0.332
Biomass (mg)	3.10	4.50	2.10	0.820	2	0.444
	Season Totals					
	2010 (*n* = 168)	2011 (*n* = 99)	*F*	*df*	*P*	
Order Richness	1.39	0.94	10.771	1	0.001*	
Abundance	2.22	1.67	2.188	1	0.140	
Biomass (mg)	5.53	3.24	2.305	1	0.130	

*Significance (P < 0.05)

Live oak — Using Pearson's correlation coefficient, I found no significant correlations between sample branch weight and arthropod abundance or biomass. I found no significant differences in mean order richness between sample periods in 2010 and 2011 (Table 19) or significant differences in mean order richness between territory reproductive success in 2010 ($F_{1,52}$ = 0.264; P = 0.610) or 2011 ($F_{1,46}$ = 1.262; P = 0.270). I found no significance differences in mean arthropod abundance between sample periods in 2010 and 2011 (Table 19) or between territory success in 2010 ($F_{1,52}$ = 0.905; P = 0.346) or 2011 ($F_{1,46}$ = 0.086; P = 0.771). I found no differences in mean arthropod biomass between sampling periods in 2010 or 2011 (Table 19). There were also no differences in arthropod biomass between territory reproductive success in 2010 ($F_{1,52}$ = 0.016; P = 0.900) or 2011 ($F_{1,46}$ = 1.500; P = 0.227).

Table 19: Comparison of sample period mean arthropod order richness, total abundance, and total biomass (mg) of live oak branch clippings taken within black-capped vireo breeding territories at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

	Live Oak 2010					
	Period 1 (n = 18)	Period 2 (n = 18)	Period 3 (n = 18)	F	df	P
Order Richness	1.50	1.17	1.28	0.410	2	0.666
Abundance	2.00	1.61	2.67	1.199	2	0.310
Biomass (mg)	4.20	15.83	11.50	0.641	2	0.531
	Live Oak 2011					
	Period 1 (n = 16)	Period 2 (n = 16)	Period 3 (n = 16)	F	df	P
Order Richness	1.00	1.31	0.81	0.960	2	0.391
Abundance	3.50	2.44	1.38	0.617	2	0.544
Biomass (mg)	4.70	5.40	2.40	0.700	2	0.502
	Season Totals					
	2010 (n = 54)	2011 (n = 48)		F	df	P
Order Richness	1.32	1.04		1.618	1	0.206
Abundance	2.09	2.44		0.189	1	0.665
Biomass (mg)	10.50	4.17		1.866	1	0.175

DISSCUSSION

There are very few publications regarding the foraging ecology or available foods for the black-capped vireo. My data and results are similar to other available resources on the foraging behavior of the black-capped vireo. My results supported Houston’s (2008) data observations of vireos gleaning arthropods from foliage as the predominant method of foraging. Gleaning is thought to be an energetically inexpensive means of obtaining prey (Remsen and Robison 1990) and allows the bird to find smaller hidden foods that may not be found with other searching methods (Robinson and Holmes 1982). Grzybowski

(1995) questioned that black-capped vireos did not solely forage in shrub habitat, but rather foraged in a variety of vegetation heights, which supports Robinson and Holmes (1982) findings that birds foraging at different vegetation layers were exposed to more foraging opportunities and available foods. I also found that male vireos foraged at a range of vegetation heights. My research did reveal some interesting findings on vegetation usage, most notably the relatively high use of Ashe juniper and live oak during both foraging and behavioral time use observations.

The percentage vegetative cover of Ashe juniper within vireo territories during my study was, however, higher than some other studies observed within the Edwards Plateau and Lampasas Cut eco-regions. USFWS (1991), observed juniper cover levels at only 3 to 6%, while I observed a 14 to 22% mean juniper cover. Although, juniper mean time-use vs. availability ratios did not significantly differ between sample periods, there are some changes in vegetation use that might be ecologically significant. Due to its invasive nature, Ashe juniper was historically removed from many of my study areas on the BCNWR, so densities of juniper were sometimes relatively low within vireo management areas. I observed, however, that much of the time the juniper trees being used were within older oak/juniper woodland on the edge of recently managed areas, and this may have contributed to the higher juniper cover estimates. I also typically observed vireos using taller juniper trees growing up within shorter dense shin oaks or junipers growing up underneath live oak canopies. Some of these observations were revealed in the observed mean maximum vegetative species heights during surveys. Mean juniper maximum height during foraging surveys was ~1.5 m taller than mean maximum shin oak height and ~1.5 m less than maximum live oak height during both years. The reason for using these particular juniper trees is unknown; but it may have to do with available foods, protective cover, singing perches, defending territories, or other reasons (Personal Observations).

