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Analysis of fringed myotis (Myotis thysanodes), with a focus on Colorado distribution, maternity roost selection, and preliminary modeling of population dynamics

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UNIVERSITY OF NORTHERN COLORADO

Greeley, Colorado

The Graduate School

AN ANALYSIS OF FRINGED MYOTIS (*MYOTIS THYSANODES*), WITH A FOCUS ON COLORADO DISTRIBUTION, MATERNITY ROOST SELECTION, AND PRELIMINARY MODELING OF POPULATION DYNAMICS

A Dissertation Submitted in Partial Fulfillment
of the Requirements for the Degree of
Doctor of Philosophy

Mark Andrew Hayes

College of Natural and Health Sciences
School of Biological Sciences
Program of Biological Education

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This Dissertation by: Mark Andrew Hayes

Entitled: *An Analysis Of Fringed Myotis (*Myotis thysanodes*) With A Focus On Colorado Distribution, Maternity Roost Selection, And Preliminary Modeling Of Population Dynamics*

has been approved as meeting the requirements for the Degree of Doctor of Philosophy in College of Natural and Health Sciences in School of Biological Sciences, Program of Biological Education

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Date of Dissertation Defense ____

Accepted by the Graduate School

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ABSTRACT

Hayes, Mark, A. *An Analysis of Fringed Myotis (Myotis thysanodes) with a Focus on Colorado Distribution, Maternity Roost Selection, and Preliminary Modeling of Population Dynamics*. Published Doctor of Philosophy Dissertation, University of Northern Colorado, 2011.

The purpose of my research was to describe the distribution and roosting ecology of *Myotis thysanodes* in Colorado, and to initiate preliminary population dynamics modeling of the potential impacts of a changing climate on forest dwelling *Myotis* in the Southern Rocky Mountains. Seven hundred and twenty-nine Colorado capture and occurrence records of *M. thysanodes* were documented. I used 546 *M. thysanodes* records that included information about sex and reproductive status in an analysis of variance comparing elevational distribution among sex and reproductive classes. There were significant differences among reproductive classes, but not between sex classes. Sixteen actual or probable *M. thysanodes* maternity sites were identified in Colorado. In the maternity roost analysis using four landscape variables (elevation, grade, aspect, and proximity to permanent water), the model that incorporated grade and transformed aspect had most support using multi-model inference and Akaike's Information Criteria. In the maternity roost analysis using three roost-site variables (mean temperature, mean relative humidity, and estimated volume of the structure), the model that estimated volume of the roost structure had the most support. In preliminary Monte Carlo population simulations using three International Panel on Climate Change emissions scenarios, by year 2100 mean *Myotis* and *M. thysanodes* populations exhibited significant decreases from the original populations of 2,000 females in year 2000. All species specific *M. thysanodes* simulations exhibited at least 95 percent reduction by year 2100 from the original populations of 2,000 female bats in year 2000. An improved understanding of *M. thysanodes* distribution, roosting ecology, and the potential impacts of a changing climate can help inform conservation and resource management decisions in Colorado and elsewhere in the Rocky Mountain West.

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I would like to express my gratitude to the following people and organizations for giving their time and resources to improve and shape my research, conservation activities, and scholarship. The U.S. Department of Education's GAANN Doctoral Fellowship Program provided crucial financial support over several years. During the time that I was a GAANN Fellow, my doctoral education and experiences were significantly enhanced and I am grateful for the opportunity. The School of Biological Sciences also provided me with teaching assistantships and the School's director, Dr. Kitty Gardiner, and my major advisor, Dr. Rick Adams, were consistently helpful and creative in providing funding opportunities. The School's graduate committee was also helpful and Dr. Susan Keenan smoothed the path on several occasions. The UNC Chiropteran Research Laboratory, including Jason Shaw, Emily Snode, Matt Willey, Richard Carter, Bandon Bales, Katelin Craven, and Jessica Kiser provided insightful advice, support, and friendship. There would still be data loggers in one of the Poudre Canyon maternity roosts without the rappelling expertise of Matt and Jason.

The Colorado Wildlife Conservation Grant program, administered cooperatively by Colorado Division of Wildlife (CDOW) and U.S. Fish and Wildlife Service, was generous in supporting the field research detailed in this dissertation. Kirk Navo, a conservation biologist with CDOW, was consistently supportive of this project and

provided a wise and patient sounding board for ideas related to the management and conservation of bats in the Rocky Mountain West. The City of Boulder Open Spaces and Mountain Parks (OSMP) department and the Boulder County Parks & Open Spaces department also were generous with funding, support, and access to their properties. Ranger Burton Stoner has been a long-time advocate for bat conservation and research within City of Boulder's OSMP and his support, assistance, and dedication are very much appreciated. The U.S. Bureau of Land Management's Colorado Uncompahgre Field Office in Montrose provided support for field work in western Colorado in 2008 and 2009 and Missy Siders at BLM was especially helpful with support and encouragement. The Graduate School and Graduate Student Association at University of Northern Colorado supported this work and provided funding for travel to several annual meetings of the North American Symposium on Bat Research and biannual meetings of the Western Bat Working Group, and provided other field travel grants. Bill and Joanne Tyree and Tyree Designs provided a travel grant that helped immensely with field travel as gas prices increased over the course of the field work.

Professor Jodie Novak in the School of Mathematical Sciences welcomed me into a mathematical biology course and series of seminars she developed, and in so doing changed my perspective of mathematicians and pedagogy. School of Mathematical Sciences graduate students and professors Joe Champion, Nathan Wakefield, Dr. Stephanie Fitchett, and Dr. Anton Dzhamay were all very generous with their time, enthusiasm, knowledge, and skills. Joe Champion wrote most of the Mathematica code used to run the population modeling simulations presented in this dissertation. Without his patient assistance and enthusiasm, I would have accomplished much less. Dr. Jay Schaffer in the Applied Statistics and Research Methods program was helpful with his time in answering several key statistical questions. And I am thankful for Amy Yackel Adams, who catalyzed my understanding of the multi-model inference process used in much of my analysis. Any errors or oversights in application are mine.

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My family, too, has been consistently supportive of this work. I was lucky in being born into a family of educators and my motivation to contribute to public education is largely a product of their influence. From my wife's side of the family I have learned to be more settled in outdoor spaces, and take the time to be quite and observe, and pull out the nearest field guide. The knowledge, skills, enthusiasm, and care they exhibit for the natural world and the Colorado Rockies are an inspiration. And my wife, Lea' Bonewell, who is my constant companion in bat work and life, has been supportive in ways too numerous to mention. She remains the best naturalist I know and for me embodies naturalistic intelligence. Her insights have consistently challenged and re-shaped my thinking and any achievements I have are as much hers as they are mine.

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INTRODUCTION

Fringed myotis (*Myotis thysanodes*) is one of 33 Vespertilionid bat species and 16 *Myotis* species occurring in the United States and Canada (Wilson and Reeder 2005). The species was first described by Miller (1897) using bat specimens collected at Old Fort Tejon, Kern County, California. *M. thysanodes* is one of seven or eight bat species in the genus *Myotis* known to occur in Colorado (Armstrong et al. 1994, Fitzgerald et al. 1994, Adams 2003 describe seven species in Colorado; O'Shea et al. 2011 recognized an eighth species, *M. occultus*). *Myotis thysanodes* is a relatively large, insectivorous North American *Myotis* with long ears. The average mass of this species in Colorado is approximately 6-7 grams and the average ear length is 16-21 mm (Fitzgerald et al. 1994, Adams 2003). The key external feature that distinguishes it from other Colorado *Myotis* is the distinctive fringe of short, stiff hairs on the trailing edge of the uropatagium (interfemoral membrane). This species has a relatively narrow rostrum with a sagittal crest that is not well defined (O'Farrell and Studier 1980). Adult *M. thysanodes* have wings with low aspect ratio (wing-span^2 / wing surface area) and relatively low wing loading (wing area / mass) (O'Farrell and Studier 1980, Kiser 2008). These wing characteristics facilitate precise, maneuverable flight in forested habitat (Black 1974, O'Farrell and Studier 1980, Findley 1993, Kiser 2008).

M. thysanodes is considered a species of conservation concern in Colorado and in western North America. *M. thysanodes* is listed as a mammal of “greatest conservation concern” by the Colorado Division of Wildlife’s *2005 Comprehensive Wildlife Conservation Strategy* (Colorado Division of Wildlife 2005) and is listed as having low population status, with unknown population trends. The United States Forest Service lists *M. thysanodes* as a "sensitive species" in the Rocky Mountain Region (United States Forest Service 2006). At the 1998 meeting of the Western Bat Working Group in Reno, Nevada, the *Western Bat Species: Regional Priority Matrix* was produced (Western Bat Working Group 1998). This priority matrix defined 10 ecoregions for the western United States, and listed *M. thysanodes* as "red or high" priority in four of the regions and "yellow or medium" priority in six other regions. In 1994, *M. thysanodes* was designated as a Category 2 candidate for listing under the United States Endangered Species Act (United States Fish and Wildlife Service 1994). Since 1996 when the Category 2 Endangered Species Act designation was eliminated, *M. thysanodes* has been considered to be a "species of concern" in the western United States (United States Fish and Wildlife Service 1996, O'Shea et al. 2003), and some populations occur in areas of increased human development and pressure.

The Colorado Front Range is characterized by some of the most rapid urbanization in North America (Grimm et al. 2008), resulting in environmental modifications and habitat fragmentation (Magle et al. 2009), and is home to known *M. thysanodes* populations. Rapid urbanization has occurred from Pueblo to Fort Collins with the most expansive growth and development centered around Denver. Because the distribution of *M. thysanodes* coincides with this band of urbanization, this species may be impacted by increased recreational activity near roost sites and by changes in water resource availability caused by increased urban and agricultural water use. Furthermore, there has been increased concern regarding the impacts of anthropogenic and climate changes on water resources (Arnell 2004, Christensen and Lettenmaier 2006, Björk and Molau 2007, Kang and Ramírez 2007, Ray et al. 2008, Saunders et al. 2008, Auble et al. 2009) and on bats in the Southern Rocky Mountains (Adams and Hayes 2008, Adams 2010).

I have used the traditional five chapter format in this dissertation, with introduction, review of literature, methodology, analysis, and conclusions and recommendations chapters. My research describes three main projects, so I have organized each chapter to clearly address each of these projects. The first project describes the distribution of *M. thysanodes* in Colorado. The second project describes maternity roost selection by *M. thysanodes* in Colorado. And the third project conducts preliminary population dynamics modeling of the forest bat community in general, and *M. thysanodes* as a species, in relationship to current climate change scenarios along the Colorado Front Range.

Distribution

The distribution of *M. thysanodes* extends from southern British Columbia through the western United States to Central America (O’Farrell and Studier 1980, Wilson and Reeder 2005). This species may be relatively uncommon in Colorado and has been found in areas with physiographic relief in lower elevation areas of the Southern Rocky Mountains, in the tablelands of southeastern Colorado, several high plains sites, on the Colorado Plateau, and in the Wyoming Basin (Armstrong et al. 1994, Fitzgerald et al. 1994, Adams 2003). *M. thysanodes* appears to exist in low density populations throughout its Colorado range and has been observed associated with a relatively narrow band of ponderosa pine forests along the Colorado Front Range at elevations up to 2,400 meters (Armstrong et al. 1994, Adams 2003).

Armstrong (1972) included *M. thysanodes* as a member of the Chihuahuan Faunal Element with possible evolutionary origins in the basins and ranges of Chihuahua, Coahuila, and Durango, Mexico. Members of this faunal element generally have geographic distributions that bifurcate around the Southern Rocky Mountains with the higher elevations of mountain ranges, mountain parks and valleys, and the Continental Divide minimizing dispersal among populations on the eastern and western slopes of the Colorado Rockies. Armstrong et al. (1994), Fitzgerald et al. (1994), and Adams (2003) proposed distributions for this species that concurred with the Chihuahuan distribution hypothesis (Figure 1). However, a recent conservation assessment for this species in the Rocky Mountain region (Keinath 2004) implied a broader distribution for *M. thysanodes* in the Southern Rocky Mountains (Figure 1).

Despite a significant amount of bat research in Colorado during the last 15 years, no recent attempt has been made to update and evaluate the geographic distribution of *M. thysanodes* in Colorado and the Southern Rocky Mountain region. The last analysis of *M.*

thysanodes distribution occurrence data in Colorado was compiled and mapped by Armstrong et al. (1994) using approximately 23 occurrence records.

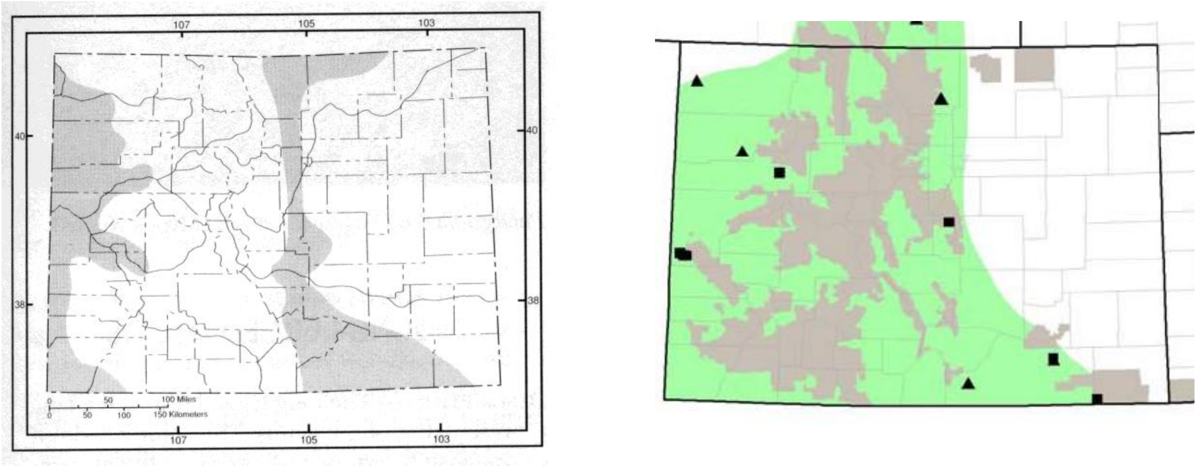


Figure 1. Maps of Colorado showing proposed distributions of *M. thysanodes*. The map at left expresses the Chihuahuan distribution hypothesis (Armstrong 1972, Armstrong et al. 1994, Fitzgerald et al. 1994, Adams 2003) and shows this species occurring in a narrow band along the Front Range and in western Colorado (grey shading) with these disjunct populations separated by the Continental Divide and high peaks of the Southern Rocky Mountains. This map is a scanned image from Fitzgerald et al. (1994). The map at right shows the distribution of *M. thysanodes* proposed by Keinath (2004). This distribution map represents a broad distribution and shows this species occurring throughout the Front Range, Southern Rocky Mountains, and western Colorado (green shaded areas indicate potential distribution and grey shading indicates USFS management units, most of which are within the green shading). This image is a copy of the distribution map for this species presented in Keinath (2004).

Maternity Roost Selection

Myotis thysanodes is known to roost in buildings (O’Farrell and Studier 1980), caves and mines (O’Farrell and Studier 1980, Navo et al. 1991, Navo 2001, Navo and

Krabacher 2005), tree snags (Rabe et al. 1998, Cryan et al. 2001, Weller and Zabel 2001), and rock crevices (Bogan et al. 1998, Cryan et al. 2001). Maternity roosts are found in a variety of substrates. Studier (1968) and Findley et al. (1975) reported maternity colonies using attics of buildings. Dalquest et al. (1990) reported finding a maternity colony of 300 females and young-of-the-year in an abandoned copper mine at the base of Black Mesa, which straddles the New Mexico-Oklahoma border and is about five miles from the Colorado state line. Weller and Zabel (2001) found that maternity colonies in northern California moved frequently, were generally located in Douglas-fir snags that on average had diameters larger than random snags, and were in forest stands with larger numbers of snags than random stands. Cryan et al. (2001) found maternity colonies in the Black Hills of South Dakota using both ponderosa snags (*Pinus ponderosa*) and rock crevices, with the majority of maternity roosts located in rock crevices. In mixed conifer forests in New Mexico, Bogan et al. (1998) found maternity colonies in rock crevices high on cliff walls.

Dr. Rick Adams and his students have identified several maternity colonies in rock crevices along the Colorado Front Range. Yet after radio-tracking females of this and other forest dwelling species (*Myotis ciliolabrum*, *M. evotis*, and *M. volans*), only rock crevice roosts were found (Adams 1996, 1997, 1998, 2000; Adams et al. 2003). These observations suggest two key questions regarding maternity roost-site selection by *M. thysanodes* along the Colorado Front Range: (1) Does this area provide a unique set of geomorphic features in the form of flatirons and other rock formations that provide preferred maternity roosts for *M. thysanodes*? (2) Do maternal *M. thysanodes* use rock crevices as roost sites because this area lacks adequate microclimates and refugia in ponderosa pine (*Pinus ponderosa*) and Douglas-fir snags (*Pseudotsuga menziesii*)?

Anthropogenic changes along the Front Range may significantly affect the availability of suitable *M. thysanodes* maternity roosts. Increasing urbanization has lead to habitat disturbance, including recreational rock climbing, which may deter use of rock crevices for maternity roost sites by *M. thysanodes*. Deforestation in the late 1800s and early 1900s, forest habitat fragmentation, and certain forest management practices (for example, removal of snags and ongoing forest thinning to reduce wood fuel), may also have significantly impacted maternity roost site availability. Further, long-term regional climate change could significantly impact the distribution of *M. thysanodes* maternity colonies availability by altering microclimates within traditionally used roost sites. Wildlife managers, researchers, and conservationist biologists have emphasized the need for more detailed information about the roosting preferences and needs of *M. thysanodes* in Colorado. For example, the Colorado Bat Conservation Plan (Ellison et al. 2003) ranked Colorado bats using a conservation priority score for each species. In this ranking, *M. thysanodes* received the second highest score of all Colorado bat species (after Townsend's big-eared bat, *Corynorhinus townsendii*). The Colorado Bat Conservation Plan emphasized the need to fill significant gaps in knowledge concerning the roost preferences of this species in Colorado (Ellison et al. 2003).

This maternity roost selection project is designed to evaluate three hypotheses about *M. thysanodes* roost use in Colorado:

H1 Warm Roost & Proximity to Water Hypothesis

H2 Rock Crevice Preference Hypothesis

H3 Rock Crevice Fidelity Hypothesis

With the Warm Roost & Proximity to Water Hypothesis (H1) I proposed that the key variables influencing *M. thysanodes* maternity roost location is warm, stable microclimates within the roost and proximity to suitable water resources, both variables that should significantly influence the ability of mothers to raise healthy pups that survive to volancy. I predicted that *M. thysanodes* maternity roosts will be warmer and closer to permanent water resources than randomly-selected potential roost sites. I evaluated this hypothesis by collecting and analyzing data on all known *M. thysanodes* maternity sites in Colorado and comparing these data to randomly selected potential roost sites.

With the Rock Crevice Preference Hypothesis (H2) I proposed that where there is a suite of potential roost sites available, including rock crevice roosts and ponderosa pine and/or Douglas-fir snags (*P. ponderosa* and *P. menziesii*), *M. thysanodes* maternity roosts will tend to be found in rock crevices rather than in tree snags and other roost types. I predicted that *M. thysanodes* maternity roosts will be found more frequently in rock crevices than predicted by chance. I evaluated this hypothesis by radio-tracking reproductive females to roost sites along the Front Range. I looked for mist-netting locations that had both potential crevice roosts in rocks and ponderosa and/or Douglas-fir snags nearby.

With the Rock Crevice Fidelity Hypothesis (H3) I proposed that *M. thysanodes* maternity colonies will exhibit higher roost fidelity to rock crevices than to roost sites in tree snags since tree snags are generally more ephemeral than rock substrates. I predicted that radio-tagged reproductive female *M. thysanodes* using rock crevices would switch roosts less frequently than bats using other roost types and also in comparison to snag roost-switching frequencies reported by Weller and Zabel (2001) and Cryan et al. (2001). This hypothesis was evaluated by comparing roost switching data from radio-tagged bats in this study to roost-switching data from other studies.

Population Modeling and Climate Change

The potential impacts of a changing climate on wildlife species in arid and semi-arid parts of western North America is of increasing concern to conservation and wildlife biologists, ecologists, resource managers, and policy makers. Christensen and Lettenmaier (2006) used the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES; Nakicenovic and Swart 2000, IPCC 2007) to investigate the potential impacts of a changing climate on water resources of the Colorado River Basin. Christensen and Lettenmaier (2006) concluded that average mean temperatures in the Colorado River Basin are likely to increase under all four families of SRES emission scenarios, with increases of 1.2 - 4.4 °C for the A2 scenario family, which assumes increased emphasis on global economic expansion and globalization. These researchers also concluded that increases of 1.3 - 2.7 °C are likely for the B1 scenario family, which assumes an increased emphasis on environmental sustainability and regional economic development (Christensen and Lettenmaier 2006, Nakicenovic and Swart 2000). Christensen and Lettenmaier (2006) also concluded that the summer months in the Colorado River Basin are likely to experience modestly decreased precipitation, reduced surface water availability, and decreased reservoir storage. Kang and Ramírez (2007) developed climate and hydrological models to investigate the impact of a changing climate on stream flows in the South Platte watershed. These researchers used the IPCC SRES B2 climate change scenario family, which, as with scenario B1, assumes an increased emphasis on environmental sustainability, but assumes continued economic globalization with an emphasis on growth (Nakicenovic and Swart 2000). Kang and Ramírez concluded that the South Platte watershed, which includes much of the Colorado Front Range, and our study area in Boulder and Larimer counties, will experience significantly increased mean summer temperatures and more variable precipitation and stream flow runoff. Saunders et al. (2008) emphasized that areas of the interior western United States are likely to become hotter and drier in the coming century. Other researchers and policy analysts have emphasized the need to analyze the potential impacts of a changing climate and water resource availability on wildlife, ecosystems, and economic development in the Rocky Mountain West (see for example: USGS 2007; Ray et al. 2008; Auble et al. 2009).

Due to their slow reproductive rates, high rates of evaporative and respiratory water loss, and need for constant access to high quality water resources, temperate zone insectivorous bats may be particularly susceptible to a warmer, drier climate in the Rocky Mountain West. Adams and Hayes (2008) investigated the potential impacts of water availability on reproductive female *M. thysanodes* in our study area at Heil Valley Ranch, Boulder County, Colorado. We presented a mathematical model demonstrating that climate warming, and the resulting loss of natural surface water, may result in reduced reproductive output and lactation by bats in arid western landscapes. Adams (2010) analyzed 13 years of bat capture data from Boulder County, Colorado, and concluded that female reproductive rates of forest-dwelling *Myotis* declined by up to 50% in drier years when stream flows and water availability were significantly reduced.

The rationale for initiating population modeling to analyze the relationships between climate change and population trends of Colorado forest bats as a community, and *M. thysanodes* in particular, is prompted by the need to better understand the potential impact of a changing climate in the Southern Rocky Mountains on ecosystems in general, and bat populations in particular. Adams' (2010) observations of reproductive rates varying significantly with abiotic factors, such as mean summer temperature and stream flows, provides the impetus to integrate these observations into stochastic population dynamics models and use computer simulations to investigate the potential impacts of regional climate change on bat population trends.

