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**FINAL REPORT**

**EFFECTS OF MOUNTAIN BIKING ACTIVITY ON FORAGING AND  
NESTING BEHAVIOR OF GOLDEN-CHEEKED WARBLERS**

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## EXECUTIVE SUMMARY

Knowledge of the compatibility of non-consumptive outdoor recreation and wildlife conservation is, for the most part, limited. Specific to this research, conflicts with recovery objectives for the endangered Golden-cheeked Warbler (*Dendroica chrysoparia*) and mountain biking activities are of concern to natural resource managers in central Texas, where the species breeds in isolated locations near considerable human activity (e.g., urbanization and military training).

This study was designed to assess the relationships between mountain biking and breeding behaviors and outcomes of Golden-cheeked Warblers. During the breeding seasons in spring 2002 and 2003, various aspects of Golden-cheeked Warbler breeding biology were investigated in 4 study areas (2 biking areas and 2 controls) on or near Fort Hood Military Base and Austin, Texas. Specifically, the following characteristics were contrasted in the biking and non-biking areas: indices of recreational use (human presence and trail densities), male territory size, time activity budgets of territorial males, parental behavior at nests, nest success, and arthropod availability. Data were collected in biking and non-biking areas with a combination of camera surveillance of human presence on trails in breeding habitats, GIS technologies, direct observations of breeding warblers, video taping of nesting warblers, and direct arthropod sampling.

In support of the general study design, intensity of trail use was greater in biking areas than in non-biking areas; mountain bikers were the predominant

users (80%) of trails in the biking areas. Relative to possible negative impacts of mountain biking activity on breeding warblers, sizes of the territories of breeding males were larger in biking areas, and that was associated with higher (2X) trail densities in the biking areas. Importantly, Mayfield nest success was nearly 50% lower in biking areas than non-biking areas.

In contrast, time activity budgets of territorial males from direct observation did not differ between biking and non-biking areas, although they did differ between years. Moreover, all parental behavior parameters at nests did not differ between biking and non-biking areas. Total arthropod relative abundance did not differ between biking and non-biking areas; relative to arthropod orders, only Acarina differed between areas.

These results suggest that mountain biking activities may influence some aspects of the breeding biology of the endangered Golden-cheeked Warbler. The observations of larger male territory size and lower nest success in biking areas than non-biking areas are cause for concern. Nevertheless, direct cause-and-effect relationships cannot be established directly at this time, but they do merit further investigation.

## INTRODUCTION

Knowledge of the compatibility of non-consumptive outdoor recreation and wildlife conservation is, for the most part, limited (Van der Zande et al. 1984a, Van der Zande et al. 1984b, Miller and Hobbs 2000). This lack of information can result in deficient conservation initiatives and thus, cause dissension between wildlife managers and the general public who are required to restrict their recreational activities for the preservation of a species. Studies on the effects of non-consumptive outdoor recreation on wildlife are critical in the development of conservation strategies aimed at balancing the needs of wildlife species with the needs of the public. Moreover, if breeding areas of a threatened or endangered species are in high demand for recreational use, visitor carrying capacities of these areas need to be established to avoid disruptive and pernicious effects (Van der Zande et al. 1984b, Lord et al. 2001). Such studies provide managers with much needed information that allows them to justify restricting recreation activities.

Non-consumptive recreation refers to such activities as mountain biking, bird watching, and hiking, in which wildlife is not physically removed or affected (Wilkes 1977, Duffus and Dearden 1990). In contrast to consumptive recreational activities such as hunting and fishing, non-consumptive activities are often assumed to be neutral or benign to wildlife. However, it has been argued that due to the extent of non-consumptive use over all landscapes, these activities can have as much of an effect, perhaps detrimental, on wildlife as consumptive use (Wilkes 1977, Duffus and Dearden 1990). In fact, non-

consumptive recreational activities have exhibited negative effects on a wide variety of wildlife species. These activities have been shown to alter behavior (Gutzwiller et al. 1994, Miller et al. 2001, Lord et al. 2001), physiology (Steen et al. 1988), distribution (Van der Zande et al. 1984a, Miller et al. 1998), reproduction (Miller et al. 1998, Miller and Hobbs 2000), and survival (Mikola et al. 1994) of various wildlife species.

Conflicts between non-consumptive outdoor recreation and wildlife conservation concerns are likely to intensify as recreational use of natural areas increases. Participation in non-consumptive activities nearly doubled between 1980 and 1990 (U.S. Fish and Wildlife Service and U.S. Bureau of Census 1993) and continues to increase throughout the U.S. (Flather and Cordell 1995). Moreover, new technological advances in equipment are rapidly changing recreational opportunities, necessitating the need for managers to be aware of such developments so that new management strategies can be implemented accordingly.

Mountain biking is a popular and relatively new outdoor recreational activity that is of concern to natural resource managers from, to name a few, the U.S. Department of Defense, U.S. Bureau of Land Management, the U.S. Forest Service, and the U.S. National Park Service (e.g., Chavez et al. 1993, Hollenhorst et al. 1995) largely due to its rapid growth. Mountain biking is one of the fastest-growing outdoor recreational activities, experiencing substantial growth in the 20 years (e.g., Mosedale 2002). Increased participation has led to

greater demands for quality outdoor experiences on trail networks in what are often fragile environments (Flather and Cordell 1995).

Managers of public lands have, therefore, raised genuine concerns regarding planning and management of this growing activity (Chavez et al. 1993, Symmonds et al. 2000). In addition to technological advances and increases in participation, managers have cited damage to natural resources, illegal trespassing and trail creation, conflicts between user groups, and safety issues as serious concerns regarding mountain biking (Chavez et al. 1993). As a result, mountain biking has been restricted from all federal wilderness areas and many other public lands in the U.S. despite very little scientific literature dealing with its impacts on wildlife (Weir 2000, Taylor and Knight 2003). Nevertheless, providing for recreational demands, while understanding the extent and mechanisms of the impact of recreation, such as mountain biking, on wildlife and wildlife habitat are among the many goals of resource management (Symmonds et al. 2000).

The Golden-cheeked Warbler (*Dendroica chrysoparia*) is a Neotropical migrant songbird that is federally listed as endangered. It is sensitive to habitat degradation from associated human activities (Ladd and Gass 1999). Extant and spotty breeding populations occur in oak-juniper woodlands associated with limestone hills and canyons in central Texas. Detailed population studies have been conducted in and around Fort Hood, Texas (e.g., Hayden and Tazik 1991, Jetté et al. 1998). Occupancy of breeding areas is related positively with steep slopes, forest interior characteristics, cover and height of juniper canopy, and landscape protection (DeBoer and Diamond 2002); more recently, Magness et al.

(2006) concluded that the amount of mature juniper-oak woodland was the most important factor determining occupancy. Similarly, singing sites of territories of breeding males often are associated with cliff edges and forest canopy breaks (Bolsinger 2000). Yet, few studies have specifically addressed the impact of mountain biking on breeding activities of the endangered Golden-cheeked Warbler.

The Golden-cheeked Warbler was listed as endangered in 1990 due to reduction of its overall range and loss of nesting habitat to urbanization and agricultural expansion (U.S. Fish and Wildlife Service 1992). Golden-cheeked warblers strip the bark of mature Ashe juniper (*Juniperus ashei*) as the principal component of their nests (Pulich 1976, Ladd and Cass 1999). They also depend on Ashe juniper along with several broad-leafed tree species (e.g., plateau live oak [*Quercus fusiformis*], Texas red oak [*Q. buckleyi*], shin oak [*Q. sinuata*], cedar elm [*Ulmus crassifolia*], and Texas ash [*Fraxinus texensis*]) for foraging substrates and nest placement.

Breeding habitat of the Golden-cheeked Warbler is used by mountain bikers in various places in its breeding range (e.g., Dinosaur Valley State Park in Somervell County, Lost Maples State Natural Area in Bandera County, Belton Lake Outdoor Recreation Area [BLORA] in Bell County, and Emma Long Metropolitan Park [ELMP] in Travis County). To mountain bikers, these areas offers solitude, scenic vistas, technical inclines, and trails for a variety of skill levels. However, disturbance from mountain biking may pose a threat to successful breeding of and therefore recovery objectives for the Golden-cheeked

Warbler (U.S. Fish and Wildlife Service 1993). Section 9 of the Endangered Species Act prohibits activities that have the potential to harm, in any way, an endangered or threatened species. As a result, the Biological Opinion of the U.S. Fish and Wildlife Service (1993) and the Balcones Canyonlands Conservation Plan (BCCP) suggested eliminating mountain biking from Golden-cheeked Warbler breeding habitat in areas of the Fort Hood Military Reservation and the City of Austin. This has been controversial as restrictions have been placed on several public-land trails.

This research was designed to address the concern that mountain biking has a negative impact on breeding behavior and outcome of Golden-cheeked Warblers. Various aspects of the breeding behavior of the Golden-cheeked Warbler and mountain biking activity were evaluated in 4 areas in and near Fort Hood and Austin, Texas. Specific objectives follow.

## **OBJECTIVES**

1. Examine the general impact of mountain biking activity on the foraging and nesting behavior of Golden-cheeked Warblers.
2. Assess effects of varying intensities of trail use by mountain bikers on Golden-cheeked Warbler behavior.
3. Examine the relationship between arthropod availabilities and Golden-cheeked Warbler foraging site selection and foraging behaviors, which will allow a better assessment of Golden-cheeked warbler response to mountain bike activities.