Results also showed that males which had lower foraging ratios in Ashe juniper were more successful. It is difficult to infer that these foraging patterns actually influenced reproductive success because of the confounding variables available, especially with only one year of data. Nest depredation, nest parasitism, climate, food availability, competition vegetation characteristics, predator densities, and adult mortality are all factors that can influence whether a nest will successfully fledge young (Graber 1961; Martin 1987; Hutto 1990a; USFWS 1991). Several studies have observed that vireos select areas with lower juniper densities (USFWS 1991; Tazik et al. 1993; Grzybowski et al. 1994); however, I did not find any differences between amount of juniper cover and reproductive success. Grzybowski et al. (1994) observed that vireos are able to tolerate areas with a large amount of juniper canopy cover, but are likely to be found in areas of lower juniper cover. Quinn (2000) and Marshall (2011) both found an increasing number of total arthropods in Ashe juniper during late - May and June, a time when other tree species are showing a declining number of caterpillars. Notably, Ashe juniper was the only vegetative species found in every sample territory during both years and it was not uncommon to find vireo nests in juniper branches.

Shin oak was, on average, the most abundant shrub species available within my vireo territories in 2010 and 2011. My percentage cover estimates were consistent with other vireo studies that have been conducted within the Edwards Plateau and Lampasas Cut eco-regions. My estimates were similar to USFWS (1991), which observed the deciduous cover component of vireo habitat, primarily shin oak, at 0 to 3 m in height, covering 30-50%. Proportionally, shin oak was observed to be the 2nd most used foraging substrate in 2010 and 3rd in 2011. Of the three focal species, shin oak had the lowest foraging use versus availability ratio in both 2010 and 2011. Shin oak is often associated with black-capped vireo habitat because it forms the low irregular shrubland habitat the vireos require (Graber 1961; USFWS 1991). Areas dominated by this species, sometimes called a "shinnery" (Graber 1961), were the most common types of habitat in which I observed vireos. This habitat was often, scattered with taller juniper, live oaks and/or Texas oaks. Carolina buckthorn, redbud, and Texas persimmon were mixed in with the shin oak, although I rarely observed foraging behavior within these species; however, I did often find vireo nests in their branches. Another shin oak habitat type I observed vireos using was more mature shin oak/juniper woodland, usually near the edge of shrub habitats or vireo management areas. Shin oak/juniper woodlands are more commonly associated with the golden-cheeked warbler (USFWS 1992), but are known to be occupied by black-capped vireos (Graber 1961).

Although mean vegetative cover of live oak was relatively low, I observed very high numbers of foraging events, behavioral time-use, and use vs. availability ratios within the species. Grzybowski et al. (1994) observed that live oak and shin oak were the primary oak species in vireo habitat in the Edwards Plateau. Houston (2008) also observed a great amount of foraging activity in live oak. In 2010 and 2011, I observed live oak having one of highest foraging and time-use vs. availability ratios when compared to juniper and shin oak. Although, live oak mean time-use vs. availability ratios did not significantly differ between sample periods, there are some changes in vegetation use that might be ecologically significant. It seems that when live oak is found in vireo habitat it is used in a much higher proportion than its availability. This may be due to higher food availability associated with the species than other vegetative species at certain times of the year.

This live oak savanna vireo habitat is sometimes referred to as "donut" habitat, because it is usually structured with one larger tree surrounded by a circle of shorter shrubby vegetation (Cimprich and Kostecke 2006). I observed vireos were using these larger trees, with a large canopy falling close to the ground, and often with a juniper understory and/or adjacent to deciduous shrub habitat. Donut habitats are usually associated with lower densities of vireos and more second year males (Noa et al. 2007). Noa et al. (2007) also found daily nest survival lower in live oak donut habitat types. Alternatively, in 2011 I found mean live oak cover significantly higher in reproductively successful territories than unsuccessful territories. For unknown reasons in 2011, possibly due to severe drought conditions and lack of available foods, I observed 2-3 vireo territories transition from shin oak shrub habitat earlier in the breeding season, to adjacent live oak dominant habitat later in the season. Unfortunately, these were not among the territories I was sampling for arthropods.