Synthesis

As Turchin (2003) has emphasized, ecological phenomena can be studied from multiple methodological perspectives. Historical data collected by previous field biologists and naturalists can be compiled and synthesized to compare with contemporary ecological patterns. Observational and field studies can be designed to investigate specific hypotheses. Long-term empirical time series data can be analyzed statistically to seek patterns in the data. And mathematical models and computer simulations can be used to evaluate current hypotheses, develop new conjectures and hypotheses, better understand ecosystem processes, and predict long term ecological change. The overarching goal of my research has been to combine these approaches to better understand the ecology of forest-dwelling bats in the Southern Rocky Mountains. The distribution component of my project strives to synthesize all available historical and current data on *M. thysanodes* in Colorado with the goal of better understanding the state-wide distribution of this species. The roost selection component of my project uses observational and field methods to better understand where *M. thysanodes* maternity colonies are found, and the abiotic characteristics of these sites. The population modeling component of my project strives to use historical records and time series data, combined with statistical analysis, mathematical models, and computer simulations to establish a framework for analyzing the potential impacts of a changing climate on forest bat populations in the Southern Rocky Mountains. My hope is that by combining these approaches some progress can be made in developing a better understanding of the ecology of *M. thysanodes* in Colorado.

CHAPTER II

REVIEW OF LITERATURE

A number of mammalogists and bat researchers have conducted basic survey work and research in Mexico, United States, and Canada, and made observations on the ecology and distribution of *M. thysanodes* in North America. I present this review of literature in the following sections: general ecology and conservation status; distribution of *M. thysanodes*; maternity roosting ecology of *M. thysanodes*; and population dynamics. In the section describing the distribution of *M. thysanodes,* I discuss the literature from a regional perspective, describing observations of this species, for example, in Mexico, the southwestern United States, the Great Plains, etc. This literature review emphasizes observations of *M. thysanodes* in the western United States and especially in the Rocky Mountain West, and those documents that discuss distribution, roost selection, and other aspects of the ecology of this species relevant to my research. I have also strived to provide a reasonably comprehensive historical review of the literature related to maternity roosting ecology of *M. thysanodes*. I conclude the review of literature with a discussion of population dynamics relevant to *M. thysanodes.*

From 1968 to 1980, Eugene Studier, Michael O'Farrell, and their colleagues and students, published 15 academic papers investigating and reviewing various aspects of the biology of *M. thysanodes* and other bat species in the southwestern United States.

Studier (1968) described a large maternity colony of *M. thysanodes* roosting in the Montezuma Seminary in Montezuma, New Mexico. This colony became a key resource for Studier and O'Farrell's research on this species over the following decade. Ewing, Studier, and O'Farrell (1970) described autumn fat deposition and body composition, and O'Farrell and Studier (1970) investigated fall metabolism of *M. thysanodes* and two other *Myotis* species. Studier et al. (1970) studied weight loss due to evaporative and respiratory water loss during day roosting by *M. thysanodes* in the Montezuma Seminary maternity roost. Studier (1970) presented a review of evaporative water loss in bats and described results for *M. thysanodes.* O'Farrell et al. (1971) described energy and water balance in *M. thysanodes* and *M. lucifugus.* Studier and O'Farrell (1972) studied thermoregulation in *M. thysanodes* and *M. lucifugus.* O'Farrell and Studier (1973) described reproduction and development in *M. thysanodes* and *M. lucifugus.* Studier et al. (1973) investigated the energetics of pregnancy and lactation in *M. thysanodes* and *M. lucifugus.* O'Farrell and Studier (1975) described population structure and activity patterns of the *M. thysanodes* maternity colony at the Montezuma Seminary. Hirshfeld and O'Farrell (1976) compared body temperatures and warming rates in seven bat species, including *M. thysanodes,* in southern Nevada. O'Farrell and Studier (1976) described seasonal variations in body composition, organ weights, and wing loadings in *M. thysanodes* and *M. lucifugus* from the Montezuma Seminary maternity colony. Studier and O'Farrell (1976) described various aspects of the physiology of *M. thysanodes* and *M. lucifugus,* including metabolic and evaporative water loss rates, heart and breathing rates, and other aspects of energetics. In 1978, Studier and O'Farrell presented a synthesis of their research and thinking in the paper "Physiological Ecology of *Myotis*", presented at the Fifth International Bat Research Conference in Albuquerque, New Mexico (Studier and O'Farrell 1978). To my knowledge, the last publication Studier and O'Farrell completed together on *M. thysanodes* is the American Society of Mammalogists Mammalian Species Monograph on *M. thysanodes* (O'Farrell and Studier 1980). In the development of knowledge about *M. thysanodes* there is the period before Studier and O'Farrell and the period after Studier and O'Farrell; their contributions to knowledge of this species are incomparable.

Findley (1972) reviewed the taxanomic and phylogenetic relationships among the *Myotis* species and discussed the functional significance of body size, appendage length, wing shape, ear size and shape, and uropatagial configuration among the *Myotis*. Findley (1972) included *M. thysanodes* in the guild of surface-gleaning bats. Findley and Wilson (1982) discussed the stiff fringe of hairs on the trailing edge of the uropatagium of *M. thysanodes*, and proposed that these hairs act to help capture small insect prey. Glass and Gannon (1994) described a newly identified muscle along the trailing edge of the uropatagium in *M. thysanodes,* which they named *M. uropataginalis,* and suggested that this muscle along the edge of the uropatagium and its fringe of hair may play a role in prey capture.

O'Farrell and Studier (1980) concluded that maternity colonies of *M. thysanodes* are especially susceptible to human disturbance. *M. thysanodes* is considered a species of conservation concern in western North America, and is listed as a species of “greatest conservation concern” by the Colorado Division of Wildlife’s *2005 Comprehensive*

Wildlife Conservation Strategy (Colorado Division of Wildlife 2005). In Colorado, this species is suspected of having low population status, with unknown population trends. The United States Forest Service lists *M. thysanodes* as a "sensitive species" in the Rocky Mountain Region (United States Forest Service 2006). At the 1998 meeting of the Western Bat Working Group in Reno, Nevada, the *Western Bat Species: Regional Priority Matrix* was produced (Western Bat Working Group 1998). This priority matrix defined 10 ecoregions for the western United States, and listed *M. thysanodes* as "red or high" priority in four regions and "yellow or medium" priority in six regions. In 1994, *M. thysanodes* was designated as a Category 2 candidate for listing under the United States Endangered Species Act (United States Fish and Wildlife Service 1994). Since 1996 when the Category 2 Endangered Species Act designation was eliminated, *M. thysanodes* has been considered to be a "species of concern" in the United States (United States Fish and Wildlife Service 1996, O'Shea et al. 2003).

Distribution

Miller and Allen (1928) presented a distribution map of *M. thysanodes* in which they described the species occurring from the highlands of Oaxaca, Mexico, northward throughout New Mexico, Arizona, Utah, Nevada, and occupying western California and Oregon, southern Idaho, and the southwestern portion of Colorado. The current known distribution of *M. thysanodes* extends from just south of the Isthmus of Tehuantepec north through central Mexico associated with the western slopes of the Sierra Madre Oriental, the Central Plateau, and the eastern slopes of the Sierra Madre Occidental, and throughout the western and southwestern United States to southern British Columbia (O’Farrell and Studier 1980, Wilson and Reeder 2005).

There are currently three recognized subspecies of *M. thysanodes* (O'Farrell and Studier 1980, Wilson and Reeder 2005). O'Farrell and Studier (1980) recognized *M. t. aztecus* as being generally associated with the Isthmus of Tehuantepec region. Jones and Genoways (1967) described *M. t. pahasapensis* as being associated with the Black Hills region of South Dakota and Wyoming. The remaining populations of *M. thysanodes* are considered to be all the same subspecies, *M. t. thysanodes* (O'Farrell and Studier 1980, Wilson and Reeder 2005).

The following presents a review of the distribution of *M. thysanodes* in six areas of North America: Mexico; the southwestern portion of the United States including Arizona, New Mexico, and Texas; the Great Plains region; Colorado; Wyoming and South Dakota; and Utah and Nevada. I have not reviewed the literature related to the distribution of *M. thysanodes* in California, the Pacific Northwest region of the United States or in Canada.

Mexico - Findley (1969) discussed the habitat relationships of six species of *Myotis*, including *M. thysanodes*, associated with the Sonoran and Chihuahuan deserts. Jones et al. (1970) compiled information about this species from western Mexico. Anderson (1972) produced his monograph on the distribution and taxonomy of the mammals of Chihuahua, Mexico, and reviewed what was known about *M. thysanodes* from this region. Watkins et al. (1972) discussed bats of the Mexican state of Jalisco and described *M. thysanodes* records known to them from this region. Easterla and Baccus

(1973) described capturing *M. thysanodes* during field work in the Fronteriza Mountains of the Mexican state of Coahuila. Generally, *M. thysanodes* in Mexico has been associated with the conifer forests and shrublands of the mountains and canyon landscapes of northern Mexico.

Southwest (Arizona, New Mexico, Texas) - Bailey (1931) discussed records of, and collecting, this species in New Mexico, and provided an account of collecting 87 specimens from a maternity colony in the Cloverdale Hills west of the Animas Valley. Jones (1965, 1966) conducted bat capture work at five locations in west-central New Mexico from 1957 through 1965 and captured 85 *M. thysanodes*. Judd (1967) observed this species in Big Bend National Park, Texas, and in Fern Canyon, Chihuahua, Mexico. Jones and Suttkus (1972) described 11 years of capture data and observations on 19 bat species, including *M. thysanodes,* related to bat capture work in western New Mexico. Findley et al. (1975) gave an overview of this species and a map of specimen localities in New Mexico. Hoffmeister (1986) gave a synopsis of *M. thysanodes* in Arizona and provided a map of specimen localities in the state. Findley (1987) provided a revised review of the mammals of New Mexico and discussed the *Myotis* that use a gleaning foraging strategy, including *M. thysanodes*. Findley concluded that "*Myotis thysanodes* tends to occur at lower elevations...and is most common from the piñon-juniper zone down into the desert" (1987; page 46). Berna (1990) conducted bat capture work on Arizona's Kaibab Plateau and provided capture information on *M. thysanodes* in his study area. Bogan et al. (1998) studied the bats at Los Alamos National Laboratories and Bandelier National Monument in the Jemez Mountains of New Mexico, and described radio-tracking *M. thysanodes* to roosts in high rock faces and described other aspects of the biology and ecology of this and other species in their study area. Valdez et al. (1999) captured *M. thysanodes* in the middle Rio Grande Valley at the Bosque del Apache National Wildlife Refuge. Chung-MacCoubrey and DeLay (2000) reported the presence of *M. thysanodes* in piñon-juniper woodlands of the Gallinas Mountains in western New Mexico, and found maternity colonies primarily in dead ponderosa pine (*Pinus ponderosa*) snags, occasionally using piñon (*Pinus edulis*) and juniper (*Sabina* spp.) trees as roosts, and one large maternity colony of at least 200 individuals in an abandoned mine adit. Chung-MacCoubrey (2005) studied the use of piñon-juniper woodlands by bats in west-central New Mexico, and includes a discussion of roost physiology related to female reproductive success. Ellison et al. (2005) used bat acoustic detection and recording technology to study bat activity patterns in Bandelier National Monument and recorded *M. thysanodes* using lower elevation and canyon bottom areas, open shrub habitat with scattered stands of ponderosa pines, piñon-juniper woodlands, and forested areas with mixed conifers. Of six *Myotis* species detected during her study, *M. thysanodes* was the least commonly identified species.

Great Plains - Jones et al. (1983, 1985) described *M. thysanodes* as occurring in the Badlands of South Dakota, the Pine Ridge escarpment, Wildcat Hills, and forested buttes, tablelands, and canyons of western Nebraska. Dalquest et al. (1990) compiled records and conducted a zoogeographical analysis of the mammals at the interface between the Southern Rocky Mountains and the Great Plains in the tri-State region of Colorado, New Mexico, and Wyoming. In this document, Dalquest et al. (1990) reported finding a maternity colony of about 300 *M. thysanodes,* as well as 100 *M. yumanensis,* 200 *Corynorhinus townsendii,* and 50 *Tadarida brasiliensis*, in an abandoned copper mine on the base of Black Mesa. Geluso (2002) compiled records of mammals from northeastern New Mexico where there is a mixture of grasslands, shrublands, and conifer woodlands associated with the mesas, canyons, river breaks, and badlands east of the Sangre de Cristo Mountains. Geluso (2002) reported capture records of *M. thysanodes* from small water resources associated with the conifer woodlands of this area, and suggested that this species may often be associated with broken and scattered woodlands on the High Plains.

Colorado **-** Anderson (1961) described the first *M. thysanodes* specimen collected at Mesa Verde National Park in Colorado. In 1972, Armstrong's *Distribution of Mammals in Colorado* listed four records of *M. thysanodes* from the state. In this monograph, Armstrong included *M. thysanodes* as one of twenty-eight Colorado mammalian species from the Chihuahuan Faunal Element. Armstrong concluded that all mammals in the Chihuahuan Faunal Element had distributions with "...a single predominant center of distribution generally concordant with the basin and range region of Chihuahua, western Coahuila, and northern Durango", Mexico (Armstrong 1972; page 357). Armstrong mapped the known distributions of the 28 Chihuahuan species (1972; page 358). This map shows the members of the Chihuahuan Faunal Element generally occurring in southeastern, southwestern, and western Colorado, and along the Front Range of the Southern Rocky Mountains. Armstrong concluded that "...at most, a single member of the Chihuahuan Faunal Element (*Plecotus [=Corynorhinus] townsendii*) crosses the Continental Divide in Colorado" (Armstrong 1972, page 358).

Finley et al. (1983) conducted a survey of the mammals of northwestern Colorado and reported a specimen of *M. thysanodes.* Freeman (1981) conducted a statewide survey of bats in Colorado and during four field seasons and more than 175 nights of capture work, captured only five *M. thysanodes*, all from "pygmy" conifer woodlands. Freeman (1984) investigated the ecology and potential niches and competition among an assemblage of 11 bat species, including *M. thysanodes,* near Elk Springs, Moffat County, in northwestern Colorado. He used 22 morphological niche characteristics and principal component analysis and other quantitative techniques to evaluate niche characteristics. Freeman concluded that a significant amount of variation among these species was accounted for using three niche components: body size, method of food capture and foraging style, and hardness of diet (Freeman 1984). During this work, however, Freeman captured only three *M. thysanodes,* which with *M. lucifugus,* were the least frequently captured species during the study. Freeman also conducted dietary analysis of stomach contents of bats captured, and identified at least seven insect orders in *M. thysanodes* stomachs: Lepidoptera, Diptera, Coleoptera, Hemiptera, Hymenoptera, Tricoptera, and at least one other insect order. Fitzgerald et al. (1989) provided an abstract of new bat capture records from northeastern Colorado, which included two records of *M. thysanodes* captured near the Pawnee Buttes in Weld County (1 lactating female from August 1985 and 1 adult male from June 1988). Fitzgerald et al. (1989) tentatively assigned both specimens to the subspecies *M. t. pahasapensis,* which had been considered restricted to the Black Hills region of South Dakota and Wyoming. Armstrong et al. (1994) published *Distribution and Ecology of Bats of Colorado,* in which they reported 13 location records of *M. thysanodes* in Colorado, with each record consisting of a museum specimen, and 9 additional records of this species in the state. These authors concluded that "Coloradan records are scattered at moderate elevations (about 1,500 - 2,400 meters) on either side of the Continental Divide" (1994, page 17). Fitzgerald et al. (1994) proposed a distribution map for *M. thysanodes* that is bifurcated around the Southern Rocky Mountains (page 105), suggesting inexplicitly that populations of this species along the Colorado Front Range may be contiguous with populations in the Black Hills region of Wyoming and South Dakota.

In the early 1990’s, the Colorado Division of Wildlife’s Bats/Inactive Mines Project (B/IMP) began surveying abandoned mines throughout Colorado looking for important bat roosts (Navo et al. 1991, Navo and Krabacher 2005). As of January 2010, B/IMP biologists had conducted over 3,100 capture and internal surveys at abandoned mines (Navo, personal communication). During 2010, oversight of the B/IMP project was transferred from Colorado Division of Wildlife to the Colorado Natural Heritage Program. The B/IMP project maintains a database of mine-site capture records and likely contains the most comprehensive data set of *M. thysanodes* associated with abandoned mines in North America (K. Navo, personal communication). The Colorado Division of Wildlife also maintains records of bat captures associated with research and collection permits administered by the Colorado Division of Wildlife.

From 2000 to 2005, the Fort Collins Bat Study conducted extensive mist-netting in the Fort Collins area and in the foothills west of Fort Collins in an effort to study the disease ecology of big brown bats (*Eptesicus fuscus*) associated with an urban environment (O'Shea 2004, 2010). The Fort Collins Bat Study maintained a database of capture records that included information about *M. thysanodes* captured during mist-netting surveys (O'Shea, personal communication). The U.S. Geological Survey's Biological Research Division has also conducted extensive survey work over several years on the bats of Mesa Verde National Park and has actively sought information on *M. thysanodes* (Chung-MacCaubrey and Bogan 2003, O'Shea et al. 2011). During 2006 and 2007, O'Shea et al. (2011) conducted extensive bat capture and radio-tracking work in Mesa Verde National Park, and provided a detailed discussion of roosting ecology, female reproductive rates, and species composition.

Siemers (2002) conducted bat surveys at 99 caves in Colorado, and did not find or capture *M. thysanodes.* Chung-MacCoubrey and Bogan (2003) conducted bat survey work in the Mesa Verde region and piñon-juniper woodlands of southwestern Colorado, and provided a brief review of each species known to occur in Mesa Verde National Park, including *M. thysanodes*. Siemers et al. (2003) and Siemers and Schorr (2006, 2007) conducted small mammal and bat survey work in latitude/longitude blocks in Colorado, including along the Front Range of Colorado, in northwestern and southwestern Colorado and documented *M. thysanodes* captured in mist-nets at several locations. Schorr (2006) conducted bat capture work in North Park in Jackson County, Colorado, and did not document *M. thysanodes.*

Dr. Rick Adams has been studying the forest bats of the foothills and mountains of Boulder County, Colorado, since 1995. This work has included efforts to better understand the ecology of *M. thysanodes,* including descriptions of the use of water resources (Adams and Simmons 2002, Adams et al. 2003, Adams and Thibault 2006, Adams and Hayes 2008) and identification of roosting locations (Adams and Thibault 2006), and other questions related to the ecology of *Myotis* species along the Colorado Front Range (Kiser 2008, Wiley 2010).

In Colorado, *M. thysanodes* is found in coniferous woodlands and shrublands (Armstrong et al. 1994, Fitzgerald et al. 1994, Adams 2003). Armstrong et al. (1994) categorized Colorado bat species into nine ecogeographical faunal districts and associated *M. thysanodes* with Raton, Rocky Mountains, Wyoming Basin, Grand Valley, and Dolores-San Juan faunal districts. Armstrong et al. suggest that *M. thysanodes* appears to exist in low density populations throughout its range and has been observed associated with a relatively narrow band of ponderosa pine forests along the Colorado Front Range at elevations up to 2,400 meters (Armstrong et al. 1994).

Wyoming & South Dakota - Bole (1935) and Jones and Genoways (1969) discussed aspects of morphology and natural history of *M. t. pahasapensis* in the Black Hills region of South Dakota and Wyoming. Turner and Davis (1969) and Choate and Anderson (1997) also discussed records of *M. t. pahasapensis* in the Black Hills of South Dakota. Boyce (1980) described the first recorded *M. thysanodes* specimen from the Laramie Mountains in southeastern Wyoming. Cryan (1997) conducted research on the bats of the Black Hills in South Dakota and included information on the roosting behavior and distribution of *M. thysanodes.* Bogan and Cryan (2000) completed a review of the bats of Wyoming, and concluded that the *M. thysanodes* in eastern Wyoming were *M. t. pahasapensis.* Bogan and Cryan also note that, at the time, there were no known maternity colonies of *M. thysanodes* in Wyoming. Cryan et al. (2000) evaluated the distribution of bats in the Black Hills region of South Dakota and concluded that reproductive female *M. thysanodes* in their study area were more likely to occur at lower elevations than non-reproductive females and males. Keinath (2003) produced a *M. thysanodes* species assessment for the Wyoming office of the U. S. Bureau of Land Management. Keinath (2004) also produced a technical conservation assessment for *M. thysanodes* for the Rocky Mountain Region of the U. S. Forest Service.

Utah and Nevada - Foster et al. (1997) conducted an inventory of the bats in forested areas in southern and central Utah, and documented *M. thysanodes* in Bryce Canyon National Park and Manti-La Sal National Forest. Mollhagen and Bogan (1997) conducted bat survey work from 1993 to 1996 in the Henry Mountains of southeastern Utah, and captured *M. thysanodes* at 10 locations ranging from 1,295 to 2,713 meters elevation. Williams et al. (2006) conducted bat capture and acoustic recording in riparian areas associated with the Muddy River in southern Nevada and documented acoustic recordings of *M. thysanodes* using the study area. However, *M. thysanodes* was the least frequently recorded bat of 15 species detected during the study.

Maternity Roost Ecology

Myotis thysanodes is known to roost in buildings, caves and mines, rock crevices, trees and snags, and maternity colonies of a few to hundreds of individual bats have been reported. In this review of publications related to maternity roosting ecology of *M. thysanodes*, I review the literature in which maternity roost sites of this species are noted, organized by roost substrate. The roost substrate categories I use are: buildings, caves, mines, rock crevices and cavities, and trees and snags. Within the category of buildings, I include any structure built by humans that is relatively permanent and intended for occupation by humans and/or other animals, such as houses, churches, and out-buildings such as shacks and barns. Within the category of caves, I include any structure described as a cave in the literature, on a map, or named as a cave by a land management agency. Within the category of mines, I include any mining structure described as a mine in the literature, on a map, or named as a mine by a land management agency; mines that are abandoned and no longer used for mineral or commodity extraction are described as abandoned mines. Within the category of rock crevices and cavities, I use the following definitions of Bogan et al. (2003, page71), applied to rock substrates only and repeated here as a bulleted quotation:

- Cavity. A hollow space, typically of small size (e.g., <1 m^3), and occurring in...rocks, or cliffs. These do not include caves.
- Crevice. A crack forming an opening in a substrate, such as a cliff...
- Rock shelter. Shallow caves of small size (e.g., < 5-10 m^3), usually moderately well-lighted and distinguished from larger caves by lack of complexity.

Within the category of trees and snags, I include living and dead trees, and use the following description of snag (USFS 1983, frontispiece), repeated here as a quotation:

> Some...birds excavate nesting holes, use cavities resulting from decay, or use holes created by other species in dead or deteriorating trees. Such trees, commonly called snags, are similarly important to numerous species.

Buildings

Myotis thysanodes was first described by Miller (1897) and the type locality is Old Fort Tejon, Kern County, California. The *M. thysanodes* type location is notable in relation to maternity roost selection because Miller's species description includes the following account by Dr. T. S. Palmer. This account describes one of the largest documented *M. thysanodes* maternity colonies of which I am aware:

> In July, 1891, while one of the parties of the Death Valley Expedition was collecting at Old Fort Tejon, California, several species of bats were observed. The most abundant was a small *Vespertilio* (=*Myotis*), which could be seen at dusk flying about the oak trees near the old barracks in great numbers, and passing in and out of the ruined buildings. A long two-storied adobe building, with the roof still intact, seemed to be the center of attraction, and about sundown bats could be seen streaming forth from a window in one of the gables. On the morning of July 5 an examination was made of the attic of this building, and the bats were found clinging to the ridgepole and the rafters, literally by the thousands. Individuals of all ages, from the recently born young to adults, were hanging together in bunches as big as a bushel basket. ... A sack was carried along under the ridgepole and specimens swept into it from several of the larger bunches. In this way more than a hundred bats were collected in a few minutes. ... The sack was carried out under one of the oak trees and the specimens examined; 160 had been captured, and of these 25 were preserved and the remainder allowed to escape. (Miller 1897, page 84).