4. Assess effects of mountain bike activity on Golden-cheeked Warbler productivity.

## **STUDY AREA**

This study was conducted at 4 study sites (2 biking areas and 2 controls areas) near Austin, TX from March to June 2002 and 2003. Biking areas were located at BLORA on Fort Hood Military Base in Bell County and ELMP in Travis County. Controls areas were located at Training Area 13A (13A) on Fort Hood Military Base and Forest Ridge Preserve (FRP) in Austin. Recreational activities were restricted from both control areas, and military activities were restricted for both sites at Fort Hood.

Fort Hood is an 88,500-ha active military installation located on the northern edge of the Edwards Plateau in Bell and Coryell counties. It is adjacent to Killeen and is about 97 km north of Austin. Fort Hood is the only installation in the United States that currently provides training facilities for 2 full-armored divisions. Military activities include tank and mobile infantry maneuvers, live-fire artillery training, helicopter tactical training, and large-scale mock offenses (U.S. Fish and Wildlife Service 1993). Additional land uses on Fort Hood include prescribed burning and juniper cutting in grassland areas, cattle grazing, and recreational activities including mountain biking (restricted to BLORA), hunting, fishing, swimming, camping, boating, and hiking (Hayden et al. 2001). Fort Hood contains about 21,850 ha of golden-cheeked warbler habitat, supporting the

largest known population of golden-cheeked warblers under one management authority (U.S. Fish and Wildlife Service 1993).

The mountain bike park at BLORA (192 ha) was constructed in 1998 by the Fort Hood Trailblazers Mountain Biking Club. Since then, The Nature Conservancy, in cooperation with the Department of Defense, has examined effects of mountain biking on golden-cheeked warbler territory density, return rates, and age structure. BLORA and Training Area 13A (198 ha) are located in the southeastern corner of Fort Hood.

In Austin, human population grew 95% from 1970 to 1990 and a disproportionate part of that growth was in western Travis County where most of the prime golden-cheeked warbler habitat was located (Eagle 1998). ELMP (116 ha) and FRP (190 ha) are part of the Balcones Canyonlands Preserve (BCP) located in western Travis County. BCP is about 10,600 ha of preserve properties managed by the City of Austin, Travis County, Lower Colorado River Authority, The Nature Conservancy, and Travis Audubon Society. The Preserve was established in 1996 to protect federally endangered species and several species of concern in western Travis County (Eagle 1998). ELMP and FRP, located about 13 km northwest of downtown Austin, are both managed by the City of Austin.

The dominant tree species in golden-cheeked warbler breeding habitat is Ashe juniper (Pulich 1976, Kroll 1980, Ladd and Gass 1999). Several oak species in the habitat vary in dominance geographically. These include Spanish oak (*Quercus buckleyi*) and plateau live oak, which are the most common

broadleaf species in the central part of the breeding range, and shin oak and Lacey oak (*Q. glaucooides*), which are important in the northern and southern parts of the range, respectively. Other common tree species include cedar elm, Texas ash, Arizona walnut (*Juglans major*), and hackberry (*Celtis* spp.) (Ladd and Gass 1999).

The climate in central Texas is characterized by long, hot summers and short, mild winters. The mean annual temperature throughout the breeding range of the Golden-cheeked Warbler is 18.5–20.0 °C (Kier et al. 1977). The mean annual temperature for Fort Hood and Austin is 20.3 °C (National Oceanic and Atmospheric Administration 1997). The mean annual precipitation throughout the breeding range is 55–85 cm (Kier et al. 1977). Precipitation has 2 major seasonal peaks with the largest occurring during May and June and a smaller peak occurring in September and October. Average annual precipitation for Fort Hood and Austin is 81 cm (National Oceanic and Atmospheric Administration 1997). Soils in Golden-cheeked Warbler habitat are dark, shallow to deep clay loams, clays, and calcareous stony clays over limestone (Pulich 1976). Elevation is 180–520 m above mean sea level (Oberholser 1974) with many steep sloped hills and ridgelines rising above the flat to gently rolling plains (Hayden et al. 2001).

## **METHODS**

### ***Recreational Use Estimation***

We used TrailMaster photoelectric trail counters to accurately assess the level of mountain bike use at different locations along the network of trails at

each site. We calibrated each trail counter by using counter-activated cameras, which also allowed us to identify the disturbance type. Trail counters consist of a scanner that emits an infrared beam and a reflector that returns the beam to the scanner. The counter is advanced when the beam is interrupted. To reduce animals and other subjects from triggering the trail counter, we installed the scanner at the chest height of the mountain bikers. Trail counters were used for the entire field season (12 weeks) during each year. We installed 4 counters for each of the biking sites and 2 counters at each of the control sites. We located the counters within male territories at each site and rotated the counters on regular schedule. During each rotation of the trail counters, data from each unit were downloaded onto a separate data collector and then downloaded onto a computer using StatPack software (Goodson & Associates, Inc.). Data from trail counters were reported as visitors per weekday, per weekend day, and per day for each territory.

### ***Territory Size***

We used a spot-mapping method (Ralph et al. 1993) to delineate territory locations for all males within each site. Individual locations of males were determined by standing directly under the location where a male was sighted and using a handheld Garmin GPS III+ unit to approximately determine the Universal Transverse Mercators (UTMs) for the male's location. We attempted to obtain at least 30 locations per individual male (Bibby and Burgess 1992). UTM locations

were then plotted on 1:4000 digital orthoquad (DOQQ) maps with 1.5-m resolution imagery and a 500 X 500 m grid overlay.

To compare male Golden-cheeked Warbler territory size across study sites with varying topographic and landscape features, a minimum sample size needed to reach an asymptote was determined using an area-observation curve for each male with  $\geq 30$  locations (Odum and Kuenzler 1955, Gese et al. 1990). Because 30 locations was a minimum number needed to estimate minimum convex polygon (MCP) territory size, only males with  $\geq 30$  locations were used to determine minimal sample size (Laundre and Keller 1984, Seaman et al. 1999). A minimum convex polygon bootstrap procedure with 100 iterations was conducted using the Home Range Extension (HRE) in ArcView 3.2 (Rodgers and Carr 1998, Environmental Systems Research Institute 2000). The minimum number of male locations needed to determine MCP's ranged from 30 to 33 and only males that had the number of locations greater than the mean minimum sample size were used to estimate MCP territory sizes for each study site. Territory sizes were then determined from observations of males entered into ArcView and a 95% MCP (Mohr 1947) was calculated in the HRE (Rodgers and Carr 1998).

We also characterized the land cover types within each study site and each territory using the National Land Cover Database of 2001 (NLCD). To standardize our analysis across the 4 study sites, land-cover categories in the NLCD were reclassified into 8 broad categories: water, bare ground, deciduous forest, evergreen forest, mixed forest, shrub/scrub, grassland, and wetland. The

proportions of landcover types from NLCD (i.e., forested, grassland) within each bird's home range were then extracted in ArcView. We walked all trails within each study area using a GPS unit to delineate the trails. We downloaded the trail locations and created a GIS cover layer of trails for each study site using ArcView.

### ***Time Activity Budgets of Territorial Males***

To assess the impact of mountain biking activity on Golden-cheeked Warbler foraging activities, we conducted behavioral observations of Golden-cheeked Warbler males on territories at each study site from March to June during each year. We conducted observations throughout the day. To minimize sampling bias due to diurnal variation in foraging behavior, we attempted to collect behavioral data equally during 3 time periods (early [sunrise to 11:00], mid-day [11:01 to 15:00], and late [15:01 to sunset]). Males were located by listening for an A- or B-song (Bolsinger 2000). After males were located, we determined if the male was banded during previous studies by using binoculars and recorded its unique colored band combination. We recorded behavioral data from banded and unbanded males.

We predominantly observed males using binoculars, but in some cases were able to observe males with the naked eye. We attempted to observe each bird for 300 sec and discarded observation sessions <30 sec long (Johnson 2000). We dictated behaviors into a handheld microcassette tape-recorder. To avoid bias toward conspicuous behaviors, we began recording behaviors 5 sec

after locating a bird (Wunderle and Latta 1998). We used focal individual sampling (Altmann 1974, Martin and Bateson 1986) to collect behavioral data. To avoid autocorrelation, we did not record behavior from the same individual more than once during each time period within a single day. We did not collect behavioral observations during times of rain or high winds (>25 mph). We also did not collect behavioral observations on the same day that a male was banded. Newly banded males generally perch and peck on their bands during much of the first day after being banded (A. Graber, personal communication).

We followed Remsen and Robinson (1990) and Robinson and Holmes (1982) to categorize behaviors. We classified behaviors into 8 main categories: singing (which was further categorized into either an A-song or B-song), preening, agonistic, mate guarding, perching (resting), locomotion (flying and hopping), foraging (searching, attacking, and food handling), feeding fledgling, and time-out (time when the bird is out-of-sight). When a focal male briefly disappeared behind vegetation during an observation, the bird was considered in “time-out.” When time-out was recorded, the tape recorder continued to run and observations resumed when the bird reappeared. If the bird did not reappear within the 300-sec period, we ended the observation at the end of the last observation before the time-out. Singing heard during the time-out periods was not recorded, so that singing behavior were not overemphasized compared with other behaviors that may have occurred behind the vegetation. During the session, we also recorded if a female, fledgling, and/or mountain biker was present.

We further examined foraging activities by recording the amount of time a male was engaged in searching, attacking, and food-handling as well as foraging site data and prey type captured if discernible. Search movements were considered any movements leading up to locating food and included hops (leg powered movements <10 cm), short flights (<20 cm), medium flights (20 cm to 2 m), and long flights (>2 m). Attack maneuvers were any movements directed at a food item or the substrate that concealed the food item after it was located and included gleaning, reaching, hanging, leaping, sally-striking, sally-hovering, and flutter-chasing (Remson and Robinson 1990). Food handling data included prey type (identified to order or family when possible), success of attack, status of prey item (consumed, delivered, or rejected), and prey size (estimated by male bill length of 8 mm).