To study why black-capped vireos use different vegetation types at different rates, one needs to examine available foods. Although, I could not statistically test for differences between sample years there was an obvious effect from the drought during the 2011 field season. Compared to 2010, there were lower mean diversity and lower biomass of arthropods in 2011. However, there was little difference in mean arthropods abundance between 2010 and 2011, mainly due to abundant low biomass arthropods like mites, aphids, ants, and immature spiders were more common in 2011. Most of the orders I collected during this study have been identified as known food sources for similar small vireo species, including the white-eyed vireo (*Vireo griseus*) (Chapin 1925; Nolan and Wooldridge 1962), Hutton's vireo (*Vireo huttoni*) (Chapin 1925), and Bell's vireo (*Vireo bellii*) (Chapin 1925; Yard et al. 2004). Many of these arthropod orders have the potential for ecological significance on the foraging habits of the black-capped vireo.

Individuals sampled from order Acari were small mites that may have little energetic impact on vireos as a food and little information is available related to mites as a food source for vireos. Chapin (1925) found only one instance of mites in his examination of over 1,900 stomach samples from 8 species of vireos. Lehman (1982), however, observed that mites may be an important prey species for other arthropods and may indirectly be important to the vireo at lower trophic levels. The high levels of mites in Ashe juniper may attract other arthropods to this species, as being an available arthropod food source.

Araneae (spiders) have been observed as food source for many vireo species (Chapin 1925; Nolan and Wooldridge 1962; Yard et al. 2004). Chapin (1925) found spiders made up only 2-3.5% of the yearly diet of similar vireo species, while, Graber (1961) found spiders made up 5-20% of the total contents in 4 of 11 black-capped vireo stomachs. Although spiders have not been documented as a major food source for many vireos, Araneae was one of the most commonly observed arthropod orders within my samples and I observed several instances of black-capped vireos feeding on spiders. Ashe juniper and live oak contained the highest mean biomass of spiders in 2010 and

2011, respectively. In 2010, mean biomass of Araneae in juniper increased from sample 1 through sample 3. Similarly, Quinn (2000) observed an increasing trend in arthropod abundance when sampling arthropods (Mar - Jun) in golden-cheeked warbler habitat, primarily due to an abundance of immature spiders collected later in the season. Quinn (2000) only examined abundance, so it is unknown if change in abundance would also be seen in biomass. In 2011, I did not observe a higher mean biomass during sample period 3 in juniper or live oak, possibly because of the severe drought conditions. Spiders may be a significant food source, especially later in the breeding season when other food sources are declining.

Coleoptera (beetles) are one of the most diverse and abundant orders of arthropods on the planet and inhabit almost every type of ecosystem with a variety of host plant species (Eaton and Kaufman 2007). Therefore, it is not surprising that beetles are known to be a major food source for similar insectivorous vireos (Chapin 1925; Nolan and Wooldridge 1962; and Yard et al. 2004). Graber (1961) observed beetles in 9 of 11 black-capped vireo stomachs ranging from 1 -80% of their total contents. Chapin (1925) observed that Coleopterans made up ~12-15% of the summer diet of the Bell's, Hutton's, and white-eyed vireos. Yard et al. (2004) found Coleoptera made up 23% of the Bell's vireos spring and summer diet. I observed live oaks with the highest mean biomass of beetles in 2010 and 2011, but beetles were also found in juniper and shin oak at varying amounts during the season, usually with the highest biomass during periods 1 or 2. Similarly, Quinn (2000) observed higher numbers of beetles in April, with a gradual decline after mid-May.

Another known food source for similar insectivorous vireos is the order Diptera (flies, midges, mosquitoes) (Chapin 1925; Nolan and Wooldridge 1962; and Yard et al. 2004). Although Dipterans have not been observed as a major food source, they have the ability under the right weather conditions to be very abundant (Eaton and Kaufman 2007). Many Dipterans are aquatic during their larvael stage (Eaton and Kaufman 2007), so this insect order may be severely affected by drought explaining the low numbers in 2011.