Miller notes that of the 25 specimens collected, he identified 16 as *M. thysanodes* and the rest as Yuma myotis (*M. yumanensis*) (Miller 1897). The Old Fort Tejon type locality is now located within Fort Tejon State Historic Park (approximate location is UTM coordinates 11S 326866 3860707, WGS84, elevation ~975 meters). Fort Tejon is located in the Tehachapi Mountains which form a barrier between the San Joaquin Valley and the Mojave Desert. Joseph Grinnell (1933) visited Old Fort Tejon during the summer of 1904, looking for *M. thysanodes,* but did not find the species during his visit.

Reproductive female *M. thysanodes* were collected from ruins associated with a pueblo in New Mexico (Miller and Allen 1928). Maslin (1938) described a maternity colony of 30-40 bats using an attic of a home in British Columbia. Dalquest (1947) reported finding a maternity colony of about 50 adult and young *M. thysanodes* in an old winery near Angwin, California, in the Napa Valley. Orr (1956) reported specimens taken from this area, and possibly from structures or cellars associated with the winery, during September, October, and February. Musser and Durrant (1960) described a colony of about 35 individuals using the attic and belfry of an old church near St. George, Utah, and suggested that *M. thysanodes* prefers old buildings to caves as roosting locations. Turner and Davis (1969) reported pregnant females roosting with *M. volans* among the rafters of the porch of a building at Wind Cave National Park on the morning of June 15, 1968. Turner and Davis indicated that this roost site was observed daily from June 12 to September 10, and bats were only seen on two days.

Much of Studier and O'Farrell's seminal research on *M. thysanodes* involved a maternity colony of this species that for over a decade used the attic of the Montezuma Seminary in Montezuma, New Mexico (San Miguel County, 2042 m; Studier 1968; Ewing et al. 1970; O'Farrell and Studier 1970, 1973, 1975, 1976; O'Farrell et al. 1971; Studier et al. 1970; Studier and Ewing 1971; Studier and O'Farrell 1972). The Montezuma Seminary building is now referred to as the "Montezuma Castle" and is part of the United World College of the American West. This building is located on the east slopes of the Sante Fe Mountains in mixed conifer forest and with permanent water resources nearby, including hot spring pools, a creek, and two small reservoirs. The current status of the Montezuma Seminary colony studied by Studier and O'Farrell is unknown.

Hoffmeister (1986) described a *M. thysanodes* maternity colony roosting in the wall of an abandoned shack in the Bradshaw Mountains of Arizona. Hoffmeister and his companions estimated that on July 4 this colony included 100 - 150 adult females, not including volant and non-volant young. Tigner (personal communication reported in Bogan and Cryan 2000), and Navo (personal communication) reported maternity colonies in attics of buildings and cabins.

Caves

Miller and Allen (1928, page 126) concluded that: "Under natural conditions this is doubtless a cave-haunting species." Bailey (1931) provided an account of collecting 87 specimens from a large *M. thysanodes* maternity colony in the Cloverdale Hills west of the Animas Valley, New Mexico, on August 9, 1908. Bailey's account provides a description of the roost site (Bailey 1931; page 388):

> The cave in the Cloverdale Hills where the colony was found was near the head of the Whitmire Creek among the live oaks and the Chihuahua pines. It was in a cliff of baked volcanic ash with the entrance only 6 feet above the base. It was a dry cavern washed out of soft rock 10 to 20 feet wide and 4 to 8 feet high, reaching back 100 feet into the mountain side. The bottom of the cave sloped upward and was dry and half filled with earth and bat guano. Back 40 feet from the entrance was a mass of bats a yard across hanging from the roof like a swarm of bees.

Bailey noted that a few "free-tailed bats" were found in this cave along with the *M. thysanodes,* but that no other species were observed. Bailey's location description appears to place this cave in Salt Canyon, in the Peloncillo Mountains, Coronado National Forest, in the Whitmire Canyon Wilderness Study Area near the border between New Mexico and Arizona. I obtained a copy of Vernon Bailey's field notes for August 9, 1908, from the Smithsonian Institution Archives, and his field notes do not add information to Bailey's later description of the roost site; the only notation in these notes mentioning the *M. thysanodes* roost is "Gray Ranch to Bat Cave" (Vernon Bailey, "Field Notes New Mexico & Arizona, July 11 - October 7, 1908", Smithsonian Institution Archives, Record Unit 7267, Box 2, Folder 10).

Baker (1962) provided a detailed description of adult females and young *M. thysanodes* using Carlsbad Caverns in New Mexico. Baker reported that a Carlsbad Caverns National Park naturalist, Richard Prasil, observed and banded bats in the caverns over a number of years, and described a colony of *M. thysanodes* using the room now referred to as the "Lake of the Clouds" room:

> ...a small colony of brown bats was observed roosting in a ceiling pocket. Seventy-five of these were collected by means of a hand net. They were banded and released in that area. They then flew into a 'Deep Hole' [Lake of the Clouds] section where they established themselves in cracks in the ceiling. The majority of the colony was Fringed Bats, *Myotis thysanodes,* and all of them were females. (Baker 1962, page 427).

Baker (1962) described capturing a female *M. thysanodes* on August 5, 1958, that Prasil had captured and banded on June 24, 1952, 6 years prior, in approximately the same location near the Lake of the Clouds room in Carlsbad Caverns. The Lake of the Clouds room is the lowest known point in Carlsbad Caverns, and is named for the lake that occupies much of the room (Hill 1987). Baker indicated that the *M. thysanodes* colony in Carlsbad Cavern never exceeded 100 bats in size. Baker also described a larger maternity colony of *M. thysanodes* of approximately 300 females and young that occupied nearby Vandalized Cave. Baker commented that this colony also regularly roosted in a portion of this cave that contained a large water body, and that "...during the nursing season when the bats are over the water, the surface is littered with the remains of young that have dropped from the ceiling and drowned." (Baker 1962, page 427.)

Easterla (1966) described finding a maternity colony using Mammoth Cave in Utah, which is a lava tube cave, and capturing *M. thysanodes* at another cave in his study area. Jones and Genoways (1967) described *M. thysanodes* specimens associated with, and captured at, Jewel Cave, South Dakota. Judd (1967) described *M. thysanodes* specimens collected "...from a cave on Mt. Emory and from a limestone cave high on the southeast slope of Mariscal Mountain in Big Bend National Park, Texas." Judd also reported collecting *M. thysanodes* from a limestone cave in Fern Canyon in Chihuahua, Mexico on August 9, 1966:

> About 20 bats were found in a cluster on the ceiling of the cave (about five feet high at this point) at 1:00 p.m. ... As I was leaving the cave, I saw another cluster of approximately 25 fringe-tailed bats hanging on the cave ceiling (about 20 feet high at this point) 30 feet from the cave entrance and exposed to dim light. No other species of bats were seen in the cave. (Judd 1967, page 193).

Martin (1972) reviewed the bat fossil record in North America and in the Caribbean and lists late Pleistocene (~20,000 years ago) *M. thysanodes* fossils from caves in Arizona, New Mexico, and Wyoming. Findley et al. (1975) reported maternity colonies from New Mexico in Isleta Cave, which is surrounded by grasslands and desert, and Embudo Cave, which Findley described as being "...near the upper limit of the yellow pine forest" (page 36).

Czaplewski and Peachey (2003) described a remarkable collection of late Pleistocene *M. thysanodes* fossils from a small section of Arkenstone Cave in southeastern Arizona. This collection of bat fossils included over 4,700 skeletal elements of adult, juvenile, and newborn *M. thysanodes*. Czaplewski and Peachey concluded that these fossils are most consistent with a large maternity colony of this species using the site over many years, and suggests that such a maternity colony must have had high fidelity to this cave roost site. Czaplewski and Peachey also considered the biogeography and climate of this part of the Sonoran Desert during the late Pleistocene, and concluded that the area was surrounded by piñon-juniper woodlands rather than the vegetation currently associated with the Sonoran Desert ecosystem.

Abandoned Mines

Cockrum (1964) reported capturing female *M. thysanodes* associated with an abandoned mine in Arizona. Hoffmeister (1986) found a maternity colony of *M. thysanodes* using an abandoned mine in the Huachuca Mountains of Arizona. Dalquest et al. (1990) reported finding a maternity colony of about 300 *M. thysanodes,* as well as 100 *M. yumanensis,* 200 *Corynorhinus townsendii,* and 50 *Tadarida brasiliensis,* in an abandoned copper mine on the base of Black Mesa in the tri-state region of Oklahoma, New Mexico, and Colorado. L. Bonewell, K. Navo, and I observed large clusters of adult female and volant juvenile *M. thysanodes* in this same mine on July 24, 2007; we also captured three volant juveniles at nearby Skull Canyon Mine in southeastern Colorado, suggesting that both of these mines are maternity sites for *M. thysanodes*.

In the early 1990's, the Colorado Division of Wildlife's Bats/Inactive Mines Project (B/IMP) began surveying abandoned mines throughout Colorado looking for important bat roosts, including mines used by *M. thysanodes* (Navo et al. 1991, Navo and Krabacher 2005). As of January 2010, B/IMP biologists had conducted over 3,100 capture and internal surveys at abandoned mines (Navo, personal communication). The Colorado Bats/Inactive Mines Project documented numerous abandoned mines used by *M. thysanodes* that includes records of reproductive females.

Rock crevices & cavities

Anderson (1961) described four specimens of *M. thysanodes* collected in March, 1955, from a rock crevice at 2042 meters in Mesa Verde National Park, Colorado:

> The specimens from Square Tower House were obtained by D. Watson in a dimly lighted chamber formed by fracture in the rocks at the bottom of the canyon wall, above the talus slope. The bats were suspended from the wall of the chamber, which was at least six feet wide and fifteen feet long.

Bogan et al. (1998) found female *M. thysanodes* in rock cavities in cliffs with east- and south-facing aspects that they presumed provided warm conditions suitable for maintenance of homeothermy. Cryan et al. (2001) found maternity colonies in the Black Hills of South Dakota using both ponderosa snags and rock crevices, with about sixty percent of maternity roosts located in rock crevices. Bogan et al. (2003) compiled a review of what is known about the roosting ecology of cavity and crevice roosting bat species in the western United States. These authors included *M. thysanodes* in a list of species known to use "...crevices, cavities, and 'rock shelters' during at least part of their annual cycle." (Bogan et al. 2003; page 72), and recommended that researchers, biologists, and managers collect long-term data on bat species using rock substrates during their life cycle. In arid habitats in Oregon and Washington Lacki and Baker (2007) found most maternity colonies located in rock crevices.

Adams has identified seven maternity colonies in rock crevices along the Colorado Front Range, yet after radio-tracking females of this and other forest dwelling species (*Myotis ciliolabrum*, *M. evotis*, and *M. volans*) for over five years, only rock crevice roosts have been found (Adams 1996, 1997, 1998, 2000; Adams and Thibault 1999). Adams has observed over many years a maternity colony of *M. thysanodes* using the east face of the Der Zerkle rock formation in the foothills west of Boulder, Colorado. The high fidelity of this colony to roosting habitat on Der Zerkle has resulted in Boulder Open Space and Mountain Parks closing this rock face to climbers between April 1 and September 1 (www.bouldercolorado.gov, www.OSMP.org).

Trees and snags

Christy and West (1993) summarized the use of tree snags by bats in Douglas-fir forests. In New Mexico, Chung-MacCoubrey (1996) located maternity sites in piñon and juniper snags. Weller and Zabel (2001) observed that maternity colonies in northern California moved frequently, occurred in Douglas-fir snags that on average had diameters larger than random snags, and were in forest stands with larger numbers of snags than random stands.

Roosting Physiology

Bats that live in arid and semi-arid landscapes face physiological challenges of heat and water balance. Bats in arid regions experience water loss through evaporation from skin and pulmonary surfaces, and water contained in urine and feces. Bats that roost in sites with high temperatures and low relative humidity can lose significant amounts of water during a single roosting bout (Herreid and Schmidt-Nielsen 1966, Carpenter 1969, Studier 1970, Studier et al.1970, Humphrey 1975, Studier and O’Farrell 1976, Bassett and Studier 1988, Kurta et al. 1989, Kurta 1990, Kurta et al. 1990). Chruszcz and Barclay (2002) studied the thermoregulation of *M. evotis*, which has similar habitat affinities to *M. thysanodes.* Studier et al. (1970) found that *M. thysanodes* roosting in the attic of the Montezuma Seminary, New Mexico, lost on average 15.8 percent of their body mass during a 12 hour period of diurnal roosting at temperatures that varied between 15.6 °C and 31.1 °C. Studier et al. concluded that most of this loss in mass was due to evaporative water loss, though some of the mass loss at the beginning of the 12 hour test period was likely due to urination and defecation. Studier and O’Farrell (1976) studied the evaporative water loss and metabolic rates of six female adult *M. thysanodes* and six female adult *M. lucifugus* and found that evaporative water loss rates in *M. thysanodes* reached minimum values at roughly 25 °C, and increased rapidly to very high rates in the 30 ° to 40 °C range. O’Farrell and Studier (1980) report post-flight body temperatures for *M. thysanodes* of less than 30 °C (rectal temperature = 24.9 °C, chest muscle = 27.3 °C, interscapular muscle = 28 °C). O’Farrell and Studier (1980) also estimate that the thermal neutral zone for *M. thysanodes* was between 32.5 °C and 34.5 °C and that the upper lethal limit was 44.5 °C.

Pregnant bats require water for the developing fetus and other physiological and metabolic processes related to pregnancy (Kurta et al. 1989, Kurta et al. 1990, Barclay 1991, Grindal et al. 2002). Pregnant females have higher metabolic rates and are often found in warmer roosts (Hamilton and Barclay 1994), which are both factors that increase evaporative and metabolic water loss. Lactating bats also loose considerable amounts of water in the production of milk that feeds and nourishes pups, but lactating females must maintain a high level of energy expenditure related to the drinking and foraging bouts that continue to provide water and dietary nutrients to produce mother’s milk until pups reach volancy (Racey and Swift 1985, Kunz et al. 1989, Kurta et al. 1990, Kunz et al. 1994, McClean and Speakman 1999). Furthermore, reproduction in adult females and the ontogeny and development of fetuses and pups are strongly controlled by environmental conditions (Adams and Pederson 2000). Therefore, reproductively active female bats in arid and semi-arid regions are faced with a significant challenge in maintaining water and osmotic balance and require constant access to high quality and predictable water resources. Maternity colonies in arid environments are often located near predictable water resources (McLean and Speakman 1999, Adams and Thibault 2006, Adams and Hayes 2008).

Naturally-occurring maternity roosts can exhibit temperatures above 30 °C, at least for short periods of time. For example, our research group has used temperature sensitive radio-tags to monitor the roost location and temperatures of lactating *Myotis* in forested areas along the Colorado Front Range. In our study area, temperature-sensitive radio-telemetry tags attached to lactating adult female *M. thysanodes* have recorded next-to-skin temperatures of up to 42 °C during the daytime in rock-crevice roosts (Hayes and Adams, unpublished data). These data suggest that reproductive female *M. thysanodes* along the Colorado Front Range sometimes roost at high temperatures near the upper lethal limit reported by O'Farrell and Studier (1980). Thus reproductive *M. thysanodes* females may be selecting roosts that have physical conditions, such as higher relative humidity, that reduce evaporative water loss.

Population Modeling

In this review of literature related to population modeling and bats, I begin by briefly reviewing some basic concepts and background literature related to modeling animal populations. I review the use of age-structure and incorporation of density dependence in population models, and discuss the use of population models in computer simulations, including issues related to stochasticity. I then provide a brief discussion of Turchin's (2003) "theoretical/empirical synthesis" approach to investigating complex population dynamics. I conclude the section with a review of the relevant literature related to modeling bat population dynamics.

Ellner and Guckenheimer (2006) describe the fundamental balance law of population modeling as:

$$N(t + 1) = N(t) + \text{births} + \text{immigration} - \text{deaths} - \text{emigration}$$

[Eq. 1]

Here, $N(t)$ is the number of individuals in a population of interest at time t and $N(t + 1)$ is the number of individuals in the population at some later time, $t + 1$. In mammal population models it is often convenient to count time in years so that t_0 is the starting time, t_1 is 1 year later, t_2 is 2 years later and so on. The simplest population model assumes that the population is “closed” so that no individuals of the population of interest move into or out of the population (Hastings 1997, White 2000, Britton 2002, Ellner and Guckenheimer 2006). In this case, both immigration and emigration are zero and Equation 1 becomes:

$$N(t + 1) = N(t) + \text{births} - \text{deaths}$$

[Eq. 2]

Equation 2 is also valid if immigration plus emigration equals zero, or if the birth and death rates of any individuals moving into or out of the population are equal to those of the individuals originally in the population. Births and deaths in a population can be expressed as proportions such that birth and death rates are given per capita and the balance equation becomes (White 2000, Ellner and Guckenheimer 2006):

$$N(t + 1) = N(t) + bN(t) - dN(t)$$

[Eq. 3]

where b is the per capita birth rate and d is the per capita death rate. The population growth rate (λ) is then defined as (Ellner and Guckenheimer 2006):

$$\lambda = N(t+1) / N(t)$$

[Eq. 4]

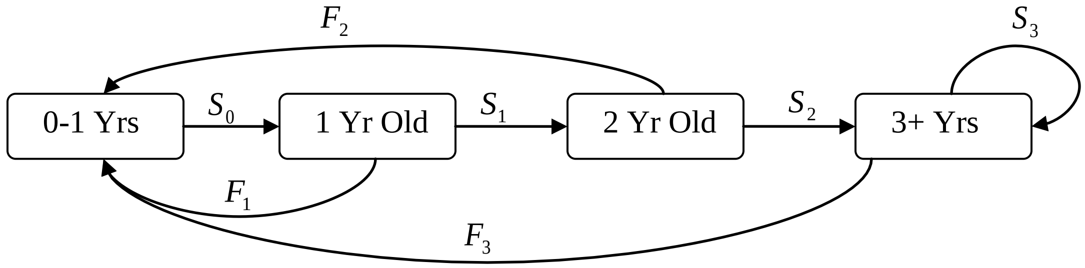
Reproductive and survival rates can vary with different age groups, and an understanding of such differences is an important part of population modeling. Population models that incorporate age-specific differences in reproduction and survival rates are referred to as age-structured population models (White 2000, Ellner and Guckenheimer 2006). Age-structured population models incorporate information about the abundance, survival rates, and fecundity of individuals in specific age classes in a population. Age-structured population models of mammalian species often use only females (Ellner and Guckenheimer 2006), since female reproduction rates largely determine the growth of a population. To keep track of the number of individuals in each group, the populations are often indexed by age class and year. As an example, $N_{0,t}$ can be defined as the population in age class 0 (0-1 years of age) at the beginning of year *t*, and $N_{1,t}$ can be defined as the population in age class 1 (1-2 years of age) at the beginning of *t* years, and so on. As an example, if there are three age classes in a population and the number of individuals in each age class in the population is $N_{0,0} = 64$, $N_{1,0} = 18$, $N_{2,0} = 12$, $N_{3,0} = 6$, then:

$$N = N_{0,0} + N_{1,0} + N_{2,0} + N_{3,0}$$

$$N = 64 + 18 + 12 + 6 = 100$$

[Eq. 5]

The information about this hypothetical population can be used to construct a transition, or life cycle, diagram (Ellner and Guckenheimer 2006), that records the relationships among the population stages. A transition diagram for an age-structured population uses arrows to describe the rates at which members of each age class contribute to the population of other age classes. In the diagram below, the rates with the letter *F* stand for fecundity and the *S* coefficients are survival rates.

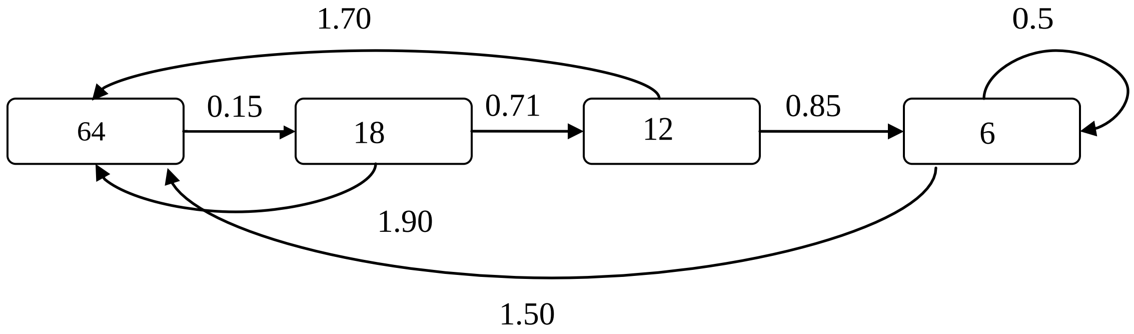


Suppose this hypothetical population is being studied and it is of interest to know whether the population is likely to stabilize, grow rapidly, or decrease to extinction. And suppose also that we know the population has the following characteristics:

1. 15 percent of newborn females survive to their first birthday.
2. Females that are one year old have a higher survival rate of 0.71 and give birth to 1.9 female offspring per year.
3. Females that are two years old have a survival rate of 0.85 and give birth to 1.7 female offspring per year.

4. Females that are three years of age and older have a lower survival rate of 0.50 and give birth to 1.5 female offspring per year.

If the population has the initial age distribution described in equation 5, then the initial population can be described by the following life cycle diagram:



The completed transition diagram can be used to find the projected population at the end of years 1, 2 and 3, by extending the iterative process as shown in the table below:

Age Classes	0 – 1 Yrs Age Class 0	1 Yrs Age Class 1	2 Yrs Age Class 2	3+ Yrs Age Class 3	Total
Year 0	$N_{0,0} = 64$	$N_{1,0} = 18$	$N_{2,0} = 12$	$N_{3,0} = 6$	100
Year 1	$N_{0,1} = 63$	$N_{1,1} = 9$	$N_{2,1} = 12$	$N_{3,1} = 13$	97
Year 2	$N_{0,2} = 56$	$N_{1,2} = 9$	$N_{2,2} = 6$	$N_{3,2} = 16$	88
Year 3	$N_{0,3} = 54$	$N_{1,3} = 8$	$N_{2,3} = 6$	$N_{3,3} = 13$	79

Note that all calculations are rounded down to the nearest whole number, since females give birth to whole offspring and whole individuals die. The transition diagram allows one to find the population of age class 0 at year $t+1$, which is expressed as $N_{0,t+1}$, using the populations of the age classes from year t. Since this is possible for each age class, there are four equations that define this population. The coefficients from the general transition diagram ($S_0, S_1, S_2, S_3, F_1, F_2, F_3$) can be used to write a model for the population in year $t+1$:

$$N_{0,t+1} = N_{1,\mathrm{t}}\mathrm{F}_1 + N_{2,\mathrm{t}}\mathrm{F}_2 + N_{3,\mathrm{t}}\mathrm{F}_3$$

$$N_{1,t+1} = N_{0,\mathrm{t}}\mathrm{S}_0$$

$$N_{2,t+1} = N_{1,t}S_1$$

$$N_{3,t+1} = N_{2,\mathrm{t}}\mathrm{S}_2$$

Linear algebra and mathematical matrices are often used to model age-structured population dynamics. Animal populations were first modeled using matrices by Leslie (1945, 1948). Others have expanded on the use of matrices in modeling animal populations (Lefkavitch 1965, Manly 1990, Caswell 2001). Neuhauser (2011) gives an introduction to the subject in a chapter on linear algebra that should be accessible to most wildlife and conservation biologists (Chapter 9: Linear algebra and analytic geometry) and includes a variety of examples that help in developing a conceptual understanding of matrices and their uses. Williams et al. (2001) gives a review of the subject in Appendix B, including discussions of eigenvectors, eigenvalues and matrix differentiation, but some readers without an appropriate foundation in mathematics may not find this treatment to be a useful introduction to the subject. Caswell (2001) provides a comprehensive review of matrix population models and is considered an authority on their use in modeling animal populations. Heppell et al. (2000) and Ellner and Guckenheimer (2006) give useful overviews of how matrix models can be used to help focus research in ways that inform wildlife conservation and management efforts, but these discussions are best pursued once one has a preliminary understanding of the use of matrices in population modeling.