For collection of foraging-site data, we recorded tree species used for foraging, substrate type (foliage, twig [ $<1$  cm– $2.5$  cm in size], branch [ $2.6$ – $12$  cm in size], trunk [ $>12$  cm in size], ground, and air), horizontal position (inner third, middle third, and outer third of tree), tree height, and diameter at breast height (DBH) of the tree. We visually estimated tree height and height of the foraging warbler using a clinometer (Keane and Morrison 1999). DBH was measured using a diameter metric tape.

Due to the unusual growth of Ashe juniper, we recorded basal diameter at 10 cm above the ground and the juniper age class when a warbler foraged in an Ashe juniper. Ashe juniper age classes were the following: 1)  $<2$  m tall with many branchlets, no stripping bark, and extensive foliage with pointed, drooping

tips; 2) full height with many branchlets, extensive white fungus on bark, little or no stripping, and foliage pointed with dropping tips; 3) branchlets thinning and tree opening up inside, bark beginning to darken and strip, foliage beginning to wad at periphery, and points and drooping tips disappearing; 4) relatively open inside, bark dark and stripping extensively, and foliage external and wadding (Rust 1993).

### ***Parental Behavior at Nests***

To assess the impact of mountain biking activity on Golden-cheeked Warbler nesting and parenting activities, we video-recorded nests located in each of the study sites. Miniature video camera systems (Fuhrman Diversified, Inc., Seabrook, TX) were used to monitor nests at each study site. In 2002, we relied on video-recordings provided by another researcher conducting research on nest predation of Golden-cheeked Warblers and Black-capped Vireos (*Vireo atricapillus*) (M. Stake, University of Missouri, Columbia, MO); in 2003, we collected nesting and parenting behavior using 8 miniature video camera systems. Protocols for video-recording were similar for 2002 and 2003. Each system consisted of a 32 by 32 by 60-mm camera with a small lens and 6 infrared diodes (950 nm) that allowed filming at night, an articulating arm that supported the camera, and a clamp at the base of the arm for attachment to a substrate. A video recorder, allowing 24 h of footage on a 120-min VHS cassette tape, was connected to the camera with a 20-m cable. We used a hand-held monitor connected to the cable for positioning the lens at the nest during set-up

and to check nest status each day without approaching the nest. Camera systems were visited daily to change tapes and replace 12-volt rechargeable batteries used to power the system every other day.

We generally found nests opportunistically during location of focal males. We relied on several behavioral cues during observations to aid with locating nests: 1) females gathering nesting material, 2) a male following a female to a nest while building, 3) copulations near the nest, 4) a male searching for a nest site with a female, and 5) both parents bringing food to the nest.

Cameras were only set up after the laying stage because of potential impacts on Golden-cheeked Warblers. Stake (2000) determined that Black-capped Vireos were sensitive to cameras during the building and egg laying stages, but were not significantly impacted by cameras following egg laying. Therefore, we monitored the camera set-up during the first hour to evaluate the female's acceptance of the set-up. Nests were monitored by video until the nest fate was known (e.g., fledged young, depredated, abandoned).

We watched videos on a monitor using a multispeed video player. Tapes for individual nests were viewed until fate of the nest was known. We recorded behaviors during the incubation stage, early nestling stage, and late nestling stage. Because female Golden-cheeked Warblers brood recently hatched nestlings for long periods during the first 3 days after hatching and continue brooding for 1–2 days (Ladd and Gass 1999), we designated the early nestling stage as the first 5 days of the nestling stage. We classified behaviors of parental behavior into 8 categories: female incubating eggs, female brooding

nestlings, female or male feeding nestlings, female shading nestlings, female or male perching/scanning at the nest, and male feeding the female. When possible, we attempted to identify food items and quantify number of food delivered to nestlings. We also recorded predation events and identified predators to the lowest taxonomic level, when possible. If portions of tapes experienced technical difficulties, we excluded those portions from our calculations of time activity budgets.

## ***Nest Success***

To assess the effects of mountain bike activities on Golden-cheeked Warbler nesting success, we monitored all nests located within each of the study sites. Most of the nests located were monitored by video camera set-ups; however, for those nests without video camera set-ups, we monitored them by climbing up nest trees and checking the contents of the nest with a small mirror. This was necessary because forcing a mirror on an extension pole through vegetation around the nest could severely impact vegetation structure around the nest. Nests monitored by video camera systems were visited daily, while nests not monitored by video camera systems were visited every 2–5 days to assess its outcome. Nests not monitored by video cameras were visited more frequently near the expected time of hatching and fledging to more accurately age nests and correctly determine nest outcome. A nest was considered successful if  $\geq 1$  young fledged. Successful production of  $\geq 1$  fledgling was confirmed by locating fledglings being fed by a parent. Data collected at nests included number of

Golden-cheeked Warbler eggs, nestlings, and fledglings; number of Brown-headed Cowbird (*Molothrus ater*) eggs, nestlings, and fledglings; nest height; species of nest tree; and nest location in the tree.

## ***Arthropod Sampling***

In 2003, we collected arthropod samples from territories where foraging observations were conducted. Because Golden-cheeked Warblers have been described as foliage gleaning insectivores (Pulich 1976, Beardmore 1994), we used branch-clipping to measure relative arthropod abundances in microhabitats (e.g., location, plant species) used by foraging warblers (Cooper and Whitmore 1990, Keane and Morrison 1999). Arthropods were sampled during a 2-day period every 2 weeks throughout the breeding season. To account for differences in diel effects on arthropod movements, we divided sampling days into morning (07:00 to 10:00) and afternoon (14:00 to 17:00) periods. Similar to Wharton et al. (1996), we selected 4 tree species for sampling: Ashe juniper, plateau live oak, Texas red oak, and cedar elm. We sampled 2 of these species in the morning on the first day and the other 2 species in the afternoon. On the second day, this procedure was repeated in reverse order to account for temporal variations in arthropod numbers between tree species.

Within each male territory, we randomly selected a point from which one of each tree species closest to the point was selected for sampling. For each tree, we selected 3 small branches (approximately 0.5 m) at 3 varying heights (0–3 m, 3–5 m, >5 m) at random cardinal directions. We then clipped about 0.5

m of terminal foliage of each branch using an extendable pruner pole with a sweep-net attached for collecting the branch. We vigorously shook the bagged branch to dislodge arthropods and removed the branch from the bag, making sure that no arthropods escaped. Collected arthropods were then placed into jars containing 80% ethyl alcohol. We identified invertebrates to family-level, according to published descriptions (Kaufman and Eaton 2007). We counted all arthropods and oven-dried them at 60°C for at least 24 hr to a constant mass.

## **STATISTICAL ANALYSES**

### ***Recreational Use Estimation***

We analyzed trail-counter data using 2-way analysis of variance (ANOVA). Trail count was the dependent variable and site (biking vs. non-biking) and years were independent variables. Tests were considered significant at  $P \leq 0.05$ .

### ***Territory Size***

We calculated a trail density index based on the area occupied by trails within each MCP. The area of trails was determined by multiplying the linear length of trails within each MCP by 2.5 m, which was considered the average width of trails. We used a 1-way ANOVA to examine differences in territory size, trail index, amount of trail area within each MCP, and habitat composition (% developed, % deciduous, % juniper, and % grassland) between biking and non-biking areas. Tests were considered significant at  $P \leq 0.05$ .

***Time Activity Budgets of Territorial Males***

Because some of the banded males had multiple observations within time periods, we averaged the behaviors for those individuals within each time period prior to conducting analyses. We analyzed time-activity data using multivariate analysis of variance (MANOVA) with a factorial arrangement (SYSTAT 2004). Treatment (biking and non-biking), time period (early, midday, and late), and year (2002 and 2003) were independent factors in the MANOVA. We used MANOVA because the dependent variables (i.e., individual behaviors) were not independent of each other (i.e., the amount of time engaged in 1 behavior influenced the amount of time engaged in other behaviors). Wilks' lambda ( $\lambda$ ) was the test criterion, and all tests were considered significant at  $P \leq 0.05$ .

Following a significant overall MANOVA, we used univariate analysis of variance (ANOVA) to determine differences in individual behaviors between years (Barker and Barker 1984). Behavioral data met assumptions of normality and homogeneity (Johnson and Wickern 1988, SYSTAT 2004). We used a similar MANOVA with factorial arrangement to analyze foraging search behavior data. We used Kruskal-Wallis tests to compare food capture techniques (i.e., proportion of attack modes engaged in by each male during foraging) of males between biking and non-biking sites. Results from Kruskal-Wallis tests were considered significant at  $P \leq 0.05$ .

## ***Parental Behavior at Nests***

Because there was considerable variability in the amount of time each nest was videotaped (which could overemphasize the activities at some nest), we calculated parental behavior parameters (e.g., % daytime spent incubating, % daytime spent perching/scanning, % daytime spent feeding nestlings, and number and length of various behavior bouts) based on a daily basis. We compared parental behavior parameters using Kruskal-Wallis tests. Results from Kruskal-Wallis tests were considered significant at  $P \leq 0.05$ .

## ***Nest Success***

We used Mayfield (1961, 1975) method to calculate daily nest survival rates (DSN) for incubation and nestling stages and nest success for biking and non-biking sites. We calculated standard errors for DSN following Johnson (1979).

## ***Arthropod Sampling***

We used a 1-ANOVA to compare total arthropod relative abundance and relative abundance of the major orders between biking and non-biking areas. Prior to analysis, the arthropod data were  $\log(x + 1)$  transformed to meet assumptions of normality and homoscedasticity (Zar 1996). Results from 1-way ANOVA tests were considered significant at  $P \leq 0.05$ .