Species of Hemiptera (true bugs) have been observed to be an important food source for many vireo species (Chapin 1925; Nolan and Wooldridge 1962; and Yard et al. 2004). Graber (1961) observed Hemipterans in 6 of 11 black-capped vireo stomachs, ranging from 5-20% of their total contents. Chapin (1925) observed that true bugs comprised 13-46% of the yearly stomach contents of similar vireo species. Nolan and Wooldridge (1962) found Hemiptera composed 20-30% of the white-eyed vireos spring and summer diet. The lower numbers of Hemiptera I observed in 2011 may also be due to drought, but Quinn (2000) also observed a peak in Hemiptera abundance in early May (period 1) and a decline later in the season. This late season decline may just suggest seasonal change in abundance as habitats become hotter and drier.

Order Hymenoptera (bees, wasps, and ants) have been observed as a food source for many vireo species (Chapin 1925; Nolan and Wooldridge 1962; and Yard et al. 2004). Chapin (1925) found white-eyed, Bells, and Hutton vireo stomachs consisted of 6-7% Hymenoptera. Yard et al. (2004) observed that Bell’s vireo’s stomachs consisted of 8% wasps and 4% ants. I found in both years, that the majority of Hymenopterans collected were ants. Nolan and Wooldridge (1962) found the spring and summer diet of white-eyed vireos consisted of only 1% ants and wasps. Graber (1961) observed no Hymenopterans in the contents of 11 black-capped vireo stomachs.

Order Lepidoptera, butterflies and moths, are known as one of the most important food sources for many vireo species, including the black-capped vireo (Chapin 1925; Nolan and Wooldridge 1962; Yard et al. 2004, personal observations) and their larvae (caterpillars) are a very important food source for nesting vireos to feed to their young (Graber 1961). Graber (1961) observed Lepidoptera in 10 of 11 black-capped vireo stomachs, ranging from 30-85% of their total contents. Chapin (1925) found Lepidoptera larvae composed 12-33% of similar vireo species yearly diet. Nolan and Wooldridge (1962) observed Lepidoptera represented 46% of the white-eyed vireos spring and summer diet. Most of the Lepidoptera observed in this study were larvae, 95.5% in 2010 and 92.3% in 2011 (personal observations). Studying the available foods of the golden-cheeked warbler, Quinn (2000) and Marshall (2011) sampled tree species also common in black-capped vireo habitat and observed many seasonal changes within arthropod communities. Quinn (2000) and Marshall (2011) both observed an increased number of Lepidoptera larvae in April, a favorite food for the young of avian insectivores. My study showed a noticeable decrease of biomass of Lepidoptera in 2011 compared to 2010 during all sample periods. In 2010, Lepidopterans were found in all three focal species during all sample periods and each species observed relatively high mean biomass of Lepidoptera larvae at certain times of the season. In 2011, caterpillars were non-existent during several sampling periods. Live oak still contained the highest mean biomass of caterpillars both years. Most Lepidopteran larvae are host plant specific. Ashe juniper is the larvael host species for the juniper budworm (*Cudonigera houstonana*), a type of moth. Quinn (2000) observed that this Lepidopteran may have been a significant food source for the golden-cheeked warbler during April and early-May, this may also be true for the black-capped vireo.

Order Orthoptera (grasshoppers, crickets, and katydids) have been observed as important food source for many vireo species (Chapin 1925; Nolan and Wooldridge 1962; and Yard et al. 2004, personal observations). In 2010, there was an outbreak of the truncated true katydids (*Paracyrtophyllus robustus*) found within my vireo study areas (personal observation). The truncated true katydid is only found in central Texas and every few years it can be found in great numbers (Schimming 2007) and, although the adults are too large to be consumed by a black-capped vireo, the smaller juveniles may be a plentiful food source if available. Both study years I observed occasions of black-capped vireos feeding on or carrying grasshoppers and katydids to feed young.