The hypothetical age-structured example used above to introduce population modeling can also be used to introduce the use of matrices. The following are the matrix and population vectors of the population:

$$\begin{vmatrix} F_0 & F_1 & F_2 & F_{3+} \\ S_0 & 0 & 0 & 0 \\ 0 & S_1 & 0 & 0 \\ 0 & 0 & S_2 & S_{3+} \end{vmatrix} \quad \text{x} \quad \begin{vmatrix} N_{0t} \\ N_{1t} \\ N_{2t} \\ N_{3+t} \end{vmatrix} = \begin{vmatrix} N_{0t+1} \\ N_{1t+1} \\ N_{2t+1} \\ N_{3+t+1} \end{vmatrix}$$

Expression 1

The population is divided into four age classes, zero-year-olds, one-year-olds, two-year-olds, and three-year-and-older-year-olds. The matrix on the left side of Expression 1 is a 4x4 matrix, which includes four rows and four columns. The first row is used to express the birth rates, or fecundity, of each age class (F_0, F_1, F_2, and F_{3+}). The sub-diagonal of the matrix is used to express the survival rates of age classes zero, one, and two-year-olds (S_0, S_1, and S_2). The survival rate of the three-year-and-older age class is located in the diagonal of the matrix at the bottom right side, since this survival rate represents a transition within the age class. Once in this age class, individuals that survive another year (for example, from year three to year four) do not transition to a new age class, but remain in the three-and-older age class. This 4x4 matrix is multiplied by the number of individuals in each of the four age classes, which are represented in the column to the right of the multiplication sign. This column is referred to as the vector of the initial population. The column to the right of the equal sign is the vector of the population at time *t*+1.

Using the example population and substituting in initial population sizes, fecundity and survival rates gives the following matrix and population vectors:

$$\begin{vmatrix} 0 & 1.9 & 1.7 & 1.5 \\ 0.15 & 0 & 0 & 0 \\ 0 & 0.71 & 0 & 0 \\ 0 & 0 & 0.85 & 0.50 \end{vmatrix} \quad \text{x} \quad \begin{vmatrix} 64 \\ 18 \\ 12 \\ 6 \end{vmatrix} \qquad = \qquad \begin{vmatrix} 63 \\ 9 \\ 12 \\ 13 \end{vmatrix}$$

$$N_t = 100 \qquad\qquad N_{t+1} = 97$$

The elements in the sub-diagonal describe survival probabilities for age classes zero, one, and two. That is, 15 percent of the zero-year-olds (newborn individuals) survive until their first birthday; 71 percent of the one-year-olds survive until their second birthday; 85 percent of the two-year-olds survive until their third birthday; and 50 percent of the three-year-olds-and-older survive until their next birthday. The initial population vector is multiplied by the fecundity and survival rates shown in the population matrix to yield the population vector of the *t*+1 generation, as follows:

$$\begin{vmatrix} 0\times 64 & 1.9\times 18 & 1.7\times 12 & 1.5\times 6 \\ 0.15\times 64 & 0 & 0 & 0 \\ 0 & 0.71\times 18 & 0 & 0 \\ 0 & 0 & 0.85\times 12 & 0.50\times 6 \end{vmatrix} = \begin{vmatrix} 34+20+9 \\ 9 \\ 12 \\ 10+3 \end{vmatrix} = \begin{vmatrix} 63 \\ 9 \\ 12 \\ 13 \end{vmatrix}$$

$$N_{t+1} = 97$$

Where N_t is 100 and N_{t+1} is 97. Using equation 4, the population growth rate (λ) is:

$$\lambda = N(t + 1) / N(t) = 97/100 = 0.97$$

Linear algebra may also be used to find eigenvalues and eigenvectors for a given matrix. The dominant eigenvalue (λ) of a matrix gives the long-term growth rate of the population. A λ of less than 1.0 indicates that the population will decline, λ of 1.0 indicates that the population will remain stable, and λ of greater than 1.0 indicates that the population will increase (Neuhauser 2011). Therefore, determining the dominant eigenvalue of a given matrix can quickly answer the question: will the growth rate of a population with the characteristics described in this matrix be positive or negative? The eigenvector (*w*) associated with the dominant eigenvalue also gives helpful information, since it indicates the “stable age distribution” of the population (Ellner and Guckenheimer 2006, Neuhauser 2011). The stable age distribution describes the numbers at which the proportion of individuals in each age class or stage becomes stable (Ellner and Guckenheimer 2006). The dominant eigenvalue and associated eigenvector for a given matrix can be found using mathematical software, such as Mathematica® (Wolfram Research, Champaign, IL) and MatLab® (The MathWorks, Natick, MA) (see also Herman and Pepe 2005).

Heppell et al. (2000), Caswell (2001), and Ellner and Guckenheimer (2006) discussed the use of sensitivity and elasticity analysis in matrix population modeling. Sensitivity analysis compares the relative affect of matrix parameters on the population. For example, it may be useful from a conservation and management perspective to know if increases in adult survival rates will have a greater impact on the population growth rate (λ) than increases in fecundity rates. However, the use of sensitivity analysis can be problematic in animal population modeling because survival and fecundity rates are often measured on different scales. Survival rates are expressed as probabilities between 0 and 1, where 0 indicates a 100 percent chance of death within the next time period and 1 indicates a 100 percent chance of survival during the next time period. On the other hand, fecundity rates are often measured on a continuous scale, and can be much greater than 1. As an example, Crouse et al. (1987) modeled loggerhead sea turtles (*Caretta caretta*) with the following stage-based matrix model:

$$\begin{vmatrix} 0 & 0 & 0 & F_3 & F_4 \\ G_1 & P_2 & 0 & 0 & 0 \\ 0 & G_2 & P_3 & 0 & 0 \\ 0 & 0 & G_3 & P_4 & 0 \\ 0 & 0 & 0 & G_4 & P_5 \end{vmatrix} = \begin{vmatrix} 0 & 0 & 0 & 4.665 & 61.896 \\ 0.675 & 0.703 & 0 & 0 & 0 \\ 0 & 0.047 & 0.657 & 0 & 0 \\ 0 & 0 & 0.019 & 0.682 & 0 \\ 0 & 0 & 0 & 0.061 & 0.8091 \end{vmatrix}$$

In this model, G_i is the probability of a loggerhead turtle surviving and growing to the next stage, and P_i is the probability of surviving and remaining in the current stage. All of the survival probabilities (G_i and P_i) in the Crouse et al. model are constrained between 0 and 1. But the fecundity rate for stage 4 (F_4) is 4.665 and the fecundity rate for stage 5

(F_5) is 61.896. In this matrix model a 0.10 change in a survival rate will have a much more significant impact than will a 0.10 change in any of the fecundity rates.

Elasticity analysis is often a preferred approach to comparing the relative effect of matrix parameters in animal population models (Caswell 2001, Ellner and Guckenheimer 2006). Elasticity can be thought of as the proportional sensitivity where elasticity (e_{ij}) is defined as (Ellner and Guckenheimer 2006):

$$e_{ij} = \frac{fractional\, change in\, \lambda}{fractional\, change in\, a_{ij}} = \frac{\partial\lambda / \lambda}{\partial a_{ij} / a_{ij}} = \frac{a_{ij}}{\lambda}\frac{\partial\lambda}{\partial a_{ij}}$$

The usefulness of calculating the elasticity for each matrix element is that it allows the direct comparison of fecundity and survival rates that use different scales. As Ellner and Guckenheimer state, “The value of e_{ij} says nothing about which matrix entries actually can be changed, or by how much, but it does identify potential targets of opportunity” (2006, page 53).

Sensitivity and elasticity analysis has been used successfully to focus conservation and management efforts targeting populations of threatened and endangered species. For example, Doak et al. (1994) used elasticity analysis to help develop conservation strategies for tortoise populations in the Mojave Desert. Even though there was uncertainty about the precision of survival and fecundity rates, Doak et al. were able to draw useful conclusions about model parameters, and these conclusions helped focus conservation efforts. The Doak et al. analysis helped show that focusing the available conservation resources on efforts to increase the survival rate of larger tortoises would likely have the most positive effect on the population growth rate. Runge et al. (2004)

employed elasticity analysis to evaluate a deterministic stage-structured model of manatee population dynamics and showed that the best management strategy was to focus resources on monitoring and reducing uncertainty in adult survival rates.

In bat population monitoring, there are occasions when all parameters in an age-structured matrix model are constrained between 0 and 1. For example, Hallam and Federico (2009) present a life table of the Indiana bat (*Myotis sodalis*) in which age specific fecundity does not exceed 1. In this case, no age class gives birth to an average of more than 1 young per year. Likewise, no age class has an annual survival probability of greater than 1. In the Hallam and Federico (2009) *M. sodalis* example, the sensitivity of each parameter used in the matrix model could be compared directly to investigate which parameter(s) have the greatest impact on the population growth rate (λ). To conduct such a sensitivity analysis, one would increase or decrease each parameter value in the matrix model independently to determine how the change effects λ. In bat population monitoring, defining model parameters with precision can be extremely resource-intensive. Bats are small, nocturnal, often roost in places that are difficult to identify and monitor, and are capable of flying long distances in short periods of time. Therefore, the use of sensitivity and/or elasticity analysis is an attractive tool in bat conservation, even when model parameter values are poorly understood (Williams et al. 2001, Hallam and Federico 2009).

Thus far, density dependence has not been considered in this discussion of population modeling. Density independent population growth can be represented with the following equation:

$$N_{t+1} = \lambda^t N_t$$

Brauer and Castillo-Chávez (2001), Gotelli (2001), Kot (2001), and Murray (2002) introduce density dependent population growth models and Turchin (2003) provides an overview of the derivation of self-limitation (density dependence) models. Bats usually reproduce annually in a predictable way. This is unlike some other mammals, such as humans, who reproduce continuously. So, when modeling density dependence in bat populations it is reasonable to use discrete models, rather than continuous models. For example, a popular density dependent model is the following discrete logistic equation, also called the Verhulst process (Murray 2002):

$$N_{t+1} = N_t + r_d N_t \left(1 - \frac{N_t}{K}\right)$$

Where r_d is the growth factor and K is the carrying capacity of the population. In this model the population growth rate (r) stays constant even as the population approaches carrying capacity. One might expect the growth rate in certain populations to decrease as the population moves closer to carrying capacity. The Ricker model (Murray 2002) accomplishes this:

$$N_{t+1} = N_t e^{R_0 (1 - N_t / K)}$$

As a result of the exponential function, density dependence in the Ricker model becomes more pronounced as the population nears carrying capacity. The Ricker model has been used extensively in fisheries studies. The Beverton-Holt model is also used in fisheries as a stock-recruitment model (Beverton and Holt 1957, Kot 2001):

$$N_{t+1} = \frac{R_0 N_t}{1 + [R_0 - 1) / K] N_t}$$

where R_0 is a reproductive ratio that can be species or population dependent. The Beverton-Holt model is considered to show compensatory density dependence, where the curve increases monotonically, but with a decreasing slope as the curve approaches carrying capacity (Kot 2001). Other models, such as the model developed by Hassell, May, and Lawton (Hassell et al.1976, Murray 2002) have been developed to model the effects of density dependence:

$$N_{t+1} = \frac{rN_t}{(1 + aN_t)^b}$$

In this model, which is usually referred to as the Hassell equation, *a* and *b* are positive parameters that have the effect of scaling the curve to fit the observed behavior of known animal populations in relation to reproductive rates and competition. The Hassell model shows weaker density dependence than either the logistic or the Ricker models.

Mammalian populations may exhibit some form of density dependence that can be expressed in individual population parameters, such as the survival and fecundity rates used in matrix models. White (2000) proposed using the following logistic equation developed by Bartmann et al. (1992) to incorporate density dependence in fawn survival:

$$S_F = \frac{e^{(1.1906 - 0.0195 \times DecemberDensity)}}{1 + e^{(1.1906 - 0.0195 \times DecemberDensity)}}$$

White (2000) provides an overview of the use of computer spreadsheets to model mammal populations, including examples of spreadsheets that use age-structured population models that incorporate stochasticity (random variability) and examples of how to use random number functions to simulate stochastic effects. White has made these spreadsheet models available in MicroSoft Excel documents on his website (http://warnercnr.colostate.edu/~gwhite/). White (2000) advocates, where appropriate, incorporating demographic and environmental stochasticity into population models. Demographic variation is randomness that exists in the rates at which individuals in a population survive and reproduce. Incorporating demographic stochasticity into population models simulates demographic variation in individual survival and fecundity rates.

An important question to address when designing stochastic models is, which probability distribution is best suited to model this process? Runge et al. (2004) suggest using the binomial distribution when modeling demographic stochasticity. This is an appropriate distribution since individual demographic parameters such as survival and fecundity are binomial events: either an animal survives or it does not; either an animal reproduces successfully or it does not. The binomial probability distribution has the following probability density function (Williams et al. 2002):

$$f(x/p) = p(1-p)^{x}$$

The normal distribution can also be used to model stochastic binomial events, but one must be careful that values less than 0 or greater than 1.0 are not selected, since a normal distribution does not have minimum or maximum values (Williams et al. 2002). Williams et al. suggest that: “the normal distribution is appropriate for continuous measurements with measurement frequencies that decline rapidly as the measurements deviate from some central value” (2002:725).

White (2000) also encourages the incorporation of environmental stochasticity into population models, which simulates random environmental variation. This can simulate, for example, random variation in food, water, and shelter availability, or other abiotic factors, that can affect survival and reproductive rates. White (2000) gives examples of using several probability functions to generate random numbers, such as using normal, log-transformed, and beta distributions. Runge et al. (2004) advocate the use of the beta distribution when modeling life history parameters that are applied to a class of organisms. The beta distribution, like the binomial distribution, is constrained between zero and one and has the following probability density function (Williams et al.2002):

$$f(x/a,b) = \left[\frac{\Gamma(a)\Gamma(b)}{\Gamma(a+b)}\right]^{-1} x^{a-1}(1-x)^{b-1}$$

where *a* and *b* are both positive parameters that change the shape of the density function curve. The beta distribution can be used to generate right-skewed, left-skewed, humped, and u-shaped curves. With the binomial and beta distributions the probability of a value being selected that is very low or very high is usually quite small. The beta distribution, though quite flexible in application, has a key drawback: for each parameter estimate that includes a different average, standard deviation, minimum, or maximum value, different shape parameters must be identified.

If it is desirable to have a higher probability of selecting high or low values, other distributions may be used. For example, with the uniform distribution there is an equal probability of selecting all values between the defined minimum and maximum values. Another example is the triangular distribution. The triangular distribution is defined by three values: minimum, maximum, and most-likely values and the shape of the probability density function is determined by the position of these three values. A triangular distribution with widely-spaced minimum and maximum values will be relatively flat and a distribution with minimum and maximum that are close to each other will produce a curve that is a sharp peak. The triangular distribution is an attractive distribution for continuous values, and has the advantage of having relatively "thick" tails, is easy to define (no shape parameters are required, as with the beta distribution), and does not yield values that are unreasonably high or low (as with the normal distribution).

Stochastic matrix models have been applied to various mammal populations, including grizzly bears in Yellowstone (Knight and Eberhardt 1985), Serengeti wildebeest (Pascual et al. 1997), North American elk (Eberhardt et al. 1996), mule deer (White and Bartmann 1998), cheetahs (Crooks et al. 1998), North Atlantic right whales (Fujiwara and Caswell 2001), and manatees (Runge et al. 2004). Fujita and Caswell (2001) modeled the population dynamics of North Atlantic right whales and developed a probability distribution for the number of years to extinction assuming demographic stochasticity. Fujita and Caswell’s research suggested that slight increases in adult female survival rates would significantly reduce the probability of extinction.

Monti Carlo simulations are often used in ecological and conservation studies. These simulations have been used to determine probabilities in games of chance, and thus acquired the name “Monte Carlo”. When using Monte Carlo simulations to model animal populations, computer programs are used to repeatedly run hypothetical population models many times. Monte Carlo simulations have the advantage of allowing the researcher to explore how different scenarios and parameter values may impact a population. Once the mathematical model, probability density functions, and computer programming have been established, the researcher can easily explore population trends and dynamics using many simulations of a theoretical population.

Turchin (2003) advocates studying population dynamics in a way that combines the statistical analysis of time series data, mathematical modeling of populations, and field experiments. In this approach, Turchin encourages ecologists to initiate collection of long-term data sets that estimate population size or some index of population size, such as animals captured per trap, or mist-net, night . Once data sets of sufficient length have been collected (for example 10-20 years), the time series population data can be used to conduct a set of statistical analyses that are designed to identify characteristics of the dynamics exhibited by the population, such as how the population fluctuates or oscillates with time, and the impact of intrinsic and/or extrinsic factors (Turchin 2003). In this approach, ecologists also strive to develop preliminary mathematical models of the population's dynamics. These mathematically expressed models represent hypotheses about the ecological mechanisms that drive population dynamics. Turchin explicitly recognizes, as do most mathematical modelers, that all models are in some sense false, and that mathematical models are by their nature simplifications of complex ecological processes. Turchin's approach, however, encourages a "theoretical/empirical synthesis" between the theoretical processes of hypothesis development and mathematical model building on the one hand, and the collection of empirical field data on the other. As a third and final stage in population dynamics inquiry, Turchin advocates developing field experiments that are designed to evaluate multiple competing hypotheses regarding the ecological factors driving population dynamics. Turchin provides case studies demonstrating how this theoretical-synthesis approach has helped explain the population dynamics of diverse species, from larch budmoth and southern pine beetle to lemmings and voles, snowshoe hare, and ungulates.

O'Shea et al. (2003) reviewed the status of bat population monitoring in the United States and territories and provided recommendations for future population monitoring developed by a workshop of experts convened in 1999 to address key challenges in the field. These authors provided an overview of the natural history of bats and the key challenges faced by those who monitor bat populations. O'Shea et al. also presented several case studies describing how different bat populations have been, and are being, monitored. For example, these authors described: the monitoring of large maternity colonies of Mexican free-tailed bats; how bats that roost in mines, caves and rock crevices have been, and can be, monitored; and how flying foxes on Pacific island territories have been monitored. O'Shea et al. (2003) provided several recommendations for improving the monitoring of bat populations in the United States and its territories.

O'Shea et al. (2004) provided a review of survival estimation in bats. This review included a historical and critical review of bat banding and suggestions for future research. The review also provided a historical review of survival estimation used by bat researchers and ecologists and presents a detailed case study of survival estimation used in a study of big brown bats (*E. fuscus*) in Fort Collins, Colorado. This case study included discussion of sampling and marking of bats, use of passive integrated transceiver (PIT) tags for mark-recapture monitoring, and data analysis. The review also included a detailed appendix with summaries of 41 published bat survival studies from 1952 through 2003, ranging in duration from approximately 1 to 20 years. Of these studies 14 provided information about survival rates in 10 *Myotis* species, including five European species (*M. dasycneme, M. daubentoni, M. emarginatus, M. myotis,* and *M. mystacinus*), and five North American species (*M. austroriparius, M. grisescens, M. leibii, M. lucifugus,* and *M. sodalis*). O'Donnell (2009) reviewed standard approaches to estimating survivorship in bats and Hallam and Federico (2009) reviewed the use of population dynamics modeling to bat populations.

McDonald and Ise (2004) used simple deterministic matrices to model the population dynamics of *M. thysanodes*. In this model, McDonald and Ise assumed that the probability of a female pup being born to a female adult was 0.50, or fifty percent. They also assumed that the ratio of males to females in the population was 1:1. They estimated that: (1) the probability of a newborn female pup surviving to its first birthday was 0.481 (48.1 percent); (2) the “annual survival rate of females at age of first reproduction” was 0.75 (seventy-five percent) (page 29); and the “annual survival rate of fully developed, reproductive females" was 0.85 (eighty-five percent) (page 29). McDonald and Ise (2004) also incorporated stochasticity into their model of *M. thysanodes* population dynamics using random numbers picked from a normal distribution and incorporated into their model in three variations: The first variation added stochasticity to the first-year survival rate; the second variation added stochasticity to the survival rates of all three age classes; and the third variation added stochasticity to all three age classes and increased the amount of variation allowed in the random number sampling scheme to produce stochastic effects. McDonald and Ise ran each of these model variants with an initial population size of 10,000 over a 2,000 year period. Each model variant was repeated 100 times. McDonald and Ise concluded that the survival rate of reproductive females was the key factor influencing population viability.

CHAPTER III

METHODOLOGY

Distribution

Geographic and Elevational Distribution of Myotis thysanodes: All available information on capture and occurrence locations of *M. thysanodes* in Colorado was compiled. This information was obtained from the primary literature, Colorado Division of Wildlife documents and databases, museum records, and the records, reports, and field notes of bat researchers, mammalogists, and others who have conducted bat surveys in Colorado. This information included occurrence records for *M. thysanodes* from the Colorado Bats/Inactive Mines Project, which has conducted over 3,000 capture and internal surveys at abandoned mines throughout the Colorado Rockies since 1991. Capture and occurrence locations were then mapped in an Arc-GIS map of Colorado. This map was compared to the distribution map for this species proposed by other authors. This data set was then used to perform a 2-way analysis of variance (ANOVA) comparing the elevation of occurrence among levels within reproductive and sex classes, using the model:

Individual elevation = grand mean + reproductive effect + sex effect + interaction + error

This model is expressed mathematically as,

$$X_{ij} = \mu + \alpha_i + \beta_j + \alpha_i\beta_j + \varepsilon_{ijk}$$

where *X* is the elevation of the individual occurrence record, μ is the mean elevation of all *M. thysanodes* records, α is reproductive class (juvenile, non-reproductive adult, and reproductive adult), β is sex class (male or female) and ε is an error term. I tested the following reproductive and sex class hypotheses:

Reproductive hypotheses:

H_0 Null hypothesis that all reproductive classes are equal.

H_A Alternative hypothesis that at least one reproductive class is not equal.

These hypotheses expressed in mathematical terms are:

$H_0 : \alpha_j = \alpha_n = \alpha_r = 0$

$H_A : \alpha_i \neq 0$

Sex hypotheses:

H_0 Null hypothesis that males and females are equal.

N_A Alternative hypothesis that males and females are not equal.