## RESULTS

### *Recreational Use Estimation*

From the TrailMaster photoelectric trail counters, we were able to determine the intensity of trail use (not just bikers) among our 4 study sites. Overall, the intensity of trail use was greater at biking sites than non-biking sites ( $F_{1, 79} = 37.19$ ,  $P < 0.001$ ; Fig. 1) and consistent between years ( $F_{1, 79} = 0.38$ ,  $P = 0.54$ ). Among the 4 sites, trail use was lowest at 13A ( $0.46 \pm 0.1$  [SE] counts/day) and highest at EMLP ( $24.41 \pm 1.90$  counts/day). Trail use intensities at FRP and BLORA were  $2.52 \pm 1.05$  counts/day and  $4.58 \pm 0.84$  counts/day, respectively. At the 2 biking sites, mountain bike intensity was  $4.77 \pm 1.47$  bikers/day (range = 0–17 bikers/day) for BLORA and  $16.57 \pm 2.24$  bikers/day (range = 4–30 bikers/day) for EMLP. During both years, mountain bikers were the predominant trail users at biking sites (80%), and researchers were the predominant trail users at non-biking sites (62%; Fig. 2).

### *Territory Size*

Territory sizes for male Golden-cheeked Warblers were larger in biking sites than non-biking sites (Table 1). The sizes of the territories ranged from 0.48 to 7.27 ha in biking sites and from 0.24 to 4.33 ha in non-biking sites. Among the 4 sites, 13A ( $n = 15$ ) had the smallest territory sizes ( $1.19 \pm 0.14$  ha) and BLORA ( $n = 49$ ) had the largest territory sizes ( $2.47 \pm 0.35$  ha). The territory sizes at EMLP ( $n = 13$ ) and FRP ( $n = 15$ ) were  $1.96 \pm 0.19$  ha and  $1.68 \pm 0.26$  ha, respectively. Trails occupied twice the area within territories of Golden-

cheeked Warbler males in biking sites than non-biking sites (Table 1). The trail density index for Golden-cheeked warbler male territories was also higher in biking sites than non-biking sites. The habitat composition of the territories within biking and non-biking sites did not differ.

### ***Time Activity Budgets of Territorial Males***

During the 2 years of the study, we had 400 total observations of banded and unbanded males. Each individual was observed an average of 152 sec and observations ranged from 30 sec to 492 sec. At biking and non-biking sites, golden-cheeked warbler males spent the most time engaged in locomotion and perching followed by singing, preening, and foraging (Table 2).

Overall behavior (i.e., simultaneous behaviors) did not differ between biking and non-biking sites (Wilks'  $\lambda = 0.97$ ,  $P = 0.265$ ; Table 2) and time periods (Wilks'  $\lambda = 0.95$ ,  $P = 0.365$ ; Table 3), but differed between years (Wilks'  $\lambda = 0.87$ ,  $P < 0.001$ ). There were no significant 2-way or 3-way interactions (Wilks'  $\lambda \geq 0.93$ ,  $P \geq 0.116$ ). Singing and feeding nestlings were the only behaviors that differed between years (Table 4). Male Golden-cheeked Warblers spent more time singing in 2003 than 2002 and more time feeding nestlings in 2002 than 2003.

Similar to overall behavior, prey search behaviors of male Golden-cheeked Warblers did not differ between biking and non-biking sites (Wilks'  $\lambda = 0.97$ ,  $P = 0.677$ ; Table 5). The total number of search bouts also did not differ between biking and non-biking sites ( $F_{1,93} = 0.03$ ;  $P = 0.866$ ;  $26.25 \pm 4.43$

bouts/observation period vs.  $27.15 \pm 3.25$  bouts/observation period). Male Golden-cheeked Warbler males also used similar attack techniques to capture prey at biking and non-biking areas (Table 6).

### ***Parental Behavior at Nests***

We monitored 32 Golden-cheeked Warbler nests (17 nests in biking sites and 15 nests in non-biking sites) by video during 2002 and 2003. We collected a total of 4,094.5 hr of data (incubation stage: 1,141.2 hr from nests at biking sites and 828.2 hr from nests at non-biking sites; nestling stage: 1,109.7 hr from nests at biking sites and 1,015.4 hr from nests at non-biking sites). Nests were videotaped an average of  $110.6 \pm 17.4$  hr (range = 15.2–432.8 hr). None of the parental behavior parameters for male and female Golden-cheeked Warblers differed between biking and non-biking sites during each nest stage (Tables 7–9).

The most common food items delivered by parents to nestlings were Lepidopteran larvae and katydids (Orthoptera) for nests at biking and non-biking areas (Figure 3). At nests in biking areas, only 2 taxa (Lepidopteran larvae and katydids) were delivered to nestlings, while in non-biking areas, 6 taxa (Lepidoptera larvae, katydids, spiders (Araneida), leafhoppers (Homoptera), mayflies (Ephemeroptera), and lacewings (Neuroptera) were delivered to nestlings.

**Nest Success**

We monitored 55 Golden-cheeked Warbler nests (33 nests in biking sites and 22 nests in non-biking sites) for nest survival. In biking areas, 21 nests (63.6%) successfully fledged at least 1 Golden-cheeked Warbler young, while in non-biking areas, 19 nests (86.4%) successfully fledged at least 1 Golden-cheeked warbler young. Seven nests (33.3%) were lost to predators in biking areas. Texas rat snakes (*Elaphe obsoleta*) accounted for 5 of the depredations at biking areas. An American Crow (*Corvus brachyrhynchos*) and fire ants (*Solenopsis invicta*) each depredated a nest in biking areas. Warbler parents abandoned the remaining nests (23.8%) at biking areas. Abandonment may have been caused by disturbance associated with placement of video cameras (Stake et al. 2004) or possibly disturbance from trail activity because 3 of the abandoned nests were located <2 m from the trail. In contrast, only 2 nests (10.5%) were lost to predators at non-biking sites. A Cooper's Hawk (*Accipiter cooperii*) and Texas rat snake each depredated a nest at non-biking areas. One nest was abandoned at non-biking areas. None of the nests were parasitized by Brown-headed Cowbirds.

Daily nest survival rate for biking areas was  $0.964 \pm 0.018$  for the incubation stage and  $0.945 \pm 0.019$  for the nestling stage, while daily nest survival rate for non-biking areas was  $0.986 \pm 0.014$  for the incubation stage and  $0.981 \pm 0.013$  for the nestling stage. The Mayfield nest success estimate for non-biking areas was nearly twice the estimate for biking areas (Fig. 4).

## ***Arthropod Sampling***

We collected a total of 1,730 arthropods from biking areas and a total of 1,868 arthropods from non-biking areas. For biking areas, 40% of the arthropods collected were insects, while for non-biking areas, 61% of the arthropods collected were insects. We identified 23 taxa from biking sites and 24 taxa from non-biking areas. Twenty-one taxa occurred at both areas, with 5 each only occurring at biking (Asilidae, Reduviidae, Platygasteridae, Isoptera, and Opilliones) and non-biking (Scolytidae, Fulgoridae, Membraeidae, Pteromalidae, and Isopoda) areas. In biking sites, total arthropod relative abundance primarily consisted of 4 arthropod groups (Acari, Araneida, Hymenoptera, and Thysanoptera) that accounted for 90% of the total abundance, while in non-biking areas, total arthropod relative abundance primarily consisted of 3 arthropod groups (Araneida, Hymenoptera, and Thysanoptera) that accounted for 73% of the total abundance (Table 10). Total arthropod relative abundance did not differ between biking and non-biking areas and the relative abundance of only 1 of the major orders differed between biking and non-biking areas (Table 11). Acarina relative abundance was greater in biking sites than non-biking areas.

## **CONCLUSIONS**

This study was designed to assess the relationships between breeding behaviors and outcomes of Golden-cheeked Warblers and mountain biking. During the breeding seasons in spring 2002 and 2003, various aspects of Golden-cheeked Warbler breeding biology were investigated in 4 study areas (2

biking areas and 2 controls) near Fort Hood and Austin, Texas: indices of recreational use (human presence and trail densities), male territory size, time activity budgets of territorial males, parental behavior at nests, nest success, and arthropod availability.

Time activity budgets of territorial males from direct observation did not differ between biking and non-biking areas, although they did differ between years. Moreover, all parental behavior parameters at nests did not differ between biking and non-biking areas. Total arthropod relative abundance did not differ between biking and non-biking areas; relative to arthropod orders, only Acarina differed between areas. We do not believe that these minor differences caused appreciable effects on breeding success of Golden-cheeked Warblers.

In contrast and of importance to managers, intensity of trail use was greater in biking areas than in non-biking areas; mountain bikers were the predominant users (80%) of trails in the biking areas. Relative to possible negative impacts of mountain biking activity on breeding warblers, sizes of the territories of breeding males were larger in biking areas, and that was associated with a higher (2X) index of trail densities in the biking areas. Importantly, nest success was about twice as low in the biking areas compared with non-biking areas. Although sample size was small, more than 3 times as many nests (33.3% vs. 10.5%) were lost to predators in biking areas than in non-biking areas. Future research could be focused on whether or not predator densities are higher in biking areas, perhaps associated with trail densities and associated habitat fragmentation and/or opening of the forest structure.

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## **LITERATURE CITED**

Altmann, J. 1974. Observational study of behavior: samplings methods.

Behavior 49:227–265.

Barker, H. R., and B. M. Barker. 1984. Multivariate analysis of variance

(MANOVA): a practical guide to its use in scientific decision making.