Individuals collected from order Thysanoptera were small thrips that may have little energetic impact on vireos as a food and little information is available for thrips as a food source for vireos. Ananthakrishnan (1984) stated that thrips may be an important prey species for other predatory arthropods. Thrips may indirectly be important to the vireo at a lower trophic level, being a food source for the vireos prey. Of the focal vegetative species, shin oak had the highest mean biomass of order Thysanoptera in both 2010 and 2011. The higher numbers of thrips in shin oak may have helped attract other arthropods to this species, as being an available arthropod food source.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Habitat management for any species requires an understanding of the species' biology and how that species uses available resources. Food availability affects clutch size, breeding time, and reproductive success in migratory passerines (Lack 1968; Martin 1987; Aho et al. 1999). Enhanced foraging opportunities in vireo habitat may help increase the reproductive success. Foraging and food resource information may allow managers who are creating new habitats for black-capped vireos to identify and protect areas for future vireo habitat management based on available woody plant species. These data may then allow managers to use prescribed fire, selective vegetation manipulation, and other tools to manage areas of vireo habitat for an optimum mosaic of woody vegetation and provide favorable foraging habitat.

Current TPWD black-capped vireo habitat management recommendations describes typical habitat as patchy, mostly deciduous, shrubland covering 30-60% of the ground, with woody vegetation from the ground extending 2 m or more in height (USFWS 1991; Campbell 2003). Management recommendations suggest plant composition is less important than presence of deciduous shrubs with foliage extending to the ground and a proper mixture of open grassland and woody cover (Campbell 2003). There is no mention of woody plant species that are beneficial to vireos in breeding habitat, only a list of common species found. I agree with the recommended percentage of woody cover and woody vegetation needs to extend from the ground up at least 2 m or more I would suggest that the composition and juxtaposition of woody vegetative species plays an important role in providing optimum foraging opportunities for the black-capped vireo. I would suggest if planning to manage an area for black-capped vireo to choose areas that have a diversity of plant species but also have abundant shin oak, Ashe juniper, and live oak available. Along with Ashe juniper, shin oak, and live oak, I would encourage the growth of a variety of deciduous woody plants within vireo habitat including, but not limited to, redbud, Carolina buckthorn, Texas Persimmon, hackberry, and Texas oak. I observed foraging and nesting attempts in each of these 5 species. Central Texas is known to have great differences in rainfall year to year and plant and arthropod species respond differently to drought conditions. Yard et al. (2004) found that neotropical migrant birds can prefer to settle in food rich environments and McGrath et al. (2008) observed the flowering phenology of a tree species can act as a settlement indicator for insectivorous birds. A diversity of woody plants should increase the number of available foraging opportunities on a year to year basis and changing climactic conditions.

Grzybowski et al. (1994) suggested juniper cover should be kept well below 10% except in areas with only marginal amounts of deciduous vegetation available, and then juniper may be more beneficial at higher levels. Until additional research is conducted on the specific importance and vegetative characteristics of Ashe juniper in black-capped vireo habitat, I would suggest from the observations in this study, that Ashe juniper cover should be held between 10–25%, but not forming thick monoculture juniper thickets or "cedar breaks". Rather juniper should be in small clumps or individual trees mixed next to or in deciduous vegetation or as the understory of larger canopy trees, if possible, with the branches of juniper and other vegetation extending to the ground. Juniper should provide excellent foraging opportunities for Lepidoptera, Coleoptera, and Diptera during the first half of the breeding season; and Araneae, Orthoptera, and Hemiptera during the second half of the season with variable amounts of other orders throughout the breeding season.

Shin oak can provide an excellent structural characteristic within vireo habitat. Its low lying shrubby branches offers good nesting branches and protective cover, as well as many foraging opportunities. I would recommend managing shin oak cover between 15-50%, varying heights from 1.5m up with branches extending to the ground. Shin oak should provide foraging opportunities for Lepidoptera larvae early in the breeding season and Araneae during the middle and late breeding season, and a variation of other arthropod orders including Hemiptera, Hymenoptera, and Coleoptera throughout the breeding season.

Live oak can provide excellent foraging opportunities for black-capped vireos. I would recommend managing live oak cover between 5-25%, mainly consisting of older large canopy trees with a deciduous or evergreen understory and branches extending low to the ground. I would also suggest live oak be spread throughout black-capped vireo habitat and not in large continuous blocks to ensure live oak is available to multiple vireo territories. Live oak should provide early season foraging opportunities for Diptera; mid-season opportunities for Hymenoptera; and mid-late foraging for Lepidoptera and Coleoptera, as well as variable amounts of Araneae and Hemiptera throughout the breeding season.

Shin oak and live oak will root sprout after fire or other disturbances. Ashe juniper will not root sprout, so managers would need to selectively allow juniper to remain or grow within vireo habitat (personal observations). However, managers may need to use tools like prescribed fire or mechanical disturbance to keep juniper and other species at the required levels and to keep vireo habitat within the early-mid vegetative successional stages vireos require.