These hypotheses expressed in mathematical terms are:

$H_0 : \beta_m = \beta_f$

$H_A : \beta_m \neq \beta_f$

Statistical analysis was conducted with the General Linear Model (GLM) procedure using SAS 9.1 statistical software (SAS Institute Inc., Cary, North Carolina). I checked for interaction between the main effects using a plot of age and sex classes and levels against elevation. I then performed a Student-Newman-Keuls test to look for means that were significantly different from each other. Statistical significance for this analysis was set at $\alpha = 0.05$.

Maternity Roost Selection

The study area for the roost site selection project was within the known range of *M. thysanodes* in Colorado (Armstrong 1994, Fitzgerald et al. 1994, Adams 2003). Field work emphasized Colorado Front Range locations in Boulder and Larimer Counties. This area of the Front Range consists primarily of Douglas-fir and ponderosa pine forests, meadows, montane shrublands, and grasslands and is at the transition zone between the Colorado Piedmont section of the Great Plains physiographic province and the Southern Rocky Mountains (Chapman et al. 2006).

In an effort to identify additional *M. thysanodes* maternity roosts in Boulder and Larimer Counties, Colorado, I conducted mist-netting in areas likely to be visited by bats, which consisted of placing mist-nets over or near water, trails, roads, forest edges, or meadows. Once bats were captured, standard data were gathered including species, age class (Anthony 1988), reproductive status (Racey 1988), and presence of ectoparasites. Eight standard radio-transmitters (Holohil Systems Ltd., Carp Ontario, Canada; LB-2N, weight 0.36g, 12 day battery life) and 10 temperature-sensitive transmitters (Holohil

Systems Ltd. Carp Ontario, Canada; LB-2NT, weight 0.38g, 12 day battery life at 40 °C, with temperature calibrated signal) were purchased for use on this project. I followed the 5% rule when applying radio-tags only to non-pregnant individuals with which the tag weighed less than or equal to 5% of their body weight (Aldridge et al.1988, Neubaum et al. 2005). Radio-tags were attached to parted fur between the scapulae using waterproof Perma-Type surgical cement (Figure 2; The Perma-Type Company Inc., Plainsville, Connecticut). To facilitate identification of *M. thysanodes* maternity roost sites, radio-tagging preference was given to females of reproductive age. However, on several occasions, I radio-tagged lactating Townsend's big-eared bats (*Corynorhinus townsendii*) in an attempt to find maternity roosts of this species, which is also a species of concern in Colorado and western North America. I attempted to track radio-tagged individuals to identify roost sites. Once a bat was radio-tagged, I initially searched for the bat from near the capture location and by driving along nearby roads using a roof-mounted whip antenna mounted on my field vehicle. Once a signal was located, I tracked bats on foot using hand-held receivers and antennas (Figure 2; TRX-48S Receiver, Wildlife Materials Inc., Murphysboro, Illinois). In this study, I did not attempt to track bats using fixed-wing aircraft. Temperature and relative humidity data loggers (iButton Hygrochron DS-1923-FS Temperature and Relative Humidity data loggers, Embedded Data Systems, Lawrenceburg, Kentucky) were installed in known maternity roost sites and randomly selected unoccupied sites to gather roost site temperature and humidity data. All capture and handling of bats was conducted under State of Colorado Division of Wildlife scientific collection licenses.

Figure 2. Photographs of a radio-tag being attached using surgical glue to a lactating *M. thysanodes* and radio-tracking the bat the next morning, beginning near the capture location (Photos by L. Bonewell).

Newly identified *M. thysanodes* roosts were photographed, characterized, and added to a database of known roosts of this species in Colorado. For maternity roosts located within the Front Range study area, a 100 x 100 meter square plot was created with the roost as the center of the plot. I also randomly selected 100 square 100 x 100 meter plots throughout the known range of *M. thysanodes* along the Front Range in Boulder and Larimer Counties. Tree snags and geologic features were characterized within each of the maternity plots and randomly selected plots. Each tree snag > 10 cm in diameter at breast height (DBH) was characterized using DBH, height (using a clinometer, Brunton Clino Master^{TM}, Stockholm, Sweden), decay class, canopy cover (using a spherical densiometer, Model A, Forest Densiometers, Bartlesville, Oklahoma) and slope (using a clinometer, Brunton Clino Master^{TM}, Stockholm, Sweden), and aspect of the substrate following Cryan et al. (2001) and Neubaum et al. (2006). Geologic features that provide potential rock crevice roosts within each plot were also characterized using rock type, average height, canopy cover, and slope and aspect of the substrate. All maternity roosts and randomly-selected sites were mapped using DeLorme Topo USA 5.0 (Delorme, Yarmounth, Maine) and Arc-GIS software (ESRI, Redlands, California). These data on maternity plots and randomly selected plots allowed me to compare known *M. thysanodes* maternity plots to the roosting habitat available in randomly selected plots.

The following information was collected and recorded at each occupied maternity roost and two randomly-selected potential roost sites per random plot: whether *M. thysanodes*, or any other bats, were present at the site; if present, the number of *M. thysanodes* found and whether they were roosting singly or in groups; roost substrate (rock crevice, tree snag, bridge, cave, mine, etc.); elevation; approximate dimensions of the roost; height of the roost off the ground, if applicable; DBH, if the roost was in a tree snag; approximate dimensions of the rock feature if the roost was within a rock crevice; canopy cover; and slope and aspect of the substrate. Habitat variables, such as habitat type, dominant vegetation, and distance to nearest water near the roost were also measured and recorded. Mean annual temperature (MAT) and other climate variables were estimated for each site. Historical climate data from weather stations in the study area were used to estimate these values (Western Regional Climate Center 2010). The GPS location of each roost was determined using a Garmen eTrex GPS unit (Olathe, Kansas) and UTM coordinates (North American Datum 1927).

Final Analysis of Landscape and Roost Site Variables: Potential *M. thysanodes* maternity roost sites in Colorado are often clustered on the landscape (for example, in rocky areas with potential rock crevice roosts or within forested areas with tree snags) and it would be helpful if biologists and managers could prioritize potential roosts within and among clusters of potential sites. I therefore developed two balanced model sets, one that included landscape variable**s** and a second that included roost-site variables. I developed 15 landscape models to provide information about 4 landscape variables that might influence maternity roost selection by this species (Table 1). The variables used in the landscape analysis included elevation (m), the grade (or slope; percent) of the landscape on which the roost or randomly selected plot was located, transformed aspect of the roost as described in Table 3 (this is a unit-less variable), and proximity to a permanent water source (m). For this landscape analysis, I used data from known *M. thysanodes* maternity roosts, and the 100 square 100 x 100 meter plots described above located within the known range of *M. thysanodes* along the Front Range in Boulder and Larimer counties, Colorado.

I developed the roost-site model set to provide information about characteristics of individual potential roost sites that might influence maternity roost selection by *M. thysanodes*. Such information might help identify suitable maternity roost sites within a cluster of possible roost options. This analysis of roost-site variables used a final set of seven candidate models using the three variables that I predicted to most strongly influence roost selection at the roost scale (Table 2). The variables used in the roost-site analysis are listed in Table 2**,** and include average temperature (°C), relative humidity (%), and estimated roost volume (m^3).

Table 1. Landscape variables used in final modeling of maternity roost selection by *M. thysanodes* along the Front Range, Colorado. Data were collected at maternity roosts and randomly selected potential roost sites ($n = 9$ maternity roosts and $n = 100$ randomly selected potential roosts).

Variable	Type of variable	Units
Elevation	Continuous	Meters
Grade (slope)	Continuous	Percent
Aspect (A_t)*	Continuous	Unit-less
Proximity to water	Continuous	Meters

*The transformed aspect is:

$$A_t = Sin(aspect(\deg rees)) \big/ 114.59$$

where 114.56 is the diametian number, which is 360°/π. This transformation converts each degree to a number between 0 and 1, with 1° and 359° both approximately equal to 0, and 180° equal to 1.0. This transformation creates an index of aspect where south-facing slopes receive a high score and north-facing slopes receive a low score.

Table 2. Roost-site variables used in final modeling of maternity roost selection by *M. thysanodes* in Colorado. Data were collected at maternity roosts and randomly selected potential roost sites (*n* = 9 maternity roosts and *n* = 18 randomly selected potential roosts).

Variable	Type of variable	Units
Mean Temperature	Continuous	°C
Mean Relative Humidity	Continuous	% RH
Estimated Roost Volume	Continuous	m^3

For this roost-site analysis, I used data from nine known *M. thysanodes* maternity roosts in Colorado, including one roost in New Mexico that is within 5 miles of the Colorado state line. The roost-site comparison was conducted comparing variables associated with known *M. thysanodes* roosts to variables associated with two randomly-selected unoccupied potential roosts per known maternity roost. These randomly-selected potential roosts were identified by selecting random points within a 4 kilometer radius of the capture location. In our study area *M. thysanodes* have been observed traveling up to 2.8 kilometers between capture locations and day roosts (Hayes, unpublished data). Thus, the rationale for using a 4 kilometer radius is that such an area will delineate a reasonable sample of potential roosting options for the bats in a given maternity colony. These random points were each defined by first randomly selecting a number between 0 and 360. This number was used as a compass bearing expressed in degrees. A second random number was selected between 0 and 4,000. This number indicated the radius in meters from the known maternity roost. The compass and measurement tool in Delorme Topo USA mapping software and a GPS unit were used to identify the randomly selected point described by these two numbers. Once at a randomly selected point, the nearest potential rock crevice/rock debris or tree snag/loose bark roost was identified and used as a potential, but unoccupied, roost. The decision about which type of roost to select was made by flipping a coin once the first randomly selected point had been located on foot. Each potential unoccupied roost was inspected visually for bats and/or guano to confirm that the location was not occupied by bats. If there was no tree snag or tree with loose or peeling bark identified from the random point, a rock crevice/rock debris site was chosen; likewise, if no potential rock crevice/rock debris roost site was identified, a tree snag or loose bark roost was be chosen. In several cases a randomly selected point was near a road bridge. In these cases, crevices in the bridge were used as potential roost locations. Hygrochon temperature and humidity iButton data loggers (Figure 3; DS1923-F5**,** Dallas Semiconductor, Sunnyvale, CA) were installed in the known maternity roost sites and randomly selected unoccupied sites for at least four weeks during the maternity season, from June 1 to August 15. These data loggers were programmed to gather roost site temperature (°C) and humidity (%RH) data for the roost-site analysis. Data loggers were set to sample data every 120 minutes during deployment. This sampling interval allows storage of up to 170 days of data. Temperature and relative humidity data were downloaded directly from the data loggers to a laptop computer using a USB to 1-

wire/iButton Adaptor (DS9490R/DS9490B, Dallas Semiconductor, Sunnyvale, CA**)**. Data were accessed and viewed using iButton Viewer/1-Wire Viewer Software (SW-DVB, Dallas Semiconductor, Sunnyvale, CA). Temperature and relative humidity data were collected at each site during the maternity periods of 2009 and 2010.

Figure 3. Photograph of an iButton Hygrochron temperature and relative humidity data logger deployed in a *M. thysanodes* maternity roost site (Photo by L. Bonewell).

Data related to some variables, such as canopy cover and diameter of tree snags, were excluded from the final analysis because it became clear during preliminary field work that there were no meaningful differences between these variables in the maternity roost and randomly-selected potential roost data. I also did not find any maternity roosts located in tree snags and concluded that the availability of tree snags in our study area (including height, diameter, canopy cover, and decay class of individual snags) was not a significant variable in determining location of maternity roosts. Likewise, given that roosts were often found in prominent rock faces, abandoned mines, and in an abandoned cabin, I concluded that canopy cover was not likely to be a significant variable in determining location of roosts. I also strived to develop final sets of candidate models that would be a balanced model set, such that each variable appeared in the same number of models (Burnham and Anderson 2002). By using a balanced model set, I was able to perform model selection, determine model selection uncertainty, and estimate the relative importance of each variable.

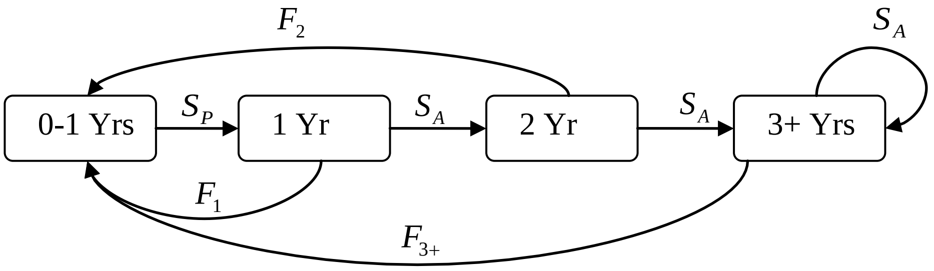
I used logistic regression (Keating and Cherry 2004) and an information-theoretic approach to evaluate and guide inference from the set of candidate models. An information-theoretic approach is useful because it allows the comparison of multiple hypotheses simultaneously (Burnham and Anderson 2002). This approach has been used successfully to identify important roost site variables in other projects (Weller and Zabel 2001, Neubaum 2005, Neubaum et al. 2006, Hayes et al. 2011). I analyzed data using logistic regression and the logit link function (MiniTab, Inc., State College, Pennsylvania). I assessed the global model's fit using the Pearson and/or Hosmer-Lemeshow χ^2 goodness-of-fit test (Burnham and Anderson 2002). I calculated a variation inflation factor ($\hat{c}$) for the global model to determine if data were over-dispersed (Burnham and Anderson 2002). I compared models using Akaike's Information Criterion for small sample sizes (AIC_c) (Burnham and Anderson 2002). I ranked models using AIC_c weights (w_i) and a cumulative AIC_c weight (w_+) was calculated for each predictor variable. I then calculated unconditional parameter estimates ($\tilde{\bar{\beta}}_i$) and 95% confidence intervals for the regression coefficient for each model variable. I considered variables with a 95% confidence interval around $\tilde{\bar{\beta}}_i$ that did not overlap 0 to have a stronger effect (Burnham and Anderson 2002).

I did not include all known *M. thysanodes* maternity sites in Colorado in this analysis. Known maternity roost sites were selected for inclusion in this study based primarily on knowledge of the roost location and safe accessibility. One known roost site (Der Zerkle in Boulder County) is known by R. Adams to have been used as a maternity site for a number of years, but it is my understanding that the exact roost crevice is not known. Similarly, we know there is a maternity site associated with a rock outcrop in Geer Canyon (Heil Valley Ranch, Boulder County), but repeated radio-tracking efforts have failed so far to identify the exact location of this roost. Thus, these site were not included in this analysis.

Population Modeling and Climate Change

Population modeling was conducted to analyze the potential relationships between climate change and population dynamics of *Myotis* populations living in forested landscapes of Colorado’s Front Range. I explored the dynamics of hypothetical populations over a 100 year period from 2000 to 2100 following the general procedures for developing deterministic and stochastic age structured population dynamics models described by White (2001) and Williams et al. (2002), and incorporating into these population models the potential impacts of a changing climate in the Colorado Front Range.

Using the literature and data from our study area, plausible fecundity and survival rates appropriate for this analysis were used (Pryde 2003, O'Shea et al. 2004, O'Donnell 2009, Hallam and Federico 2009, O'Shea et al. 2010). The following age-specific survival rates were used: mean pup survival from birth to first birthday (S_P) was 0.4750 (min = 0.4000, max = 0.5500); mean annual survival rate for adults (S_A) was 0.7950 (min = 0.7500, max = 0.8400); mean female birth rates of 1-year-old females (F_1) was 0.3500 (min=0.2950, 0.4050); mean female birth rates of 2-year-old females (F_2) was 0.4425 (min=3950, 0.4900); and mean female birth rates of 3-year-old-and-older females (F_{3+}) was 0.4550 (min=0.4200, 0.4900). These vital rates are similar to those reported by O'Shea et al. (2010) for big brown bats (*Eptesicus fuscus*) in maternity roosts associated with buildings in Fort Collins, Colorado. However, the vital rates I used here are slightly lower on average, as I have assumed that the forest-dwelling and smaller bodied *Myotis* species analyzed here have slightly lower, and more variable, vital rates than the larger bodied *E. fuscus* associated with urban environments. In all simulations, I used an initial population of 2000 females as follows: 600 pups; 290 1-year-old females; 230 2-year-old females; and 880 3-year-and-older females. I assumed that the newborn male-to-female sex ratio was 1:1, and remained constant in all simulations over the period analyzed. A transition diagram and associated matrix model is shown below to describe age-structured dynamics of the population.



$$\begin{vmatrix} F_0 & F_1 & F_2 & F_{3+} \\ S_0 & 0 & 0 & 0 \\ 0 & S_A & 0 & 0 \\ 0 & 0 & S_A & S_A \end{vmatrix} \quad \text{x} \quad \begin{vmatrix} N_{0t} \\ N_{1t} \\ N_{2t} \\ N_{3+t} \end{vmatrix} \quad = \quad \begin{vmatrix} N_{0t+1} \\ N_{1t+1} \\ N_{2t+1} \\ N_{3+t+1} \end{vmatrix}$$

I developed an age-structured population model for forest-dwelling *Myotis* that incorporated biologically plausible survival and fecundity rates and that resulted in an approximately stable age distribution and a population growth rate of $\lambda \approx 1.0$. The initial age distribution was close to a stable age-distribution of approximately two thousand females. The dominant eigenvalue (λ) and eigenvectors (*w*) were calculated to determine the population growth rate and stable age distributions of the starting population. I assumed that female bats gave birth to either one or zero pups per year, and therefore fecundity rates were constrained between 0 and 1 and expressed as females born per year per adult female (females born/year · adult female). It is possible that forest-dwelling *Myotis* occasionally give birth to twins, but for this analysis I have assumed that only single pups are born and survive parturition. In this situation, all vital rates are constrained between 0 and 1. Sensitivity analysis was conducted by varying estimated fecundity and survival rates by minus ten percent (-10%). This sensitivity analysis describes the relative affects of changes in fecundity and survival rates on the population growth rate (λ).

I added stochasticity to all models for each age class, year, and simulation run, by incorporating a random number generator into vital rates using a triangular probability density function. This function randomly selected a vital rate between the minimum and maximum vital rate, with the peak of the distribution positioned at the mean of the vital rate. Using a triangular distribution produces relatively heavy tails but keeps the vital rates between the minimum and maximum values.

I developed and ran seven Monte Carlo simulations for forest bat populations in the Southern Rocky Mountains using the age-structured population model described above. The "Stable" model assumed that the climate in our study area in Boulder County, Colorado, will stay approximately at year 2000 levels through year 2100. I then used three *Myotis* simulations employing Adams' generic *Myotis* model of female reproductive success and mean high summer temperatures (Adams 2010; Figure 2, mean summer high temperature) and the IPCC SRES Climate Change Scenarios (B1, B2, and A2) downscaled for our study area as described below using the results of Kang and Ramírez (2007) for the IPCC SRES B2 climate change scenario for their study area in the South Platte watershed. I then used three species specific *M. thysanodes* models employing the multi-model inference approach for reproductive condition analysis described below for female reproductive success and mean high summer temperatures, and other climatic variables, in our study area. As with the generic *Myotis* simulations, I used three IPCC

SRES Climate Change Scenarios (B1, B2, and A2) downscaled for our study area using the results of Kang and Ramírez (2007). Each Monte Carlo simulation consisted of 100,000 runs of 100 years each from years 2000 to 2100, using the models described. Wolfram Mathematica® 8.0 (Wolfram Research, Inc., Champaign, Illinois) mathematical software was used to perform linear algebra calculations, sensitivity analysis, and Monte Carlo simulations. The code used to program two of the Monte Carlo simulations (the stable climate and *M. thysanodes* IPCC SRES B1 Scenario) are shown in Appendix B.

I used the climate change modeling and scenarios developed by Kang and Ramírez (2007) for the South Platte watershed and their study area of the Headwaters basin of the South Platte watershed. Kang and Ramírez (2007) used the output of the Canadian Climate Centre's second Global Circulation Model (CGCM2) and the IPCC SRES B2 climate change scenario to create downscaled climate predictions for the South Platte watershed, which includes our study area. Because these predictions are for a portion of the South Platte watershed that has a higher mean elevation than our study area, the Kang and Ramírez study yields average summer temperatures that are significantly lower than for our Boulder study area. To develop mean summer temperature projections for our study area under the IPCC SRES B2 climate change scenario, I adjusted the Kang and Ramírez mean summer temperature predictions so the summer temperatures for year 2000 were equivalent to the actual mean summer temperature for Boulder in year 2000. I then used the same adjustment to modify the Kang and Ramírez predictions for our Boulder study area through year 2100. Finally, to develop mean summer temperature projections for our study area under the IPCC SRES

B1 and A2 climate change scenarios, I adjusted my IPCC SRES B2 projections by using data presented in the IPCC Forth Assessment Report on Climate Change (IPCC 2007; see figures in the SPM5 Figures supplement comparing IPCC SRES scenarios B1, B2, A1, and A2).

In order to model the dynamics of *M. thysanodes* populations, I compiled and analyzed all available data for adult female *M. thysanodes* captured or collected in Boulder County, Colorado. The study area for this analysis is within the Southern Rockies ecoregion and includes foothills shrublands, crystalline mid-elevation forests, and Front Range fans (Chapman et al. 2006). Boulder County, Colorado, is within the South Platte River basin.

I used data from adult female *M. thysanodes* capture records from Boulder County in which the biologist or collector listed the following information: that the species was *M. thysanodes*; that the sex of the individual was female; that the individual was an adult; and that the reproductive status of the adult female individual was determined as non-reproductive, pregnant, lactating, or post-lactating. Early in the reproductive season (for example in May and early June) it can be difficult to identify whether individuals are pregnant. Similarly, it can be difficult to identify if a female is post-lactating in the late summer. Therefore, I restricted the data set to those records collected by a biologist or collector who I expected had the knowledge, skills, and experience to accurately identify the age and reproductive condition of species of the genus *Myotis*.

I followed the approach of Adams (2010) and used temperature and precipitation data for Boulder, Colorado, maintained by the U.S. National Oceanic & Atmospheric Administration's Climate Analysis Branch at the Earth System Research Laboratory (Physical Sciences Division) in Boulder, Colorado, and used daily maximum temperature and precipitation data from 1995 to 2009 that was collected at the NOAA/Skaggs Building on the U.S. Department of Commerce Boulder Labs campus (325 Broadway, Boulder, Colorado, 80305). This data set expresses temperature in degrees Fahrenheit (precise to 1 degree) and precipitation in inches (precise to 0.01 inch), includes data from 1897, and is publically accessible on the Earth System Research Laboratory's website (http://www.esrl.noaa.gov/psd/boulder/getdata.html). I used daily maximum temperature and precipitation data during the four month period from May 1 to August 31 for each year from 1995 to 2009. The rational for using weather data for this period is that this is the period during which *M. thysanodes* are pregnant, give birth, lactate, and juveniles become volant; therefore, it is plausible to hypothesize that the temperatures and precipitation experienced during this period are likely to influence the proportion of adult females that are reproductively active. I imported this data into a Microsoft Excel spreadsheet, converted temperature into degrees Celsius and precipitation into centimeters, then calculated average daily high temperature (°C) and total precipitation (cm) for the period for each year.