University of Alabama Press, Birmingham, AL.

- Beardmore, C. J. 1994. Habitat use of Golden-cheeked Warblers in Travis County, Texas. Master's Thesis, Texas A&M Univ., College Station.
- Bibby, C. J., and N. D. Burgess. 1992. Bird census techniques. Academic Press Harcourt Brace and Company, London, England.
- Bolsinger, J. S. 2000. Use of two song categories by Golden-cheeked Warblers. *Condor* 102:539–552.
- Chavez, D. J., P. L. Winter, and J. M. Baas. 1993. Recreational mountain biking: a management perspective. *Journal of Park and Recreation Administration* 11:29-36.
- Cooper, R. J. and R. C. Whitmore. 1990. Arthropod sampling methods in ornithology. *Studies in Avian Biology* 13: 29–37.
- Cutler, T. L., and D. E. Swann. 1999. Using remote photography in wildlife ecology: a review. *Wildlife Society Bulletin* 27:571–581.
- DeBoer, T. A., and D. D. Diamond. 2002. Predicting presence-absence of the endangered Golden-cheeked Warbler (*Dendroica chrysoparia*). *Southwestern Naturalist* 51:181–190.
- Duffus, D. A., and P. Dearden. 1990. Non-consumptive wildlife-oriented recreation: a conceptual framework. *Biological Conservation* 53:213–231.
- Eagle, J. 1998. The Balcones Canyonlands Conservation Plan. Stanford Law School, Environmental and Natural Resources, Law and Policy Program. SLS Case No. 98-024.
- Environmental Systems Research Institute. 2000. ArcView GIS, Version 3.2a. Environmental Systems Research Institute, Redlands, California, USA.

- Flather, C. H., and H. K. Cordell. 1995. Outdoor recreation: historical and anticipated trends. Pages 3–16 *in* R. L. Knight and K. J. Gutzwiller, editors, *Wildlife and Recreationists: Coexistence through Management and Research*, Island Press, Washington, DC.
- Gese, E. M., D. E. Andersen, and O. J. Rongstad. 1990. Determining home-range size of resident coyotes from point and sequential locations. *Journal of Wildlife Management* 54:501–506.
- Gutzwiller, K. J., R. T. Wiedenmann, K. L. Clements, and S. H. Anderson. 1994. Effects of human intrusion on song occurrence and singing consistency in subalpine birds. *Auk* 111:28–37.
- Hayden, T. J., and D. J. Tazik. 1991. Project status report of the 1991 field studies of two endangered species (the Black-capped Vireo and the Golden-cheeked Warbler) and the cowbird control program at Fort Hood, Texas. U.S. Army Corps of Engineers, Construction Engineering Research Laboratory, Champaign, Illinois.
- Hayden, T. J., J. D. Cornelius, H. J. Weinberg, L. L. Jette, and R. H. Melton. 2001. Endangered species management plan for Fort Hood, Texas; FY 01-05. U.S. Army Corps of Engineers, Construction Engineering Research Laboratory, ERDC/CERL TR-01-26.
- Hollenhorst, S. J., M. A. Schuett, and D. Olson. 1995. Conflicts and issues related to mountain biking in the national forests: a multimethodological approach. U.S. Forest Service General Technical Report PSW-156.

- Jetté, L. A., T. J. Hayden, and J. D. Cornelius. 1998. Demographics of the Golden-cheeked Warbler (*Dendroica chrysoparia*) on Fort Hood, Texas. Technical Report 98/52, U.S. Army Corps of Engineers, Construction Engineering Research Laboratory, Champaign, Illinois.
- Johnson, D. H. 1979. Estimating nest success: the Mayfield method and an alternative. *Auk* 96:651–661.
- Johnson, M. 2000. Evaluation of an arthropod sampling technique for measuring food availability for forest insectivorous birds. *Journal of Field Ornithology* 71: 88–109.
- Johnson, R. A., and D. W. Wichern. 1988. Applied multivariate statistical analysis. 2<sup>nd</sup> edition. Prentice Hall, Englewood Cliffs, NJ.
- Kaufman, K., and E. R. Eaton. 2007. Kaufman field guide to insects of North America. Houghton Mifflin Company, New York, NY.
- Keane, J. J., and M. L. Morrison. 1999. Temporal variation in resource use by Black-throated Gray Warblers. *Condor* 101:6775.
- Kier, R. S., L. E. Garner, and L. F. Brown, Jr. 1977. Land resources of Texas. Bureau of Economic Geology, University of Texas at Austin, Austin.
- Kroll, J. C. 1980. Habitat requirements of the Golden-cheeked Warbler: management implications. *Journal of Range Management* 33:60–65.
- Ladd, C., and L. Gass. 1999. Golden-cheeked Warbler (*Dendroica chrysoparia*). In *The Birds of North America*, No. 420 (A. Poole and F. Gill, eds.). The Birds of North America, Inc., Philadelphia, PA.

- Laundre, J. W., and B. L. Keller. 1984. Home-range size of coyotes: a critical review. *Journal of Wildlife Management* 48:127–139.
- Lord, A., J. R. Waas, J. Innes, and M. J. Whittingham. 2001. Effects of human approaches to nests of northern New Zealand dotterels. *Biological Conservation* 98:233–240.
- Magness, D. R., R. N. Wilkins, and S. J. Hejl. 2006. Quantitative relationships among Golden-cheeked Warbler occurrence and landscape size, composition, and structure. *Wildlife Society Bulletin* 34:473–479.
- Martin, P., and P. Bateson. 1986. *Measuring behavior: an introductory guide*. Cambridge University Press, New York, NY.
- Mayfield, H. 1961. Nesting success calculated from exposure. *Wilson Bulletin* 73:255–261.
- Mayfield, H. F. 1975. Suggestions for calculating nest success. *Wilson Bulletin* 87:456–466.
- Mikola, J., M. Miettinen, E. Lehtinen, and K. Lehtila. 1994. The effects of disturbance caused by boating on survival and behavior of Velvet Scoter *Melanitta fusca* ducklings. *Biological Conservation* 67:119–124.
- Miller, J. R., and N. T. Hobbs. 2000. Recreational trails, human activity, and nest predation in lowland riparian areas. *Landscape and Urban Planning* 50:227–236.
- Miller, S. G., R. L. Knight, and C. K. Miller. 1998. Influence of recreational trails on breeding bird communities. *Ecological Applications* 8:162–169.

- Mohr, C. O. 1947. Table of equivalent populations of North American small mammals. *American Midland Naturalist* 37:223–449.
- Mosedale, J. 2002. Mountain biking in the Canadian Rocky Mountains: a situational analysis, case study of mountain tourism, and the conservation of biological and cultural diversity. *Mountain Forum E-consultation for the UNEP/Bischkek Global Mountain Summit*.
- National Oceanic and Atmospheric Administration. 1997. Climatological data, Texas. Vol. 102, No. 13, National Climatic Data Center, Asheville, NC.
- Oberholser, H. C. 1974. *The bird life of Texas*. Vol. 2. University of Texas Press, Austin.
- Odum, E. P., and E. J. Kuenzler. 1955. Measurement of territory and home range size in birds. *Auk* 72:128–137.
- Pulich, W. M. 1976. *The Golden-cheeked Warbler: a bioecological study*. Texas Parks and Wildlife, Austin.
- Ralph, C. J., G. R. Geupel, P. Pyle, T. E. Martin, and D. F. DeSante. 1993. *Handbook of field methods for monitoring landbirds*. General Technical Report PSW-GTR-144. USDA Forest Service Pacific Southwest Research Station, Albany, California.
- Remsen, J. D. and S. K. Robinson. 1990. A classification scheme for foraging behavior of birds in terrestrial habitats. *Studies in Avian Biology* 13: 144–160.

- Robinson, S. K., and R. T. Holmes. 1982. Foraging behavior of forest birds: the relationships among search tactics, diet, and habitat structure. *Ecology* 63: 1918–1931.
- Rodgers, A. R. and Carr, A. P. 1998. HRE: the home range extension for ArcView™: user's manual. Beta test version 0.9, July 1998. Ontario Ministry of Natural Resources, Centre for Northern Forest Ecosystem Research, Thunder Bay, Ontario, Canada.
- Rust, S. 1993. 1993 field season report: endangered bird survey on Camp Bullis Training Reservation, Fort Sam Houston, Texas. Unpublished report, Stewardship Services, Inc., San Antonio, Texas.
- Seaman, D. E., J. J. Millspaugh, B. J. Kernohan, G. C. Brundige, K. J. Raedeke, and R. A. Gitzen. 1999. Effects of sample size on kernel home range estimates. *Journal of Wildlife Management* 63:739–747.
- Stake, M. M. 2000. Using video to identify black-capped vireo nest predators at Fort Hood, Texas. Endangered species monitoring and management at Fort Hood, Texas: 2000 Annual Report, The Nature Conservancy of Texas, Fort Hood Project.
- Stake, M. M., J. Faaborg, and F. R. Thompson, III. 2004. Video identification of predators at Golden-cheeked Warbler nests. *Journal of Field Ornithology* 75:337-344.
- Steen, J. B., G. W. Gabrielsen, and J. Kanwisher. 1988. Physiological aspects of freezing behavior in Willow Ptarmigan hens. *Acta Physiologica Scandinavica* 134:299–304.