I would recommend that further research needs to be conducted on the habitat use of the black-capped vireo in relation to foraging and food availability in other areas of the vireos range. Along with more intensive research on the importance of Ashe juniper and live oak within vireo habitat, research may also be needed on the foraging behavior of female and juvenile vireos, as well as post-breeding foraging behavior and available foods. Several recent studies have shown that native grasses can contain a greater abundance and diversity of arthropods than invasive grasses (Herrera and Dudley 2003; Levin et al. 2006; Cord 2011). With the branches of woody vegetation extending to the ground in vireo habitat, the presence or absence of native grasses could affect the available foods at lower vegetation heights.

APPENDIX A

Total woody vegetative species mean (± SE) percentage vegetative cover within male black-capped vireo territories at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

Common Name.	Scientific Name	2010 Mean (%) ± SE			2011 Mean (%) ± SE		
Shin Oak	*Quercus sinuata*	24.78	±	13.64	25.24	±	17.96
Ashe Juniper	*Juniperus ashei*	14.79	±	11.71	22.06	±	14.03
Dead Vegetation	NA	11.74	±	9.51	7.96	±	7.46
Greenbriar	*Smilax spp*	8.80	±	8.39	3.84	±	5.65
Prickly Pear	*Opunita spp.*	5.39	±	5.67	7.42	±	10.15
Elbowbush	*Forestiera pubescens*	4.69	±	4.12	2.93	±	5.30
Hackberry	*Celtis spp.*	4.39	±	5.54	1.86	±	2.56
Flameleaf Sumac	*Rhus copallina*	3.59	±	4.43	4.89	±	8.61
Texas Oak	*Quercus buckleyi*	3.34	±	5.03	3.16	±	3.86
Live Oak	*Quercus fusiformis*	3.30	±	5.71	6.57	±	10.48
Grape Vine	*Vitis spp.*	2.34	±	3.27	2.87	±	3.17
Gum Bumelia	*Sideroxylon lanuginosum*	2.24	±	2.02	1.10	±	1.88
Yaupon Holly	*Ilex vomitoria*	1.39	±	2.33	0.49	±	0.87
Texas Ash	*Fraxinus texensis*	1.25	±	2.27	0.83	±	2.37
Cedar Elm	*Ulmus crassifolia*	1.13	±	2.31	2.33	±	4.21
Poison Ivy	*Toxicodendron pubescens*	1.07	±	1.81	0.65	±	1.35
Skunkbush	*Rhus aromatica*	1.01	±	2.37	0.21	±	0.64
Carolina Buckthorn	*Frangula caroliniana*	0.91	±	2.00	0.93	±	1.65
Baccaris spp.	*Baccharis spp.*	0.82	±	1.87	0.18	±	0.47
Toothache Tree	*Zanthoxylum hirsutum*	0.56	±	1.15	0.65	±	1.69
Redbud	*Cercis canadensis*	0.46	±	0.96	0.31	±	0.73
Wafer Ash	*Ptelea trifoilata*	0.41	±	0.98	0.14	±	0.63
Escarpment Cherry	*Prunus serotina*	0.40	±	0.84	0.28	±	0.59
Texas Persimmon	*Diospyros texana*	0.18	±	0.48	2.18	±	4.22
Con't							

APPENDIX A - Continued

Common Name.	Scientific Name	2010 Mean (%) ± SE			2011 Mean (%) ± SE		
Blackjack Oak	*Quercus marilandica*	0.18	±	0.47	0.33	±	0.87
Acacia spp.	*Acacia spp.*	0.18	±	0.48	0.00	±	0.00
Little Walnut	*Juglans microcarpa*	0.18	±	0.68	0.14	±	0.99
Virginia Creeper	*Parthenocissus quinquefolia*	0.12	±	0.38	0.15	±	0.63
Western Soapberry	*Sapindus drummondii*	0.09	±	0.39	0.00	±	0.00
Mexican Buckeye	*Ungnadia speciosa*	0.06	±	0.24	0.00	±	0.00
Rusty Blackhaw	*Viburnum rufidulum*	0.05	±	0.26	0.08	±	0.32
Chinaberry	*Melia azedarach*	0.04	±	0.18	0.05	±	0.25
Honey Mesquite	*Prosopis glandulosa*	0.04	±	0.17	0.00	±	0.00
Brazil Wood.	*Condalia hookeri*	0.04	±	0.23	0.00	±	0.00
Eves Necklace	*Sophora affinis*	0.02	±	0.09	0.00	±	0.00
Agarita	*Berberis trifoliata*	0.01	±	0.06	0.11	±	0.38
Texas Mulberry	*Morus microphylla*	0.00	±	0.00	0.04	±	0.22
Silktassle	*Garrya ovata*	0.00	±	0.00	0.01	±	0.09
Total		100.00			100.00		