I used streamflow data for Boulder Creek near Boulder, Colorado, maintained by the Colorado Division of Water Resources (CDWR). I again followed the approach of Adams (2010) and used monthly total streamflow discharge data from 1995 to 2009 that were collected at the Orodell streamflow gauging station (Station location: UTM in Zone 13 using NAD 83, 471763.3 ,4428517.0; Boulder County, on left bank along State Highway 119, 0.7 mi southwest of old Orodell, 1.1 mi upstream from Fourmile Creek, and 2.9 mi southwest of courthouse in Boulder). This data set expresses daily and monthly streamflow volume in cubic feet per second, includes data from October 1906 to the present full month, and is publically accessible on the Colorado Division of Water Resources' Colorado's Surface Water Conditions website and data bases (http://www.dwr.state.co.us/SurfaceWater/Default.aspx). I used monthly streamflow data during the four month period from May to August for each year from 1995 to 2009. As before, the rational for using weather data for this period is that this is the period during which *M. thysanodes* are pregnant, give birth, lactate, and juveniles become volant; therefore, as with the temperature and precipitation data, it is plausible to hypothesize that the surface water conditions experienced during this period are likely to influence the proportion of adult females that are reproductively active. I imported these data into a Microsoft Excel spreadsheet, and calculated streamflow averages in cubic feet per second (cfs) for the May to August period for each year.

I compiled reproductive condition, climate, and streamflow data from 15 years of bat capture and survey work during May, June, July, and August 1995-2009. I used four variables to model the relationship among reproductive condition in adult female *M. thysanodes* and climate and surface water conditions: Average daily maximum temperature (°C) from May through August for the year of capture (TEMP); total precipitation (cm) from May through August for the year of capture (PRECIP); Average streamflow (cfs) from May through August for the year of capture (STREAMFLOW); and peak streamflow (cfs), expressed as the streamflow for the month with the highest streamflow from May through August for the year of capture (PEAK FLOW).

I developed a global model using the four predictor variables described above (TEMP + PRECIP + STREAMFLOW + PEAK FLOW). I created a balanced model set (Burnham and Anderson 2002) of 15 models, each representing a competing hypothesis about the relationship between female reproductive success and the four predictor variables. I analyzed data using logistic regression and the logit link function (MiniTab, Inc., State College, Pennsylvania). I assessed the global model's fit using the Pearson χ^2 and Hosmer-Lemeshow goodness-of-fit tests (Burnham and Anderson 2002). I calculated variation inflation factors ($\hat{c}$) for the global model to determine if data were over-dispersed and compared models using Akaike's Information Criterion for small sample sizes (AIC_c) (Burnham and Anderson 2002). I ranked models using AIC_c weights (w_i) and a cumulative AIC_c weight (w_+) was calculated for each predictor variable. I then calculated unconditional parameter estimates ($\tilde{\bar{\beta}}_i$) and 95% confidence intervals for the regression coefficient for each model variable. I considered variables with a 95% confidence interval around $\tilde{\bar{\beta}}_i$ that did not overlap zero to have a strong effect (Burnham and Anderson 2002).

For the population dynamics analysis conducted here, I used only the unconditional parameter estimate for the variable "maximum daily summer temperature" to estimate yearly reproductive rates for *M. thysanodes.* This is because I did not feel comfortable that I had access to high quality climate projections related to precipitation and streamflows in our study area through all years from 2000 to 2100. As more data becomes available, such data will be useful in future population modeling and investigation of climate change impacts in the Southern Rocky Mountains. To estimate the proportion of reproductive females in our study area for future years, I used the mean June, July, and August temperature projections for the South Platte watershed provided by Kang and Ramírez (2007) and adjusted these projections to our study area, as described above. This approach rescaled the Kang and Ramírez (2007) temperature projections to an appropriate mean for our study area. I then estimated the proportion of females that will be reproductive using the unconditional parameter estimate for maximum daily summer temperature.

CHAPTER IV

ANALYSIS

Distribution

Seven hundred and twenty nine Colorado capture and occurrence records of *M. thysanodes* were documented (see Appendix A). Using these capture and occurrence records I created the Arc-GIS map in shown in Figure 4, which shows capture and occurrence locations in Colorado. This map shows a bifurcated geographic distribution with separate populations occurring in a narrow band along the Front Range and in western Colorado. I used 546 *M. thysanodes* records that included information about sex and reproductive status in the analysis of variance (ANOVA) comparing elevational distribution among sex and reproductive classes (Table 3). There were significantly different elevational mean sum of squares among reproductive classes (F Value = 7.03, P = 0.0010), but not between sex classes (F Value = 0.10, P = 0.7578). Student-Neuman-Keuls (SNK) test results comparing reproductive and sex classes are shown in Table 4. In these SNK groupings, means with the same letter are not considered to be significantly different. Sex class groupings do not suggest a significant difference between mean elevation of males and females (mean elevation of males was 1920 meters and mean elevation of females was 1892 meters). However, reproductive class groupings suggest a significant difference in mean elevation of occurrence between reproductive and non-reproductive adults, with reproductive adults of both sexes occurring at a mean elevation of 1884 meters, while non-reproductive adults of both sexes occurred at a higher mean elevation of 1950 meters. A box plot of elevation of occurrence versus sex and reproductive status is shown in Figure 5. The evaluation of interaction between age and sex class and elevation of occurrence suggested that there is ordinal interaction between reproductive and sex classes, but that the main effects can be interpreted independently of each other.

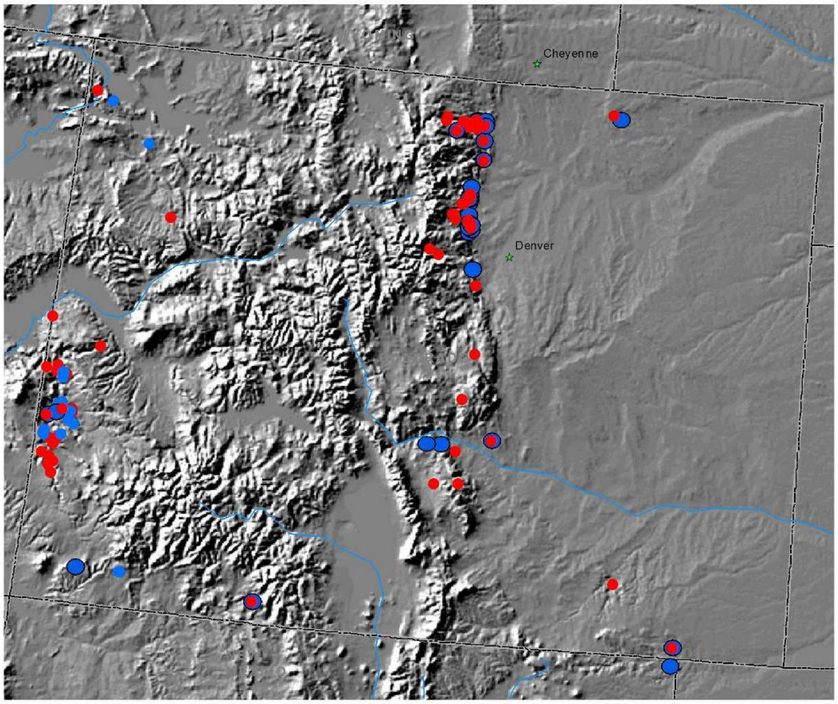


Figure 4. GIS map of Colorado showing all occurrence locations of *M. thysanodes* compiled in this study. Red dots indicate males and blue dots indicate females. This map strongly supports the Chihuahuan distribution hypothesis with separate populations occurring in a narrow band along the Front Range of the Southern Rocky Mountains and in western Colorado. Map prepared by M. Hayes.

Table 3. Analysis of Variance comparing reproductive classes, sex classes, and the interaction between reproductive and sex classes using 546 individual records of *M. thysanodes* from Colorado.

Source	DF	Mean Square	F Value	Pr > F
Reproductive Class	2	330,931	7.03	0.0010
Sex Class	1	4,478	0.10	0.7578
Repro*Sex	2	124,495	2.65	0.0718

Table 4: Student-Newman-Keuls test results comparing reproductive and sex classes using 546 individual records of *M. thysanodes* from Colorado. In the SNK groupings, means with the same letter are not significantly different.

SNK Grouping	Mean Elev	N	Sex
A	1920.4	233	M
A	1892.4	313	F

SNK Grouping	Mean Elev	N	Repro
A	1949.8	210	N
B	1884.0	271	R
B	1842.5	65	J

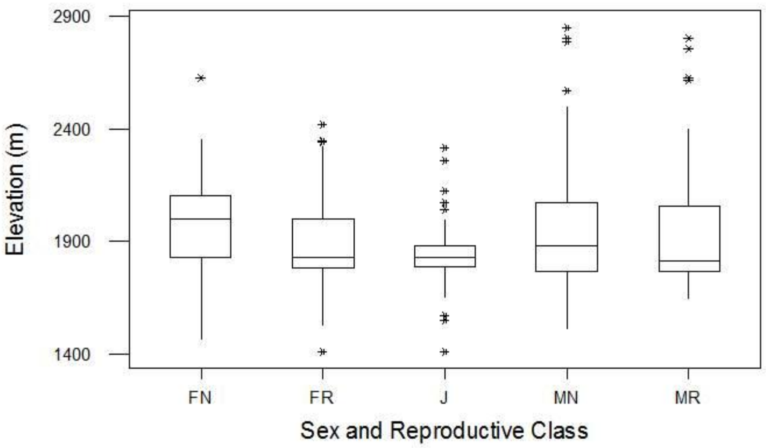


Figure 5: Box plot of elevation of occurrence in meters of *M. thysanodes* in Colorado versus sex and reproductive classes. FN = adult non-reproductive females; FR = adult reproductive females (pregnant, lactating, or post-lactating); J = juveniles (male and female combined); MN = adult non-reproductive males; and MR = adult reproductive males. Total number of individual records = 546. These plots show the distributional characteristics of the data, including medians, quartiles, and outliers.

Maternity Roost Selection

Fourteen maternity sites were identified in or near Colorado. Of the female *M. thysanodes* tracked to maternity roosts, all but two bats stayed in the same roost location until the transmitter battery failed. Of the two females that moved, each moved only once to a nearby roost within a 500 meter radius of the original roost. An example maternity roost site is shown in Figure 6. Radio-tracking results are shown in Table 5. Of 13 transmitters used, eight bats were tracked to roosts (seven *M. thysanodes* and 1 *C. townsendii*). A list of *M. thysanodes* maternity roosts that I documented thus far in Colorado is shown in Table 6. Within our study area along the Front Range in Boulder and Larimer counties, I documented ten maternity roosts for this species (Figure 7).

Figure 6. Photographs of a maternity roost site of *M. thysanodes* located in a south-facing rock face in the Cache la Poudre Canyon. Both photos are of the same roost site, Hewlett Gulch #1. The yellow arrow points to the roost location. The photo on the right is taken from the banks of the Cache la Poudre River. (Photos by M. Hayes).

Table 5. Summary of radio-tracking results. Listed are the date the radio-transmitter was applied; the location (including county; BC = Boulder County, LC = Larimer County, FC = Fremont County); frequency of the transmitter (MHz); species tagged (COTO = *C. townsendii*, MYTH = *M. thysanodes*); sex; reproductive status (L = lactating, PL = post-lactating); mass in grams; and tracking outcome. The dates listed in tracking outcome describe the dates during which the bat was tracked, unless otherwise specified. NOTE: I only captured one reproductive female *M. thysanodes* during the 2009 field season, and none were captured during the 2010 field season.

Date Applied	Location	Frequency	Species, Sex, Repro, Mass, and Results
July 22, 2007	Sunset City Mine (FC)	164.381	MYTH, F, L, 8.5g. Located in rock face 7/22-7/29.
Aug 8, 2007	HVR Quarry (BC)	164.406	COTO, F, L, 11.2g, Located in St. Vrain Canyon 8/10-15. Rock feature. No longer there on 8/23.
Aug 27, 2007	Redstone pool (LC)	164.431	MYTH, F, PL, 8.6g, Rock face 8/28-9/5. Switched locations on 9/1. No signal on 9/6.
June 27, 2008	Hewlett Gulch-SC (LC)	164.355	MYTH, F, L, 9.1g, Unable to locate. Radio malfunction?
July 10, 2008	HVR Quarry (BC)	164.331	COTO, F, L, 10.7g. Unable to locate.
July 18, 2008	Redstone pool (LC)	164.104	MYTH, F, L, 8.9g. Located 7/19-26. Rock face.
July 20, 2008	Hewlett Gulch (LC)	164.005	MYTH, F, L, 7.1g. Located 7/21-7/30. Rock face.
July 27, 2008	Hewlett Gulch-SC (LC)	164.280	MYTH, F, L, 8.4g. Located 7/28- 8/11. Rock face.
July 28, 2008	Long Canyon (BC)	164.030	MYTH, F, PL, 7.1g. Located 7/30 in 2nd Flatiron. Lost 8/1.
Aug 11, 2008	Hewlett Gulch-p (LC)	164.254	MYTH , F, PL, 7.9g. Located 8/12-8/24. Rock face.
July 17, 2009	HVR Quarry (BC)	164.180	MYTH, F, L, 7.8g. Unable to locate.
July 17, 2009	HVR Quarry (BC)	164.154	COTO, F, L, 10.2g. Unable to locate.
Aug 12, 2009	HVR Quarry (BC)	164.130	COTO, F, L, 11.1g. Unable to locate.

Table 6. *M. thysanodes* maternity colonies identified in Colorado or near Colorado. The abbreviation MYTH indicated *M. thysanodes.*

Maternity Site	County	Roost Substrate	Comments
Murry Cabin	Archuleta, CO	Abandoned cabin	Occupied by MYTH females in 2009.
Wiggin's Mine	Union, NM	Abandoned mine	Occupied by MYTH females 2007-9.
Skull Canyon Mine	Baca, CO	Abandoned mine	Occupied by MYTH females 2007-9.
Sunset City Roost	Fremont, CO	Rock Face	MYTH female tracked to roost in 2007.
2nd Flatiron	Boulder, CO	Rock Face	Multiple MYTH females tracked prior to and during 2008 by Adams & Hayes.
Der Zerkle	Boulder, CO	Rock Face	MYTH female tracked and multiple females observed by Adams over multiple years.
Eldorado Mountain	Boulder, CO	Rock Face	MYTH female tracked by Adams.
Geer Canyon	Boulder, CO	Rock Face	MYTH female tracked by Adams.
Mt. Sanitas	Boulder, CO	Rock Face	MYTH female tracked by Adams.
North Eldorado	Boulder, CO	Rock Face	MYTH female tracked by Adams.
Redstone Canyon	Larimer, CO	Rock Face	MYTH females tracked to rock face in 2007-8.
Hewlett Gulch #1	Larimer, CO	Rock Face	MYTH females tracked to site in 2007-8.
Hewlett Gulch #2	Larimer, CO	Rock Face	MYTH female tracked to site in 2007-8.
Hewlett Boulder	Larimer, CO	Large boulder	MYTH female tracked to site in 2008.

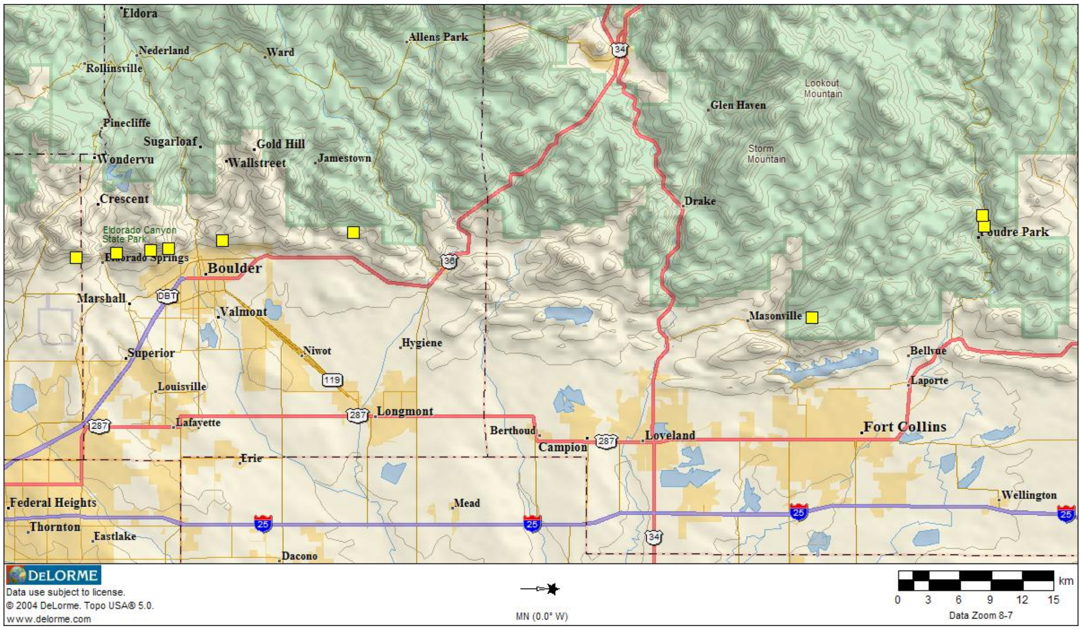


Figure 7: Locations of nine known maternity roosts of *M. thysanodes* in Boulder and Larimer Counties, Colorado. Yellow squares represent the locations of maternity roosts.

Landscape variables used in final modeling of maternity roost selection by *M. thysanodes* along the Front Range in Boulder and Larimer counties, Colorado, are shown in Table 7. The chi-square goodness-of-fit test for the landscape analysis of maternity roost selection by *M. thysanodes* along the Front Range in Boulder and Larimer counties, Colorado, suggested that data adequately fit the landscape global model (Hosmer-Lemeshow $\chi^2 = 1.363$, df = 8, $P = 0.995$; Note: a P-value of ≤ 0.05 indicated significant evidence that the data do not adequately fit the global model). The estimated variation inflation factor ($\hat{c} = 0.17$) suggested data were not over-dispersed (Burnham and Anderson 2002). The model that incorporated Grade and Transformed Aspect had most support (G+A; $w_i = 0.43$) (Table 8). The next most parsimonious model was one that incorporated Elevation, Grade, and Transformed Aspect (E + G + A; $w_i = 0.23$). The third most parsimonious model utilized Grade, Transformed Aspect, and Proximity to Water (G + A + W; $w_i = 0.16$). The second and third best models are both within 2 AIC_c points of the best model, and are therefore considered to be competing models, given this data set.

Grade received the highest cumulative AIC_c weight ($w_+ = 1.00$), followed by Transformed Aspect ($w_+ = 0.89$), Elevation ($w_+ = 0.37$), and Proximity to Water ($w_+ = 0.27$) (Table 9). Unconditional parameter estimates ($\tilde{\bar{\beta}}_i$), unconditional standard errors, and associated 95% confidence intervals for each model variable is shown in Table 10. The 95% confidence interval for the unconditional parameter estimates for Grade did not overlap 0 (0.0840 – 0.0952) and this variable is considered to have stronger support, given this data set. The 95% confidence interval for the unconditional parameter estimate Transformed Aspect also did not overlap 0 (4.6508 – 11.1891) and is considered to have stronger support, given this data set.

A preliminary *M. thysanodes* maternity roost suitability index is shown in Figure 8. In this figure, the unconditional parameter estimates ($\tilde{\bar{\beta}}_i$), unconditional standard error, and associated 95% confidence interval for the variables grade and transformed aspect are used to show a “maternity roost suitability index” for *M. thysanodes* along the Front Range in Boulder and Larimer counties. The x-axis represents a Z-value and incorporates the intercept, grade and transformed aspect using the formula for Z derived from the best model. The y-axis is the suitability index ($f(\hat{z})$) and is constrained between 0 and 1.0.

Table 7. Landscape variables used in final modeling of maternity roost selection by *M. thysanodes* along the Front Range in Boulder and Larimer counties, Colorado. Data were collected at maternity roosts and randomly-selected potential roost sites (n = 9 maternity roosts and n = 100 randomly selected potential roosts).Variables at randomly-selected potential roosts and maternity roosts are shown as the mean ($\bar{X}$), standard error (SE), and associated 95% confidence interval (%CI).

	Potential Roosts		Maternity Roosts	
Variable	$\bar{X}$ (SE)	95% *CI*	$\bar{X}$ (SE)	95% *CI*
Elevation (m)	3,750	3,456 – 4,064	3,880	3,631 – 4,129
Grade	11.32	8.48 – 14.16	43.22	32.61 – 53.58
Aspect (transformed)	0.69	0.64 – 0.74	0.93	0.86 – 0.99
Proximity to water	988	744 – 1,202	546	274 – 817

Table 8. Log-likelihood, number of parameters (*K*), Akaike's Information Criterion adjusted for small sample size (AIC_c), AIC_c difference (Δ_i), and AIC_c weight (w_i) for each landscape model used in the balanced model comparison using data collected at 109 sites. *n* = 9 *M. thysanodes* maternity sites and *n* = 100 randomly selected potential roost sites. E = elevation; G = grade; A = transformed aspect; W = proximity to water. The model "E+G+A+W", for example, includes all four variables, elevation, grade, transformed aspect, and proximity to water. Higher AIC_c weights (w_i) indicate more support for the model, given the variables and data used.

Model	Log-Likelihood	*K*	AIC_c	Δ_i	w_i
E+G+A+W	-15.510	5	41.60	3.23	0.08
E+G+A	-15.575	4	39.59	1.25	0.23
E+G+W	-18.156	4	44.70	6.42	0.02
E+A+W	-23.945	4	56.26	17.99	0.00
G+A+W	-15.940	4	40.26	1.98	0.16
E+G	-18.232	3	42.69	4.41	0.05
E+A	-25.207	3	56.64	18.38	0.00
E+W	-30.022	3	66.27	27.99	0.00
G+W	-19.484	3	45.20	6.92	0.00
A+W	-23.961	3	54.15	15.87	0.01
G+A	-16.026	3	38.28	0.00	0.43
E	-31.038	2	66.19	27.91	0.00
G	-19.830	2	43.70	5.49	0.03
A	-25.234	2	54.58	16.30	0.00
W	-30.081	2	64.28	25.99	0.00

Table 9. Cumulative AIC$_c$ weight (w_+) for each landscape variable used in the balanced model comparison using data collected at 109 sites. n = 9 *M. thysanodes* maternity sites and n = 100 randomly selected potential roost sites. A cumulative AIC$_c$ weight (w_+) of 1.00 indicates the highest possible weight and suggests that the variable is the most important variable, given the variables and data used.

Variable	w_+
Elevation	0.37
Grade	1.00
Aspect (transformed)	0.89
Proximity to water	0.27

Table 10. Unconditional parameter estimates ($\tilde{\bar{\beta}}_i$), unconditional standard error, and associated 95% confidence interval for the 4 landscape variables used in the balanced model comparison using data collected at 109 sites. n = 9 *M. thysanodes* maternity sites and n = 100 randomly selected potential roost sites.