- Symmonds, M. C., W. E. Hammitt, and V. L. Quisenberry. 2000. Managing recreational trail environments for mountain bike user preferences. *Environmental Management* 25:549–564.
- SYSTAT. 2004. SYSTAT 11. SYSTAT Software, Incorporated, San Jose, CA.
- Taylor, A. R., and R. L. Knight. 2003. Responses of wildlife to human activity: terminology and methods. *Wildlife Society Bulletin* 31:1263–1271.
- U. S. Fish and Wildlife Service, 1992. Golden-cheeked Warbler (*Dendroica chrysoparia*) recovery plan. U.S. Fish and Wildlife Service, Albuquerque, NM.
- U. S. Fish and Wildlife Service. 1993. Biological opinion. U. S. Fish and Wildlife Service, Austin, Texas.
- U.S. Fish and Wildlife Service and U.S. Bureau of Census. 1993. 1991 National survey of fishing, hunting, and wildlife-associated recreation. U.S. Government Printing Office, Washington, DC.
- Van der Zande, A. N., J. C. Berkhuisen, H. C. van Latesteijn, W. J. ter Keurs, and A. J. Poppelaars. 1984a. Impact of outdoor recreation on the density of a number of breeding bird species in woods adjacent to urban residential areas. *Biological Conservation* 30:1–39.
- Van der Zande, A. N., and P. Vos. 1984b. Impact of a semi-experimental increase in recreation intensity on the densities of birds in groves and hedges on a lake shore in The Netherlands. *Biological Conservation* 30:237–259.
- Weir, D. V. 2000. A guide to the impacts of non-motorized trail use. Unpublished.

Wharton, R. A., E. G. Riley, M. A. Quinn, J. B. Woolley, J. S. Shaffner, and H.A.

Burke. 1996. Invertebrate species available as food for the Golden-cheeked Warbler in its nesting habitat. Research Report, Texas Transportation Institute, Texas A&M University, College Station.

Wilkes, B. 1977. The myth of the non-consumptive user. *Canadian Field-Naturalist* 91:343–349.

Wunderle, J. M., and S. C. Latta. 1998. Avian resource use in Dominican shade coffee plantations. *Wilson Bulletin* 110:271–281.

Zar, J. H. 1996. *Biostatistical analysis*. Third edition. Prentice-Hall, Incorporated, Englewood Cliffs, NJ.

**Table 1.** —Mean ( $\pm$  SE) for minimum convex polygon (MCP) territory size (ha), habitat composition (%) within MCPs, trail area (ha) within MCPs, and trail density (area of trail with MCP/area of MCP) within MCPs for Golden-cheeked Warblers at biking and non-biking sites near Austin, TX and on Fort Hood, TX during 2002–2003.

Variable	Biking ( <i>n</i> = 30)	Non-biking ( <i>n</i> = 61)	<i>F</i> <sup>a</sup>	<i>P</i>
Territory size	2.16 (0.19)	1.43 (0.16)	6.01	0.016
Habitat composition				
Developed	0.67 (0.42)	0.00 (0.00)	1.21	0.274
Deciduous	6.00 (1.50)	3.48 (2.70)	0.78	0.378
Juniper	92.00 (1.78)	96.52 (2.70)	2.05	0.155
Grassland	1.34 (0.83)	0.00 (0.00)	1.27	0.262
Trail area within MCP	0.068 (0.009)	0.029 (0.004)	9.77	0.002
Trail density index	0.033 (0.003)	0.021 (0.002)	6.21	0.015

<sup>a</sup> *F* and *P* values for analysis of variance comparisons between biking and non-biking sites; 1,89 df.

**Table 2.** —Diurnal time activity budget for Golden-cheeked Warblers at biking at biking ( $n = 139$ ) and non-biking ( $n = 204$ ) locations near Austin, TX and on Fort Hood, TX during spring 2002–2003.

Behavior	Day time (%)	
	Biking	Non-biking
Perching	32.1 (2.3)	30.1 (1.8)
Singing	13.4 (1.0)	14.2 (0.9)
Preening	7.1 (1.3)	7.0 (1.2)
Agonistic	0.4 (0.3)	0.2 (0.1)
Mate guarding	0.2 (0.1)	0.0 (0.0)
Locomotion	42.9 (2.7)	44.1 (2.2)
Foraging	2.9 (0.5)	3.2 (0.5)
Food handling	0.7 (0.3)	0.6 (0.2)
Feeding fledgling	0.2 (0.1)	0.5 (0.2)

**Table 3.** —Diurnal time activity budgets of Golden-cheeked Warblers within periods of the day at biking and non-biking areas near Austin, TX and on Fort Hood, TX during spring 2002 and 2003. Time periods were early (sunrise–11:00), midday (11:01–15:00), and late (15:01–sunset). Sample sizes for time periods were early ( $n = 146$ ), midday ( $n = 133$ ), and late ( $n = 64$ ).

Behavior	Day time (%)		
	Early	Midday	Late
Perching	29.7 (2.2)	31.2 (2.4)	32.9 (3.2)
Singing	14.3 (1.1)	14.8 (1.2)	11.1 (1.2)
Preening	7.3 (1.5)	7.9 (1.4)	4.7 (1.4)
Agonistic	0.2 (0.1)	0.1 (0.1)	0.7 (0.7)
Mate guarding	0.0 (0.0)	0.1 (0.1)	0.2 (0.2)
Locomotion	43.6 (2.6)	42.1 (2.7)	46.9 (3.6)
Foraging	4.4 (0.9)	3.3 (0.8)	3.3 (0.9)
Feeding Fledgling	0.4 (0.2)	0.5 (0.2)	0.2 (0.1)

**Table 4.** —Diurnal time activity budgets of Golden-cheeked Warblers within years at biking and non-biking sites near Austin, TX and on Fort Hood, TX during spring 2002 and 2003.

Behavior	Day time (%)		<i>P</i> <sup>a</sup>
	2002 <i>n</i> = 94	2003 <i>n</i> = 249	
Perching	31.3 (2.9)	30.8 (1.7)	0.874
Singing	8.3 (0.6)	16.0 (0.9)	<0.001
Preening	8.7 (2.0)	6.4 (0.9)	0.241
Agonistic	0.1 (0.1)	0.2 (0.1)	0.475
Mate guarding	0.1 (0.1)	0.01 (0.01)	0.868
Locomotion	45.2 (3.3)	43.0 (2.0)	0.572
Foraging	3.9 (0.6)	2.8 (0.4)	0.144
Food handling	1.2 (0.4)	0.5 (0.2)	0.078
Feeding fledgling	1.2 (0.4)	0.1 (0.0)	<0.001

<sup>a</sup> *P*-values from analysis of variance comparisons between years; *df* = 1, 341.

**Table 5.** —Food searching behaviors for male Golden-cheeked Warblers at biking ( $n = 41$ ) and non-biking ( $n = 54$ ) locations near Austin, TX and on Fort Hood, TX during spring 2003.

Behavior	Percent of total food searching time	
	Biking	Non-biking
Hop (<10 cm)	59.4 (5.0)	59.8 (4.0)
Short flight (<20 cm)	10.7 (1.9)	11.6 (2.2)
Medium flight (20 cm – 2m)	5.4 (1.2)	7.4 (1.3)
Long flight (>2 m)	24.5 (5.0)	21.1 (4.3)

**Table 6.**—Foraging attack techniques used by male Golden-cheeked Warblers at biking ( $n = 16$ ) and non-biking ( $n = 21$ ) locations near Austin, TX and on Fort Hood, TX during spring 2003.

Attack technique	Percent		$P^a$
	Biking	Non-biking	
Gleaning	57.4 (10.1)	47.4 (8.9)	0.555
Reaching	13.4 (7.2)	29.3 (8.1)	0.192
Hanging	3.1 (3.1)	4.3 (4.3)	0.823
Sally-striking	5.2 (3.6)	1.1 (1.1)	0.323
Sally-hovering	20.8 (8.6)	16.1 (6.7)	0.506
Flutter-chasing	0.0 (0.0)	1.7 (1.2)	0.232

<sup>a</sup>  $P$ -value from Kruskal-Wallis test with 1 df.

**Table 7.**—Comparison of incubation-stage parental behavior (mean [SE]) for female (F) and male (M) Golden-cheeked Warblers between biking and non-biking sites near Austin, TX and on Fort Hood, TX during spring 2002 and 2003. Behaviors were determined from video recordings during the incubation stage and were based on daylight hours.

Parameter	Biking ( <i>n</i> = 8)	Non-biking ( <i>n</i> = 7)	<i>P</i> -value <sup>a</sup>
Attendance (%)	71.05 (2.23)	75.08 (0.94)	0.132
F Incubation (%)	67.40 (38.83)	74.84 (0.93)	0.105
F shading eggs (%)	3.28 (3.27)	0.00 (0.00)	0.171
F perching/scanning (%)	0.10 (0.03)	0.10 (0.05)	0.817
M feeding F (%)	0.15 (0.04)	0.12 (0.09)	0.157
M perching/scanning (%)	0.12 (0.04)	0.01 (0.01)	0.090
No. of incubation bouts/day	17.98 (2.38)	14.05 (2.12)	0.355
Length of incubation bout (min.)	32.39 (6.86)	38.44 (3.22)	0.298
No. of F shading bouts/day	3.33 (3.33)	0.00 (0.00)	0.350
Length of shading bout (min.)	0.80 (0.80)	0.00 (0.00)	0.171
No. of F perch/scan bouts/day	18.64 (4.38)	10.54 (4.05)	0.165
Length of F perch/scan bout (min)	0.06 (0.02)	0.07 (0.04)	0.417
No. of M feeding F bouts	2.51 (1.34)	1.17 (0.60)	0.409
Length of M feeding F bouts (min.)	0.92 (0.33)	0.35 (0.22)	0.099
No. of M perch/scan bouts/day	0.86 (0.36)	0.40 (0.26)	0.286
Length of M perch/scan bout (min)	0.74 (0.30)	0.07 (0.05)	0.069

<sup>a</sup> *P*-value from Kruskal-Wallis test with 1 df.