APPENDIX B

Complete table of observed number and proportion (no. observed for each maneuver / total observed) of foraging attack maneuvers by male and female black-capped vireos at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

	2010					2011			
	Male		Female			Male		Female	
Vegetation spp.	Total	%	Total	%	Vegetation spp.	Total	%	Total	%
Ashe Juniper	98	34.63	7	16.28	Ashe Juniper	152	40.21	6	30.00
Shin Oak	65	22.97	10	23.26	Live Oak	94	24.87	7	35.00
Live Oak	60	21.20	6	13.95	Shin Oak	70	18.52	3	15.00
Dead Vegetation	22	7.77	3	6.98	Flameleaf Sumac	9	2.38	0	0.00
Texas Oak	7	2.47	3	6.98	Texas Oak	8	2.12	2	10.00
Hackberry	5	1.77	2	4.65	Hackberry	7	1.85	1	5.00
Elbowbush	5	1.77	1	2.33	Dead Vegetation	6	1.59	0	0.00
Grape Vine	3	1.06	10	23.26	Elbowbush	6	1.59	0	0.00
Cedar Elm	3	1.06	0	0.00	Texas Persimmon	5	1.32	0	0.00
Gum Bumelia	2	0.71	0	0.00	Carolina Buckthorn	5	1.32	0	0.00
Ground	2	0.71	0	0.00	Grape Vine	2	0.53	0	0.00
Skunkbush	2	0.71	0	0.00	Toothache tree	2	0.53	0	0.00
Yaupon Holly	1	0.35	0	0.00	Gum Bumelia	2	0.53	0	0.00
Escarpment Cherry	1	0.35	0	0.00	Cedar Elm	2	0.53	1	5.00
Redbud	1	0.35	0	0.00	Escarpment Cherry	2	0.53	0	0.00
Walnut	1	0.35	0	0.00	Honeysuckle	1	0.26	0	0.00
Carolina Buckthorn	1	0.35	1	2.33	Greenbriar	1	0.26	0	0.00
Texas Ash	1	0.35	0	0.00	Blackjack Oak	1	0.26	0	0.00
Baccaris	1	0.35	0	0.00	Redbud	1	0.26	0	0.00
Con't									

APPENDIX B - Continued

	2010					2011			
	Male		Female			Male		Female	
Vegetation spp.	Total	%	Total	%	Vegetation spp.	Total	%	Total	%
Blackjack Oak	1	0.35	0	0.00	Walnut	1	0.26	0	0.00
Flameleaf Sumac	1	0.35	0	0.00	Texas Ash	1	0.26	0	0.00
Total	283	100.00	43	100.00	Total	378	100.00	20	100.00

APPENDIX C

Complete table of total observed time (min) and proportion (no. observed vegetation min / total min) of vegetation time-use by male and female black-capped vireos at Balcones Canyonlands National Wildlife Refuge, USA, 2010-2011.