			95% Confidence Interval	
Variable	$\tilde{\bar{\beta}}_i$	SE	Lower	Upper
Constant (intercept)	-10.5654	1.9339	-14.3558	-6.7750
Elevation	0.0000	0.0000	0.0000	0.0000
Grade	0.0896	0.0029	0.0840	0.0952
Aspect (transformed)	7.9200	1.6679	4.6508	11.1891
Proximity to water	-0.0001	0.0001	-0.0003	0.0001

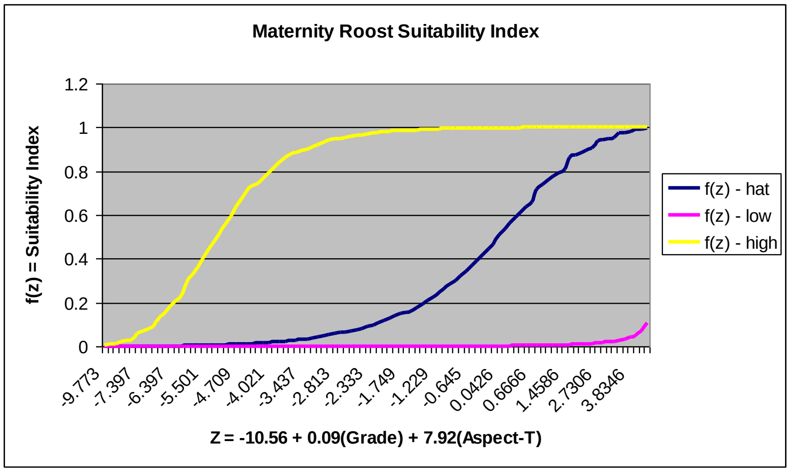


Figure 8. Preliminary *M. thysanodes* maternity roost suitability index for the Front Range Study area in Boulder and Larimer counties, Colorado. In this figure, the unconditional parameter estimates ($\tilde{\tilde{\beta}}_i$), unconditional standard error, and associated 95% confidence interval for the variables "grade" and "transformed aspect" are used to show a *preliminary* "maternity roost suitability index" for *M. thysanodes* along the Front Range in Boulder and Larimer counties. The x-axis represents a Z-value and incorporates the intercept, grade and transformed aspect using the formula for Z shown. The y-axis is the suitability index (f(z)) and is constrained between 0 and 1.0. The blue line ($f(\hat{z})$) uses the unconditional parameter estimates to estimate the suitability index. The pink and yellow lines represent lower and upper estimates for ($f(\hat{z})$) using the lower and upper 95% confidence interval for each parameter estimate.

Roost site variables used in final modeling of maternity roost selection by *M. thysanodes* along the Front Range in Boulder and Larimer counties, Colorado, are shown in Table 11. An example of a randomly-selected roost used in the roost site analysis is shown in Figure 9. The chi-square goodness-of-fit test for the roost-site analysis of maternity roost selection by *M. thysanodes* in Colorado suggested that data adequately fit the landscape global model (Hosmer-Lemeshow $\chi^2 = 6.176$, df = 8, $P = 0.627$). The estimated variation inflation factor ($\hat{c} = 0.77$) suggested data were not over-dispersed (Burnham and Anderson 2002). The model that estimated volume of the structure had the most support (w_i = 0.30; Table 12). The next most parsimonious models incorporated temperature and relative humidity inside the structure (w_i = 0.26) and temperature inside the structure and the estimated volume of the structure (w_i = 0.23; Table 12).

Table 11. Roost-site variables used in final modeling of maternity roost selection by *M. thysanodes* in Colorado. Variables at randomly-selected potential roosts and maternity roosts shown as the mean ($\bar{X}$), standard error (SE) and associated 95% confidence interval (CI). Data were collected at maternity roosts and randomly selected potential roost sites (*n* = 9 maternity roosts and *n* = 18 randomly selected potential roosts).

	Potential Roosts		Maternity Roosts	
Variable	$\bar{X}$ (SE)	95% *CI*	$\bar{X}$ (SE)	95% *CI*
Mean Temp (°C)	20.0 (1.2)	17.5-22.5	20.9 (1.3)	18.6-23.3
Mean Humidity (%RH)	62.6 (20.0)	23.5-101.7	60.1 (19.0)	22.8-97.3
Roost Volume (m^3)	4.3 (4.2)	0 - 12.5	785.4 (520.5)	0 - 1805
Thermal Entropy* (S)	3.6 (0.1)	3.5-3.8	3.2 (0.4)	2.4-3.9

*See the Analysis section for a discussion of thermal entropy.

Estimated roost volume received the highest cumulative AIC_c weight (w_+ = 0.74), followed by average roost temperature (w_+ = 0.56), and relative humidity (w_+ = 0.47). (Table 13). Unconditional parameter estimates ($\tilde{\bar{\beta}}_i$), unconditional standard errors, and associated 95% confidence intervals for each model variable is shown in Table 14. The 95% confidence intervals for the unconditional parameter estimates for average roost temperature, relative humidity, and estimated roost volume all overlapped 0, and therefore these variables are not considered to have stronger support, given this data set.

Example temperature and relative humidity profiles during the maternity season from June 1 to August 15, for *M. thysanodes* roosts in an abandoned mine and abandoned cabin, and a randomly selected ponderosa tree snag, are shown in Figures 10 -16. Temperatures and relative humidity profiles for a 24-hour period on June 1, 2009, inside Skull Canyon mine and Murray Cabin, which are both *M. thysanodes* maternity sites, and a randomly-selected ponderosa tree snag are shown in Figures 16-17.

Figure 9. Photographs of the randomly-selected potential roost site in a ponderosa pine tree snag near Grey Rock, in Larimer County, Colorado. The right photo shows the snag deteriorating near the base. Both photos are of the same potential roost site. (Photos by M. Hayes).

Table 12. Log-likelihood, number of parameters (*K*), Akaike's Information Criterion adjusted for small sample size (AIC_c), AIC_c difference (Δ_i), and AIC_c weight (w_i) for each roost-site model used in the balanced model comparison using data collected at maternity roosts and randomly selected potential roost sites. *n* = 9 maternity roosts and *n* = 18 randomly selected potential roosts. Model variables are: Temp = Average roost temperature (°C); Humidity = Relative Humidity (%RH); Volume = Estimated roost volume (m^3). The model "Temp+Humidity+Volume", for example, includes all three variables. Higher AIC_c weights (w_i) indicate more support for the model, given the variables and data used.

Model	Log-Likelihood	*K*	AIC_c	Δ_i	w_i
Temp+Humidity+Volume	-11.758	4	33.26	3.05	0.06
Temp+Humidity	-11.758	3	30.52	0.31	0.26
Temp+Volume	-11.861	3	30.72	0.52	0.23
Humidity+Volume	-12.336	3	31.67	1.47	0.14
Temp	-17.179	2	38.84	8.63	0.00
Humidity	-17.449	2	39.38	9.17	0.00
Volume	-12.863	2	30.21	0.00	0.30

Table 13. Cumulative $\mathrm{AIC_c}$ weight (w_+) for each roost-site variable used in the balanced model comparison using data collected at maternity roosts and randomly selected potential roost sites. $n = 9$ maternity roosts and $n = 18$ randomly selected potential roosts. A cumulative $\mathrm{AIC_c}$ weight (w_+) of 1.00 indicates the highest possible weight and the variable with the highest score is considered the most important variable, given the variables and data used.

Variable	w_+
Average roost temperature (°C)	0.56
Relative humidity (%RH)	0.47
Estimated roost volume (m^3)	0.74

Table 14. Unconditional parameter estimates ($\tilde{\tilde{\beta}}_i$), unconditional standard error, and associated 95% confidence interval for the 3 roost-site variables used in the balanced model comparison using data collected at maternity roosts and randomly selected potential roost sites. $n = 9$ maternity roosts and $n = 18$ randomly selected potential roosts. Unconditional parameter estimates ($\tilde{\tilde{\beta}}_i$) with associated 95% confidence intervals that do not overlap 0 are considered to have stronger support, given the variables and data set used.

			95% Confidence Interval	
Variable	$\tilde{\tilde{\beta}}_i$	SE	Lower	Upper
Average roost temperature (°C)	0.0963	0.1485	-0.1947	0.3872
Relative humidity (%RH)	-0.0079	0.0262	-0.0593	0.0436
Estimated roost volume (m^3)	0.0112	0.0118	-0.0119	0.0343

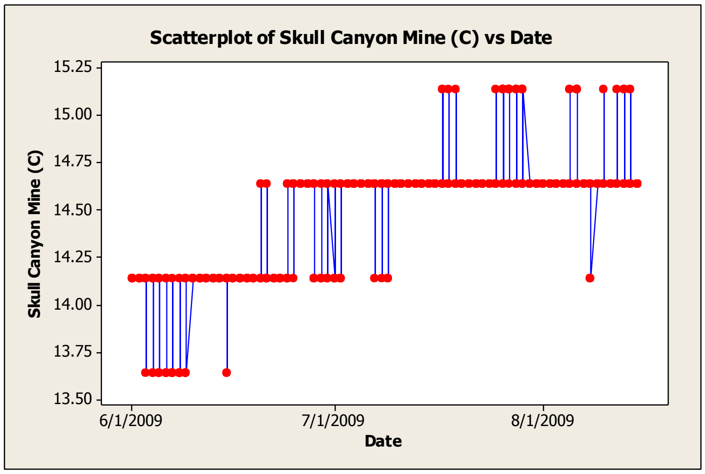


Figure 10. Temperature profile for the Skull Canyon copper mine roost in Baca County, Colorado, from June 1 to August 15, 2009. This *M. thysanodes* maternity site had the most stable temperature ($\bar{X} = 14.5$ °C, $\sigma = 0.3$) with the lowest estimated thermal entropy (*S*=0.9933) of all sites evaluated.

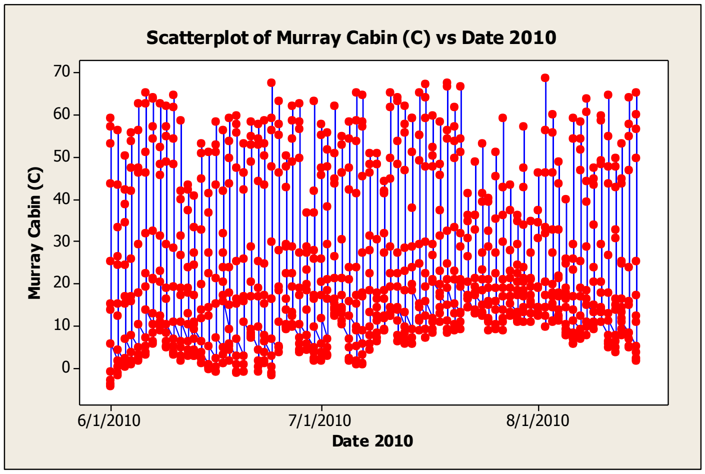


Figure 11. Temperature profile for the Murray Cabin maternity roost in Archuleta County, Colorado, from June 1 to August 15, 2010. This *M. thysanodes* maternity site had the most variable temperature ($\bar{X} = 24.3$ °C, $\sigma = 17.6$) with the highest estimated thermal entropy (*S*=4.6730) of all sites evaluated.

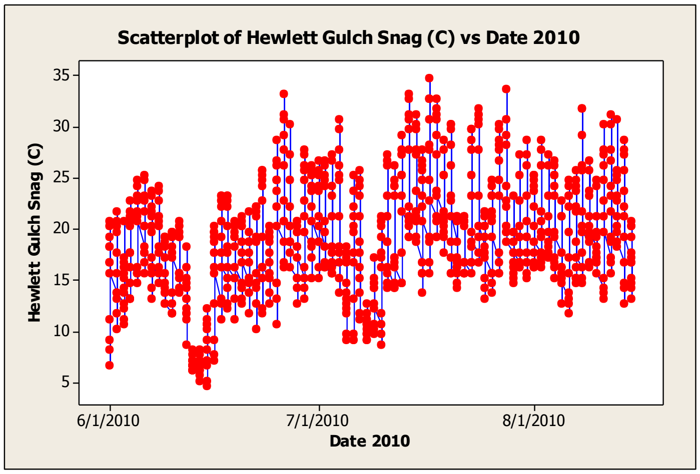


Figure 12. Temperature profile for the randomly selected ponderosa tree snag near Grey Rock, Larimer County, Colorado, from June 1 to August 15, 2010. This randomly-selected potential roost had relatively high variability in temperature ($\bar{X} = 19.1$ °C, $\sigma = 5.6$) with a relatively high estimated thermal entropy (*S*=3.8000).

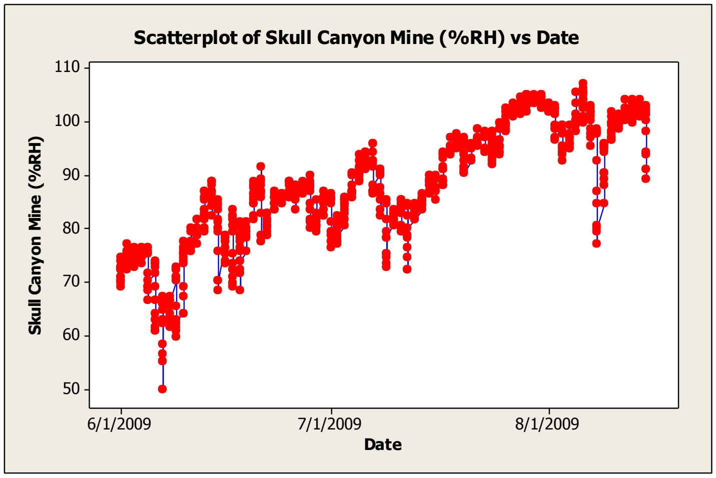


Figure 13. Relative humidity profile for the Skull Canyon copper mine roost in Baca County, Colorado, from June 1 to August 15, 2009. This *M. thysanodes* maternity site had the lowest variability in relative humidity ($\bar{X} = 87.7$, $\sigma = 10.9$) of all sites evaluated, except for one randomly-selected north-facing rock crevice (not shown).

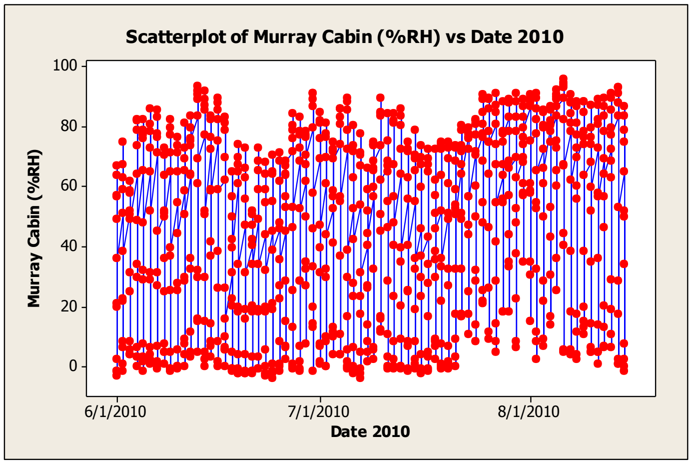


Figure 14. Relative humidity profile for the Murray Cabin maternity roost in Archuleta County, Colorado, from June 1 to August 15, 2010. This *M. thysanodes* maternity site had the highest variability in relative humidity ($\bar{X}$ = 50.2, σ = 34.6) of all sites evaluated.

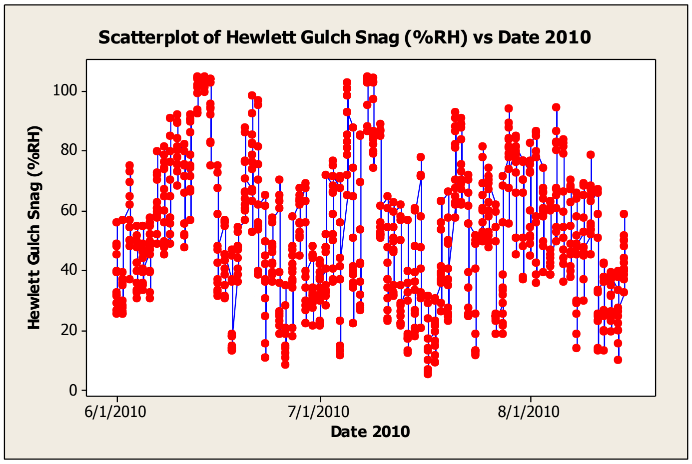


Figure 15. Relative humidity profile for the randomly selected ponderosa tree snag near Grey Rock, Larimer County, Colorado, from June 1 to August 15, 2010. This randomly-selected potential roost exhibited moderate variation in relative humidity ($\bar{X}$ = 52.6, σ = 23.6) when compared to all sites evaluated.

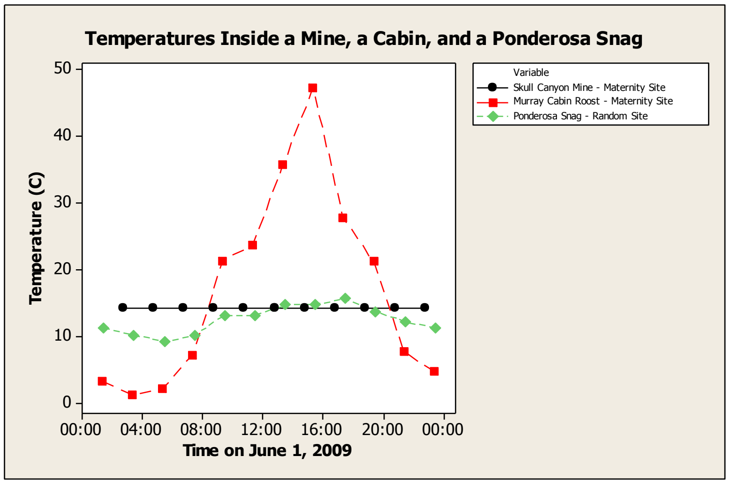


Figure 16. Temperatures (°C) inside Skull Canyon mine and Murray Cabin, which are both *M. thysanodes* maternity sites, and a randomly-selected ponderosa tree snag near Grey Rock, on June 1, 2009.

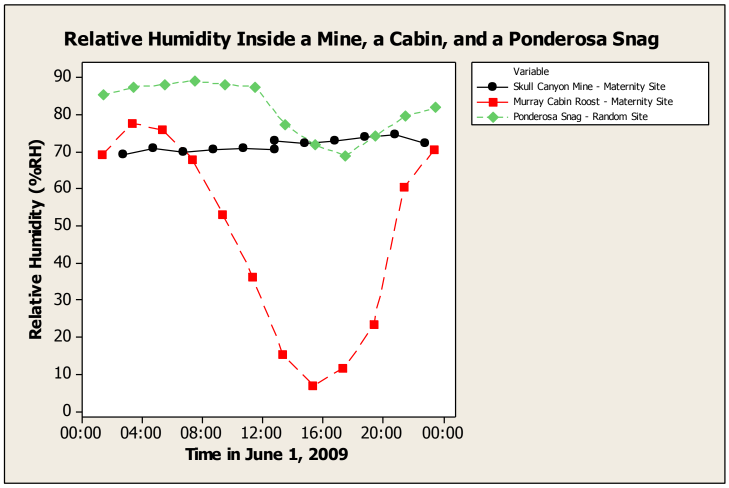


Figure 17. Relative humidity (%RH) inside Skull Canyon mine and Murray Cabin, which are both *M. thysanodes* maternity sites, and a randomly-selected ponderosa tree snag near Grey Rock, on June 1, 2009.

Population Modeling and Climate Change

I used the following age structured population model and initial age distribution in this analysis:

$$\begin{vmatrix} 0 & 0.355 & 0.455 & 0.455 \\ 0.475 & 0 & 0 & 0 \\ 0 & 0.795 & 0 & 0 \\ 0 & 0 & 0.795 & 0.795 \end{vmatrix} \quad \text{x} \quad \begin{vmatrix} 600 \\ 290 \\ 230 \\ 880 \end{vmatrix}$$

The dominant eigenvalue (λ) of this matrix is 1.00049, and is equivalent to the growth rate of the initial population. Sensitivity analysis showing the sensitivity (s), or change in population growth rate (λ), resulting from a 10% decrease in each vital rate is shown in Table 15. In this analysis the mean adult survival rate ($S_A = 0.0550$) showed the highest sensitivity and mean female birth rates of 1-year-old females (F_1) showed the lowest sensitivity.

In Boulder County, Colorado, 155 adult female *M. thysanodes* were captured from 1995-2009 (1995 = 6 bats; 1996 = 12 bats; 1997 = 10 bats; 1998 = 13 bats; 1999 = 21 bats; 2000 = 12 bats; 2001 = 5 bats; 2002 = 9 bats; 2003 = 6 bats; 2004 = 10 bats; 2005 = 8 bats; 2006 = 29 bats; 2007 = 7 bats; 2008 = 2 bats; 2009 = 5 bats). A total of 137 of the 155 adult female *M. thysanodes* were identified as pregnant, lactating, or post-lactating (88.4%).

Table 15. Sensitivity analysis showing the sensitivity (*s*), or change in population growth rate (λ), resulting from a 10% decrease in each vital rate. S_P is mean survival rate of pups from parturition to their first birthday; S_A is the mean annual survival rate for adults; F_1 is mean female birth rate of 1-year-old females; F_2 is mean female birth rate of 2-year-old females; F_{3+} is mean female birth rate of 3-year-old-and-older females. Higher sensitivity values (*s*) for a vital rate relative to other vital rates indicates that the population growth rate (λ) is more sensitive to variation in that vital rate.

Vital Rate	Original Value	Decreased Vital Rate	λ	*s*
S_P	0.4750	0.4275	0.9855	0.0145
S_A	0.7950	0.7155	0.9450	0.0550
F_1	0.3500	0.3150	0.9945	0.0055
F_2	0.4425	0.3983	0.9910	0.0090
F_{3+}	0.4550	0.4095	0.9840	0.0160

Climate and streamflow variables used to model the relationship between reproductive condition in adult female *M. thysanodes* and climate and surface water conditions are shown in Table 16. Average daily maximum temperature (°C) from May through August for the year of capture was lower for reproductive females, and the 95% confidence interval for reproductive and non-reproductive females did not overlap. Average total precipitation (cm), average streamflow (cfs), and average peak streamflow (cfs) from May through August for the year of capture were all higher for reproductive females, and the 95% confidence interval for reproductive and non-reproductive females did not overlap.

Table 16. Variables used to model the relationship between reproductive condition in adult female *M. thysanodes* and climate and surface water conditions. Average daily maximum temperature (°C) from May through August for the year of capture; total precipitation (cm) from May through August for the year of capture; average streamflow (cfs) from May through August for the year of capture; and peak streamflow (cfs), expressed as the streamflow for the month with the highest streamflow from May through August for the year of capture. Each variable is shown for pregnant, lactating, and post-lactating (reproductive) and non-reproductive adult female *M. thysanodes*, expressed as the mean ($\bar{x}$), standard error (SE) and associated 95% confidence interval (CI). Data were collected for 155 adult female *M. thysanodes* (*n* = 137 reproductive and *n* = 18 non-reproductive) in Boulder County, during May, June, July, and August, 1995-2009. All variables are continuous variables.

	Reproductive		Non-reproductive	
Variable	$\bar{x}$ (SE)	95% *CI*	$\bar{x}$ (SE)	95% *CI*
Ave. max. temp.	27.7 (0.1)	27.6–27.8	28.4 (0.2)	28.2–28.6
Total precipitation	22.5 (0.6)	21.9–23.1	18.9 (1.21)	17.6–20.1
Ave streamflow	10,147 (290)	9,857–10,437	9,353 (419)	8,934–9,772
Peak streamflow	17,119 (590)	16,529–17,709	14,276 (696)	13,580–14,972

The Hosmer-Lemeshow goodness-of-fit test suggested that data adequately fit the global model (Ave. Flow + Peak Flow + Temp + Precip; $\chi^2 = 4.323$, df = 5, $P = 0.504$). The estimated variation inflation factor ($\hat{c} = 0.865$) suggested data are not over-dispersed (Burnham and Anderson 2002). AIC$_c$ weights for each model (w_i) are shown in Table

17. The model that incorporated average stream flow, peak stream flow, and precipitation had the most support ($w_i = 0.40$). The next most parsimonious models used average stream flow, peak stream flow, and average maximum temperature ($w_i = 0.19$) and average stream flow, peak stream flow, precipitation, and average maximum temperature ($w_i = 0.17$).