**Table 8.** —Comparison of early nestling–stage parental behavior (mean [SE]) for female (F) and male (M) Golden-cheeked Warblers between biking and non-biking sites near Austin, TX and on Fort Hood, TX during spring 2002 and 2003. Behaviors were determined from video recordings during the early nestling stage and were based on daylight hours.

Parameter	Biking ( <i>n</i> = 7)	Non-biking ( <i>n</i> = 8)	<i>P</i> <sup>a</sup>
Attendance (%)	49.32 (6.30)	35.12 (5.15)	0.131
F Brooding (%)	36.59 (8.47)	25.46 (7.42)	0.257
F feeding nestlings (%)	4.19 (0.75)	3.83 (0.61)	0.998
F shading nestlings (%)	4.11 (1.74)	0.00 (0.00)	0.080
F perching/scanning (%)	0.91 (0.76)	3.38 (2.29)	0.252
M feeding F (%)	0.16 (0.09)	0.04 (0.02)	0.923
M feeding nestling (%)	3.27 (0.74)	2.19 (0.32)	0.705
M perching/scanning (%)	0.02 (0.02)	0.07 (0.41)	0.122
No. of F brooding bouts/day	16.82 (2.93)	24.60 (8.06)	0.345
Length of F brooding bout (min)	16.63 (5.72)	12.60 (4.38)	0.850
No. of F feeding nestling bouts/day	37.18 (6.53)	40.02 (10.34)	0.850
Length of F feeding nestling bout (min)	0.83 (0.15)	0.99 (0.28)	0.850
No. of F shading bouts/day	3.46 (1.60)	0.00 (0.00)	0.080
Length of F shading bout (min)	6.48 (2.78)	0.00 (0.00)	0.080
No. of F perch/scan bouts/day	4.34 (1.66)	7.48 (2.50)	0.257
Length of F perch/scan bout (min)	1.10 (0.95)	2.85 (1.91)	0.127
No. of M feeding F bouts/day	6.30 (4.67)	1.75 (0.63)	0.924
Length of M feeding F bout (min)	0.33 (0.13)	0.14 (0.05)	0.498
No. of M feeding nestling bouts/day	30.29 (10.54)	39.63 (12.41)	0.571
Length of M feeding nestling bout (min)	0.55 (0.12)	0.59 (0.20)	0.850
No. of M perch/scan bouts/day	3.71 (2.83)	1.38 (0.72)	0.772
Length of M perch/scan bout (min)	0.20 (0.17)	0.26 (0.15)	0.257

<sup>a</sup> *P*-value from Kruskal-Wallis test with 1 df.

**Table 9.** —Comparison of late nestling–stage parental behavior (mean [SE]) for female (F) and male (M) Golden-cheeked Warblers between biking and non-biking sites near Austin, TX and on Fort Hood, TX during spring 2002 and 2003. Behaviors were determined from video recordings during the late nestling stage and were based on daylight hours.

Parameter	Biking ( <i>n</i> = 9)	Non-biking ( <i>n</i> = 11)	<i>P</i> <sup>a</sup>
Attendance (%)	12.55 (4.80)	8.28 (1.56)	0.849
F Brooding (%)	2.27 (1.43)	0.88 (0.61)	0.105
F feeding nestlings (%)	2.81 (0.68)	2.85 (0.42)	0.732
F shading nestlings (%)	1.85 (1.19)	0.26 (0.26)	0.081
F perching/scanning (%)	2.32 (1.44)	1.98 (1.18)	0.542
M feeding nestling (%)	2.12 (0.40)	1.40 (0.29)	0.160
M perching/scanning (%)	0.99 (0.39)	0.21 (0.13)	0.158
No. of F brooding bouts/day	4.89 (2.84)	0.93 (0.65)	0.119
Length of F brooding bout (min)	2.42 (0.98)	1.61 (1.10)	0.399
No. of F feeding nestling bouts/day	35.55 (5.93)	44.19 (9.14)	0.425
Length of F feeding nestling bout (min)	0.59 (0.12)	0.51 (0.08)	0.514
No. of F shading bouts/day	3.30 (1.57)	3.52 (3.37)	0.141
Length of F shading bout (min)	3.01 (1.53)	1.24 (1.24)	0.122
No. of F perch/scan bouts/day	7.06 (2.78)	9.32 (3.80)	0.849
Length of F perch/scan bout (min)	1.21 (0.58)	1.00 (0.30)	0.848
No. of M feeding nestling bouts/day	26.67 (3.98)	32.05 (8.90)	0.790
Length of M feeding nestling bout (min)	0.60 (0.07)	0.36 (0.12)	0.366
No. of M perch/scan bouts/day	5.75 (1.65)	6.64 (3.09)	0.669
Length of M perch/scan bout (min)	0.81 (0.32)	0.20 (0.08)	0.182

<sup>a</sup> *P*-value from Kruskal-Wallis test with 1 df.

**Table 10.** — Composition of arthropod community collected from male Golden-cheeked Warbler territories at biking and non-biking sites near Austin, TX and on Fort Hood, TX during spring 2003.

Taxa	Percent of total number	
	Biking	Non-biking
Phalangida	0.06	0.00
Opilliones	0.06	0.00
Acarina	27.05	10.33
Araneida	31.33	25.11
Isopoda	0.00	0.11
Insecta	40.41	60.80
Orthoptera	1.21	1.87
Blattidae	0.23	0.05
Gryllidae	0.17	0.91
Tettigoniidae	0.29	0.32
Isoptera	0.64	0.00
Thysanoptera	14.10	22.16
Phloeothripidae	0.35	0.64
Thripidae	13.47	21.52
Hemiptera	0.52	1.50
Pentatomidae	0.12	0.38
Reduviidae	0.06	0.00
Homoptera	3.70	3.85
Aphididae	0.87	0.43
Cicadellidae	2.02	2.36
Fulgoridae	0.00	0.11
Membraeidae	0.00	0.21
Psyllidae	0.12	0.05
Neuroptera	0.29	0.21
Mantispidae	0.29	0.21
Coleoptera	2.60	2.36
Buprestidae	0.06	0.16
Cicinnellidae	0.58	0.21
Coccinellidae	0.23	0.21
Curculionidae	0.12	0.27
Scolytidae	0.00	0.52
Lepidoptera	0.93	2.62
Diptera	0.35	0.11
Asilidae	0.06	0.00
Hymenoptera	16.07	26.12
Formicidae	2.60	15.36
Platygasteridae	0.06	0.00

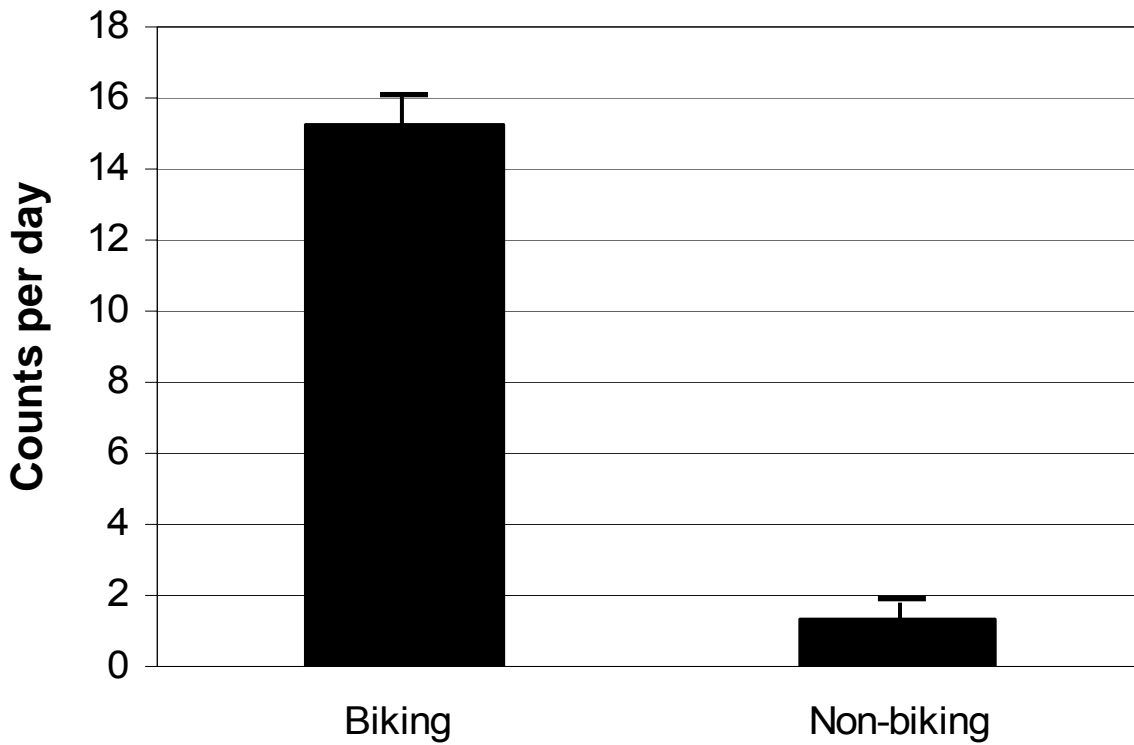
Table 10. Continued.