	2010					2011			
	Male		Female			Male		Female	
Vegetation spp.	Min	%	Min	%	Vegetation spp.	Min	%	Min	%
Shin Oak	607.45	29.84	90.50	39.49	Ashe Juniper	1052.35	32.56	45.75	29.42
Ashe Juniper	517.95	25.44	36.50	15.92	Shin Oak	874.90	27.07	38.00	24.44
Live Oak	272.75	13.40	50.50	22.03	Live Oak	551.60	17.06	12.00	7.72
Texas Oak	245.15	12.04	9.00	3.93	Texas Oak	221.30	6.85	14.00	9.00
Dead Vegetation	140.40	6.90	17.95	7.83	Dead Vegetation	93.75	2.90	8.50	5.47
Hackberry	103.20	5.07	7.55	3.29	Hackberry	63.00	1.95	4.50	2.89
Flameleaf Sumac	28.45	1.40	2.25	0.98	Flameleaf Sumac	55.75	1.72	7.25	4.66
Elbowbush	27.50	1.35	6.00	2.62	Cedar Elm	53.75	1.66	4.50	2.89
Yaupon Holly	19.00	0.93	0.00	0.00	Elbowbush	43.00	1.33	5.25	3.38
Cedar Elm	12.00	0.59	2.00	0.87	Carolina Buckthorn	35.75	1.11	6.00	3.86
Texas Ash	11.50	0.56	1.50	0.65	Texas Persimmon	31.00	0.96	1.75	1.13
Carolina Buckthorn	11.25	0.55	1.00	0.44	Yaupon Holly	30.60	0.95	2.75	1.77
Gum Bumelia	7.75	0.38	0.50	0.22	Escarpment Cherry	30.25	0.94	1.25	0.80
Escarpment Cherry	6.50	0.32	0.00	0.00	Gum Bumelia	19.00	0.59	1.50	0.96
Grape Vine	5.75	0.28	0.00	0.00	Blackjack Oak	13.50	0.42	0.00	0.00
Baccaris	3.75	0.18	0.00	0.00	Walnut	13.00	0.40	0.00	0.00
Walnut	3.50	0.17	2.50	1.09	Grape Vine	12.00	0.37	0.00	0.00
Blackjack Oak	2.75	0.14	0.00	0.00	Texas Ash	12.00	0.37	1.50	0.96
Con’t									

APPENDIX C - Continued

	2010					2011			
	Male		Female			Male		Female	
Vegetation spp.	Min	%	Min	%	Vegetation spp.	Min	%	Min	%
Mexican Plum	2.50	0.12	0.00	0.00	Redbud	7.75	0.24	0.00	0.00
Toothache Tree	2.45	0.12	0.45	0.20	Baccaris	7.75	0.24	1.00	0.64
Post Oak	1.50	0.07	0.00	0.00	Toothache Tree	5.25	0.16	0.00	0.00
Greenbriar	1.00	0.05	0.00	0.00	Wafer Ash	2.75	0.09	0.00	0.00
Eves Necklace	0.50	0.02	0.00	0.00	Post Oak	1.00	0.03	0.00	0.00
Rusty Blackhaw	0.50	0.02	0.00	0.00	Mexican Plum	0.75	0.02	0.00	0.00
Redbud	0.25	0.01	0.00	0.00	Greenbriar	0.50	0.02	0.00	0.00
Honey Mesquite	0.25	0.01	0.00	0.00	Chinaberry	0.25	0.01	0.00	0.00
Ground	0.25	0.01	0.00	0.00	--	--	--	--	--
Texas Persimmon	0.00	0.00	1.00	0.44	--	--	--	--	--
Total	2035.80	100.00	229.20	100.00	Total	3232.50	100.00	155.50	100.00

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VITA

David Timothy Morgan was born 05 May 1984 to Tim and Jane Morgan in Dallas, TX. He earned the rank of Eagle Scout at age 15 and graduated from Lake Highlands High School in the spring 2003. He entered Texas A&M University-College Station in the fall of 2003. In the summer of 2007 while studying at Texas A&M, David worked as Wetlands Monitoring Intern for the Iowa Department of Natural Resources. David received his B.S. degree in Wildlife and Fisheries Science and graduated from Texas A&M University in December 2007. In the spring and summer of 2008 and spring of 2009, David worked for the Texas A&M Institute of Renewable Natural Resources (IRNR) researching golden-cheeked warblers and black-capped vireo. In the summer of 2009 David worked in Alberta Canada on a grizzly bear research project with the University of Alberta, Edmonton. David entered graduate school at Texas State University-San Marcos, TX in the fall of 2009. During his time at Texas State, David continued working with the Texas A&M IRNR and twice received the Houston Safari Club Dan L. Duncan Scholarship. David also taught (Human Anatomy and Physiology; Vertebrate Anatomy) labs as an Instructional Assistant for 3 semesters. In the spring of 2012 David began work as a biological science technician for the U.S. Fish and Wildlife Service at the Balcones Canyonlands National Wildlife Refuge, TX.

Permanent email: dmorgan5584@gmail.com

This thesis was typed by David T. Morgan.