Taxa	Percent of total number	
	Biking	Non-biking
Pteromalidae	0.00	0.05

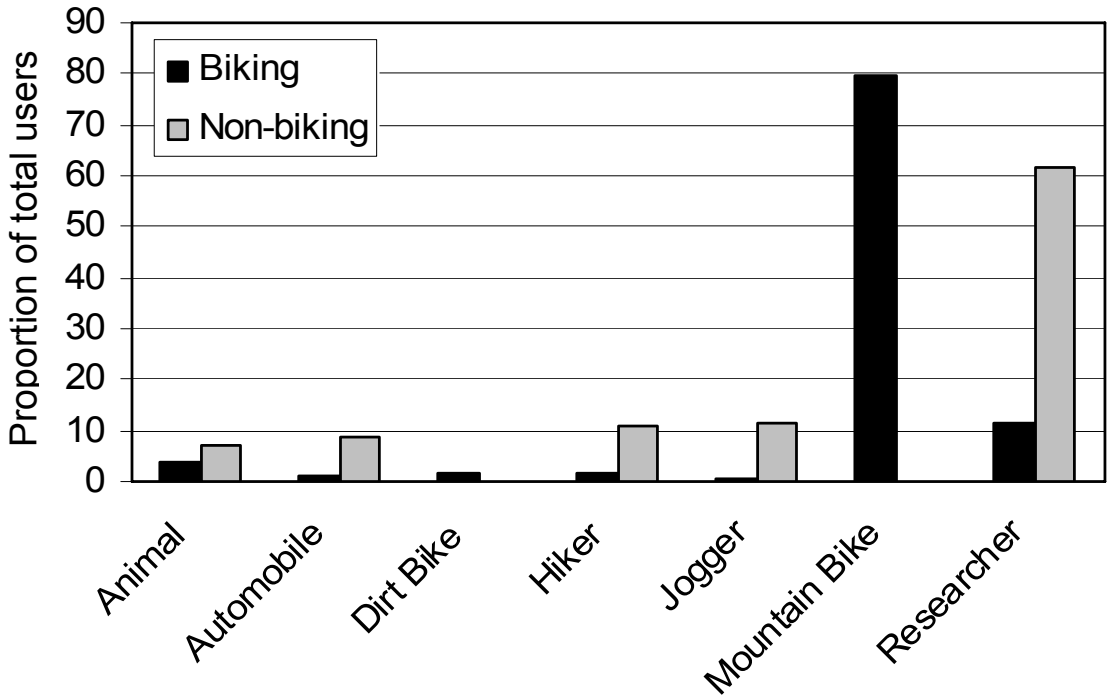
**Table 11.** —Total relative abundance (no./sweep-net sample) and relative abundance for the major orders of arthropods collected from male Golden-cheeked Warbler territories at biking ( $n = 12$  territories) and non-biking ( $n = 18$  territories) sites near Austin, TX and on Fort Hood, TX during spring 2003.

Taxa	Biking		Non-biking		$F^a$	$P$
	Mean	SE	Mean	SE		
Acarina	5.78	1.76	2.19	0.53	5.30	0.029
Araneida	6.69	1.12	5.33	0.83	3.36	0.077
Orthoptera	0.26	0.06	0.40	0.08	0.10	0.759
Thysanoptera	3.01	0.76	4.70	0.74	0.16	0.695
Hemiptera	0.11	0.04	0.32	0.09	1.68	0.206
Homptera	0.79	0.21	0.82	0.18	0.82	0.373
Coleoptera	0.56	0.14	0.50	0.10	0.95	0.337
Lepidoptera	0.20	0.06	0.56	0.12	1.73	0.199
Diptera	0.07	0.03	0.02	0.02	3.23	0.083
Hymenoptera	3.43	0.80	5.54	2.74	0.04	0.841
Total arthropod	21.36	3.45	21.23	3.32	1.02	0.320

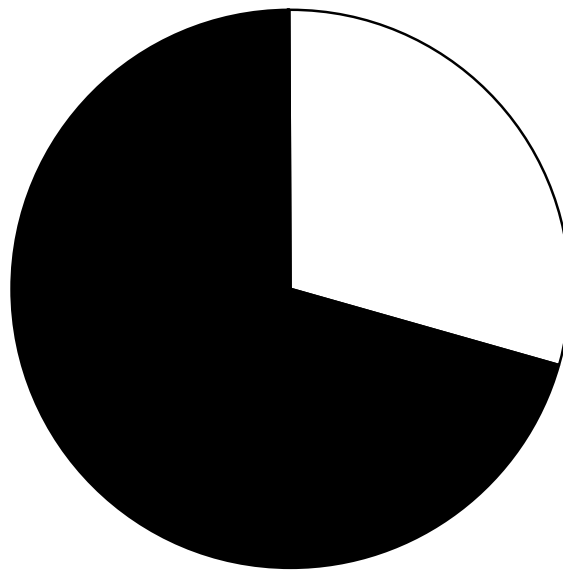
<sup>a</sup>  $F$  and  $P$  values for analysis of variance comparisons between biking and non-biking sites; 1, 28 df.



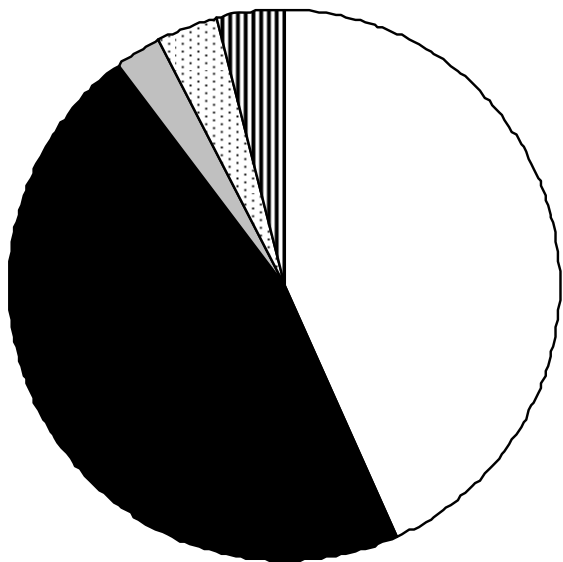
**Figure 1.** —Comparison of trail counts (mean  $\pm$  SE) between biking ( $n = 2$ ) and non-biking ( $n = 2$ ) sites near Austin, TX and on Fort Hood, TX during spring 2002 and 2003.



**Figure 2.**—Proportion of trail users at biking ( $n = 2$ ) and non-biking ( $n = 2$ ) sites near Austin, TX and on Fort Hood, TX during spring 2002 and 2003.



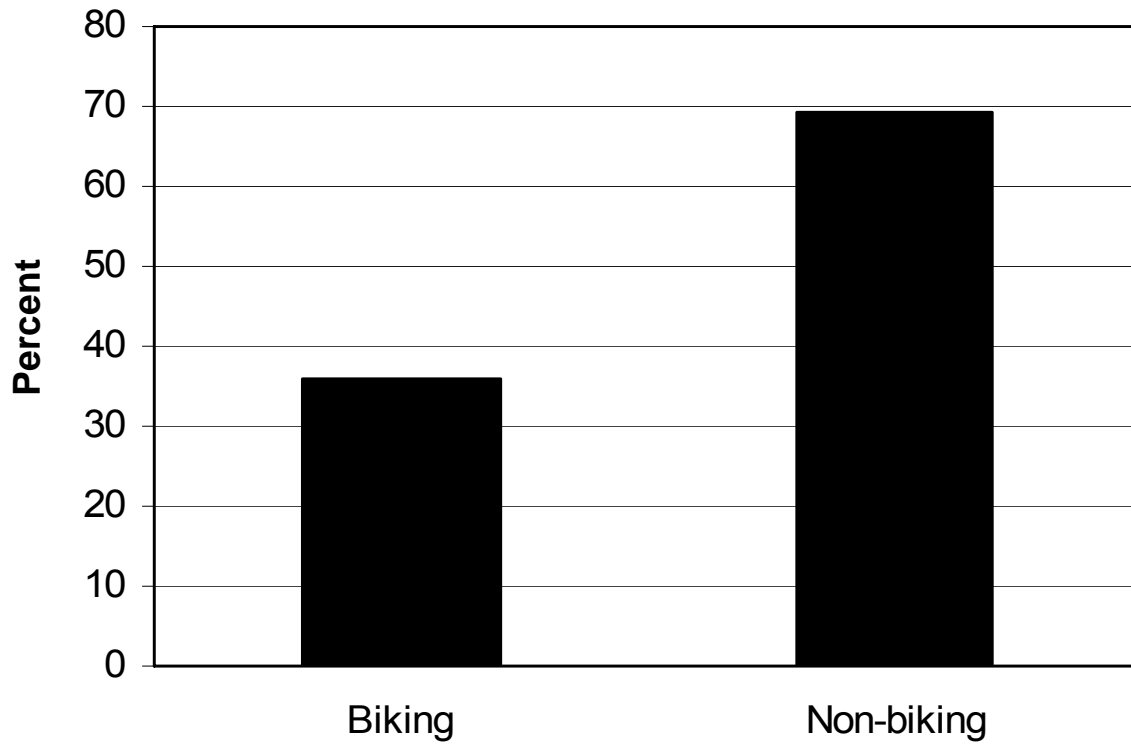
**Biking**



- Orthoptera
- Lepidoptera
- ▒ Araneida
- ▨ Ephemeroptera
- ▤ Neuroptera

**Non-biking**

**Figure 3.**—Aggregate percent of food items delivered by Golden-cheeked Warbler parents to nestlings at nests at biking (n = 8) and non-biking (n = 7) sites near Austin, TX and on Fort Hood, TX during spring 2002-2003.



**Figure 4.**—Mayfield nest success estimate for Golden-cheeked Warblers at biking ( $n = 33$  nests) and non-biking ( $n = 22$  nests) sites near Austin, TX and on Fort Hood, TX during spring 2002 and 2003.