Table 17. Log-likelihood, number of parameters (*K*), Akaike's Information Criterion adjusted for small sample size (AIC_c), AIC_c difference (Δ_i), and AIC_c weight (w_i) for each model used in the reproductive condition model comparison using data collected on 155 adult female *M. thysanodes* in Boulder County, Colorado, May through August, 1995-2009. $n = 137$ reproductive and $n = 18$ non-reproductive. Abbreviations are: Average daily maximum temperature from May through August for the year of capture (Temp, °C); total precipitation from May through August for the year of capture (Precip, cm); Average streamflow from May through August for the year of capture (Flow, cfs); and peak streamflow (Peak, cfs), expressed as the streamflow for the month with the highest streamflow from May through August for the year of capture.

Model	Log-Likelihood	*K*	AIC_c	Δ_i	w_i
Flow + Peak + Precip	−48.70	4	105.67	0.00	0.40
Flow + Peak + Temp	−49.43	4	107.12	1.45	0.19
Flow + Peak + Tmp + Precp	−48.46	5	107.32	1.65	0.17
Flow + Peak	−51.88	3	109.92	4.25	0.05
Precip	−53.14	2	110.35	4.68	0.04
Temp	−53.22	2	110.52	4.85	0.04
Flow + Temp	−52.85	3	111.77	6.10	0.02
Flow + Precip	−52.92	3	111.99	6.33	0.02
Temp + Precip	−52.99	3	112.13	6.47	0.02
Peak + Precip	−53.00	3	112.15	6.49	0.02
Peak	−54.07	2	112.22	6.55	0.02
Peak + Temp	−53.14	3	112.44	6.77	0.01
Flow + Temp + Precip	−52.46	4	113.18	7.51	0.01
Peak + Temp + Precip	−52.93	4	114.12	8.45	0.01
Flow	−55.19	2	144.46	8.79	0.00

Cumulative AIC_c weight (w_+), unconditional parameter estimate ($\tilde{\tilde{\beta}}_i$), standard error, and 95% confidence interval for each variable used are shown in Table 18. Of the variables used in this analysis, average stream flow received the highest cumulative AIC_c weight ($w_+ = 0.90$), followed by peak stream flow ($w_+ = 0.88$), average maximum temperature ($w_+ = 0.73$), and total precipitation ($w_+ = 0.71$). Of the variables used, the 95% confidence interval for the unconditional parameter estimates for the average stream flow (−0.00124,−0.00015) and peak stream flow (0.00009, 0.00059) did not overlap 0. All other 95% confidence intervals for the unconditional parameter estimates, including the intercept, overlapped 0.

Table 18. Cumulative AIC_c weight (w_+), unconditional parameter estimate ($\tilde{\tilde{\beta}}_i$), unconditional standard error, and 95% confidence interval for the variables used in the reproductive condition balanced model set using data collected on 155 adult female *M. thysanodes* in Boulder County, Colorado, May through August, 1995-2009. $n = 137$ reproductive and $n = 18$ non-reproductive. Abbreviations are: Average daily maximum temperature (°C) from May through August for the year of capture (Temp); total precipitation (cm) from May through August for the year of capture (Precip); Average streamflow (cfs) from May through August for the year of capture (Ave. Flow); and peak streamflow (cfs), expressed as the streamflow for the month with the highest streamflow from May through August for the year of capture (Peak Flow).

				95%Confidence Interval	
Variable	w_+	$\tilde{\tilde{\beta}}_i$	SE	Lower	Upper
Intercept	--	8.1635	8.0755	−7.6644	23.9914
Ave. max. temp.	0.73	−0.2340	0.2543	−0.7326	0.2645
Total precipitation	0.71	0.0957	0.0659	−0.0335	0.2248
Average streamflow	0.90	−0.0007	0.00028	−0.00124	−0.00015
Peak streamflow	0.88	0.0003	0.00013	0.00009	0.00059

The model that included average stream flow, peak stream flow, and precipitation provided the best model for predicting reproductive status for adult female *M. thysanodes*. However, there was a significant correlation between all variables used in this analysis, using the Pearson product moment correlation calculation (Table 19).

Table 19. Pearson product moment correlations (ρ) and p-value for each variable combination of the variables used to model the relationship between reproductive condition in adult female *M. thysanodes*, climate and surface water conditions. The variable used are: Average daily maximum temperature (°C) from May through August for the year of capture; total precipitation (cm) from May through August for the year of capture; Average streamflow (cfs) from May through August for the year of capture; and peak streamflow (cfs), expressed as the streamflow for the month with the highest streamflow from May through August for the year of capture. Data were collected for 155 adult female *M. thysanodes* (*n* = 137 reproductive and *n* = 18 non-reproductive) in Boulder County, during May, June, July, and August, 1995-2009. All variables are continuous variables.

Variable Combination	ρ	P-Value
Ave. Flow × Peak Flow	0.928	0.000
Ave. Flow × Precip	0.697	0.000
Ave. Flow × Temp	−0.686	0.000
Peak Flow × Precip	0.627	0.000
Peak Flow × Temp	−0.643	0.000
Precip × Temp	−0.852	0.000

For the population dynamics analysis conducted here, I used only the unconditional parameter estimate for the variable "maximum daily summer temperature" to estimate yearly reproductive rates for *M. thysanodes*. This is because I did not feel comfortable that I had access to high quality climate projections related to precipitation and stream flows in our study area through all years from 2000 to 2100. As more data becomes available, such data will be useful in future population modeling and investigation of climate change impacts in the Southern Rocky Mountains. A time plot of estimated adult female reproductive rates for females that are 2 years old and older is shown in Figure 18. In this figure I have used estimated reproductive rates for *M. thysanodes* for our study area in Boulder County, Colorado, using historical data to estimate reproductive rates through 2010 and the parameter estimate for average daily maximum summer temperature shown in Table 18 ($\tilde{\bar{\beta}}_i = -0.2340$) to estimate reproductive rates through year 2100.

Histograms of the seven Monte Carlo simulations are shown in Figures 19 - 25. The simulation using a stable age structured population model without incorporating climate change had mean final population in year 2100 of 1,981. This represents 99.05% of the original population size of 2,000 in year 2000. All six simulations of forest bat populations in the Southern Rocky Mountains using Monte Carlo simulations and the age-structured population model exhibited significant decreases in mean population size by year 2100 (Myotis B1, $\bar{X} = 234$, $\sigma = 43.0$; Myotis B2, $\bar{X} = 138$, $\sigma = 24.0$; Myotis A2, $\bar{X} = 32$, $\sigma = 5.6$; *M. thysanodes* B1, $\bar{X} = 68$, $\sigma = 12.0$; *M. thysanodes* B2, $\bar{X} = 68$, $\sigma = 12.0$; *M. thysanodes* A2, $\bar{X} = 27$, $\sigma = 4.8$) (Figures 20-25). Simulations of forest bat populations (*Myotis* and *M. thysanodes*) in the Southern Rocky Mountains using the seven Monte Carlo simulations and the age-structured population model presented are shown in Figure 26.

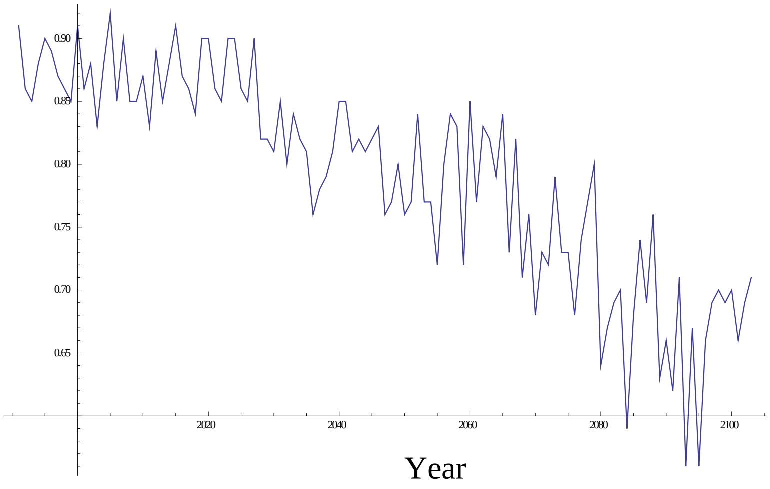


Figure 18. Plot of estimated adult female reproductive rates for *M. thysanodes* from year 1991 to 2103. Estimates are derived from historical data from 1991 to 2010, and from the parameter estimate for average daily maximum summer temperature shown in Table 18 ($\tilde{\bar{\beta}}_i = -0.2340$).

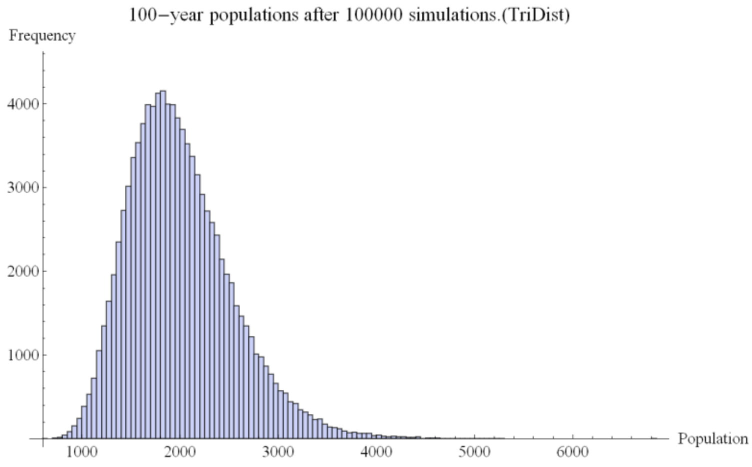


Figure 19. Histogram of the Monte Carlo simulation using the age-structured population model without incorporating a climate change scenario. This Monte Carlo simulation shows the theoretical bat population in the year 2100 after beginning with a population of 2,000 females in the year 2000 (600 newborn pups, 290 one-year-olds, 230 two-year-olds, and 880 three-plus-year-olds) and using 100,000 runs of 100 years each from years 2000 to 2100. The mean population at year 2100 ($\bar{X} = 1981$, $\sigma = 530$, min = 599, max = 5893) is 99.05% of the original population of 2,000 females.

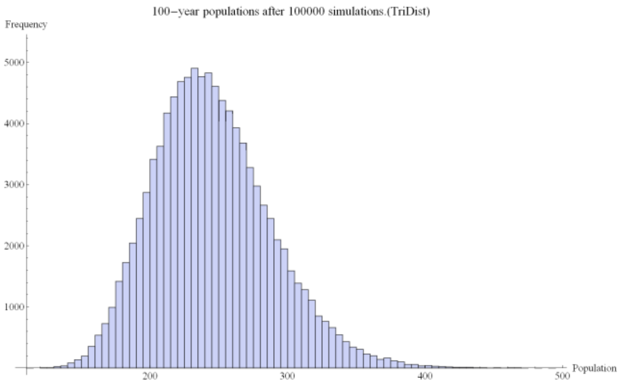


Figure 20. Histogram of the Monte Carlo simulation using the age-structured population model, Adams' *Myotis* model of female reproductive success and mean high summer temperatures, and the IPCC SRES B1 Climate Change Scenario, rescaled for our Boulder, Colorado study area. This Monte Carlo simulation shows the theoretical bat population in the year 2100 after beginning with a population of 2,000 females in the year 2000 (600 newborn pups, 290 one-year-olds, 230 two-year-olds, and 880 three-plus-year-olds) and using 100,000 runs of 100 years each from years 2000 to 2100. The mean population at year 2100 ($\bar{X} = 234$, $\sigma = 43$, min = 113, max = 505) is 11.7% of the original population of 2,000 females.

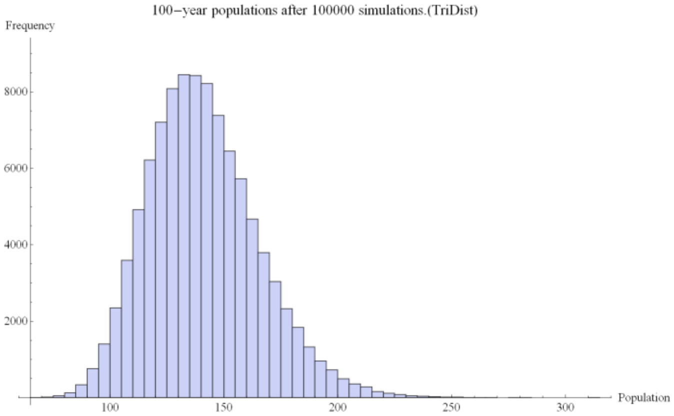


Figure 21. Histogram of the Monte Carlo simulation using the age-structured population model, Adams' *Myotis* model of female reproductive success and mean high summer temperatures, and the IPCC SRES B2 Climate Change Scenario, rescaled for our Boulder, Colorado study area. This Monte Carlo simulation shows the theoretical bat population in the year 2100 after beginning with a population of 2,000 females in the year 2000 (600 newborn pups, 290 one-year-olds, 230 two-year-olds, and 880 three-plus-year-olds) and using 100,000 runs of 100 years each from years 2000 to 2100. The mean population at year 2100 ($\overline{X} = 138$, $\sigma = 24$, min = 63, max = 290) is 6.9% of the original population of 2,000 females.

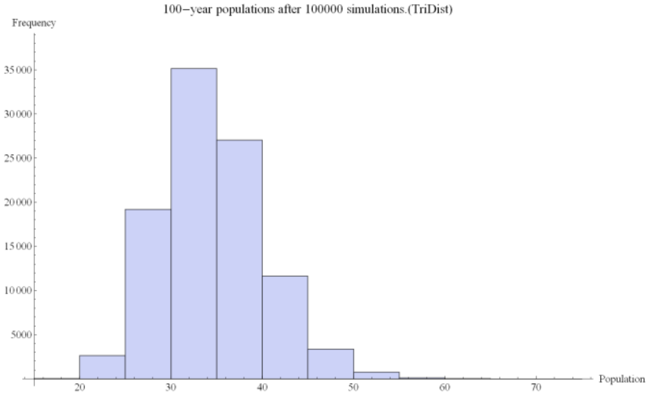


Figure 22. Histogram of the Monte Carlo simulation using the age-structured population model, Adams' *Myotis* model of female reproductive success and mean high summer temperatures, and the IPCC SRES A2 Climate Change Scenario, rescaled for our Boulder, Colorado study area. This Monte Carlo simulation shows the theoretical bat population in the year 2100 after beginning with a population of 2,000 females in the year 2000 (600 newborn pups, 290 one-year-olds, 230 two-year-olds, and 880 three-plus-year-olds) and using 100,000 runs of 100 years each from years 2000 to 2100. The mean population at year 2100 ($\overline{X} = 32$, $\sigma = 5.6$, min = 14, max = 65) is 1.6% of the original population of 2,000 females.

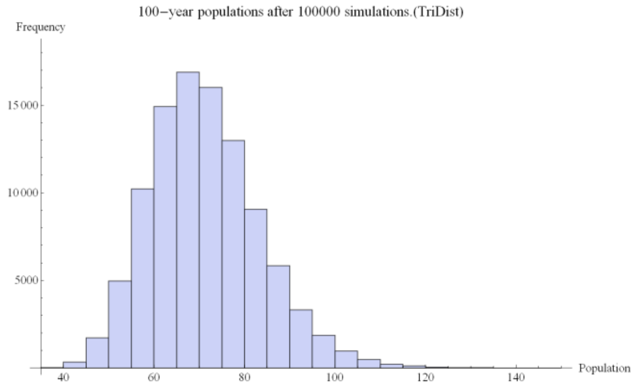


Figure 23. Histogram of the Monte Carlo simulation using the age-structured population model, the *Myotis thysanodes* model of female reproductive success and mean high summer temperatures, and the IPCC SRES B1 Climate Change Scenario, rescaled for our Boulder, Colorado study area. This Monte Carlo simulation shows the theoretical bat population in the year 2100 after beginning with a population of 2,000 females in the year 2000 (600 newborn pups, 290 one-year-olds, 230 two-year-olds, and 880 three-plus-year-olds) and using 100,000 runs of 100 years each from years 2000 to 2100. The mean population at year 2100 ($\overline{X} = 68$, $\sigma = 12.0$, min = 31, max = 158) is 3.4% of the original population of 2,000 females.

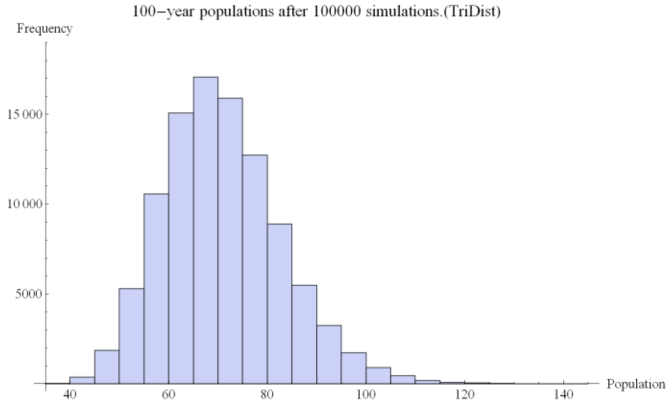


Figure 24. Histogram of the Monte Carlo simulation using the age-structured population model, the *Myotis thysanodes* model of female reproductive success and mean high summer temperatures, and the IPCC SRES B2 Climate Change Scenario, rescaled for our Boulder, Colorado study area. This Monte Carlo simulation shows the theoretical bat population in the year 2100 after beginning with a population of 2,000 females in the year 2000 (600 newborn pups, 290 one-year-olds, 230 two-year-olds, and 880 three-plus-year-olds) and using 100,000 runs of 100 years each from years 2000 to 2100. The mean population at year 2100 ($\overline{X} = 68$, $\sigma = 12.0$, min = 32, max = 141) is 3.4% of the original population of 2,000 females.

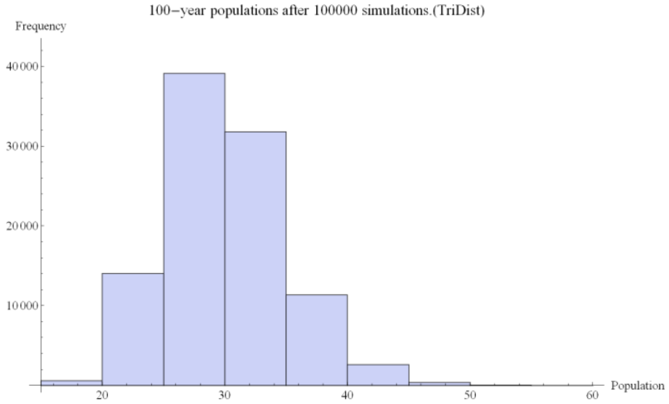


Figure 25. Histogram of the Monte Carlo simulation using the age-structured population model, the *Myotis thysanodes* model of female reproductive success and mean high summer temperatures, and the IPCC SRES A2 Climate Change Scenario, rescaled for our Boulder, Colorado study area. This Monte Carlo simulation shows the theoretical bat population in the year 2100 after beginning with a population of 2,000 females in the year 2000 (600 newborn pups, 290 one-year-olds, 230 two-year-olds, and 880 three-plus-year-olds) and using 100,000 runs of 100 years each from years 2000 to 2100. The mean population at year 2100 ($\overline{X}$ = 27, σ = 4.8, min = 12, max = 55) is 1.4% of the original population of 2,000 females.

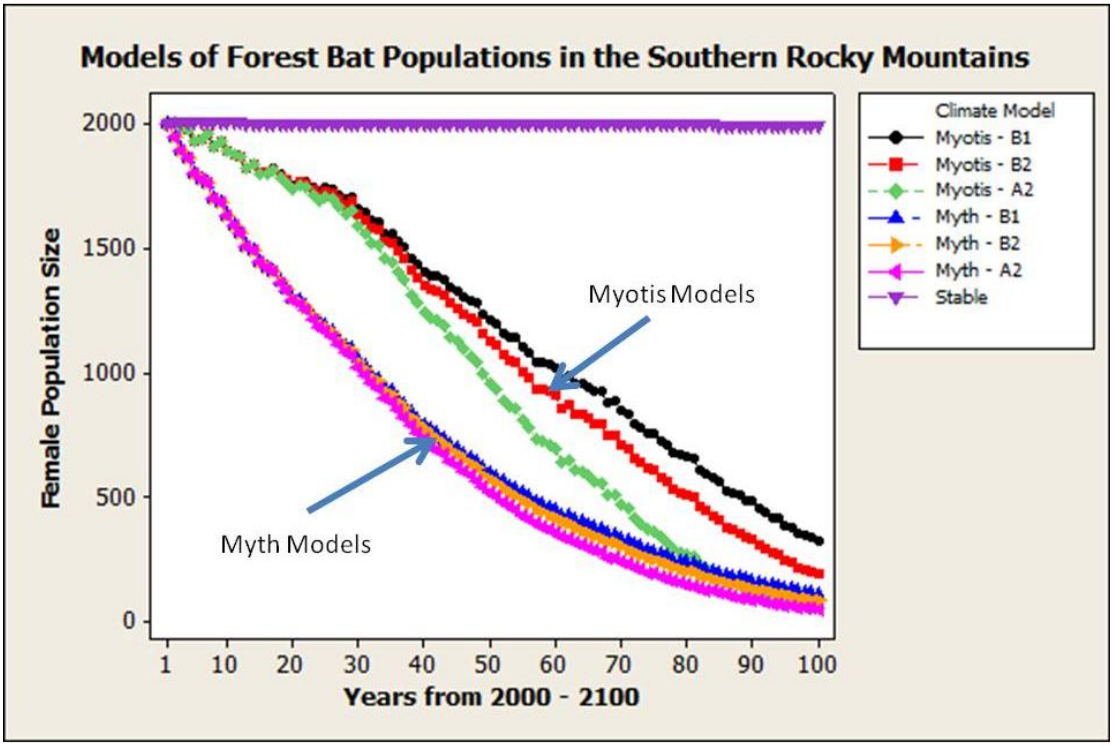


Figure 26. Simulations of forest bat populations in the Southern Rocky Mountains using 7 simulations and the age-structured population model presented. The "Stable" model assumes that the climate stays approximately at year 2000 levels. The "Myotis" simulations use Adams' (2010) generic *Myotis* model of female reproductive success and mean high summer temperatures. The "Myth" simulations use my species-specific *M. thysanodes* model of female reproductive success and mean high summer temperatures. All models are rescaled for our Boulder, Colorado study area. All models, except the stable model, use IPCC SRES Climate Change Scenarios (B1, B2, and A2). These simulations show the theoretical bat populations in the year 2100 after beginning with a population of 2,000 females in the year 2000 (600 newborn pups, 290 one-year-olds, 230 two-year-olds, and 880 three-plus-year-olds).

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Distribution

During this study, I compiled over 700 Colorado records of *M. thysanodes* from all available sources. This data set represents the most comprehensive assessment to date of the distribution of this species in the Southern Rocky Mountains. This information included capture and occurrence records for *M. thysanodes* from the Colorado Bats/Inactive Mines Project, which has conducted over 3,000 capture and internal surveys at abandoned mines throughout the Colorado Rockies since 1991.

These results strongly support the Chihuahuan distribution hypothesis that *M. thysanodes* exhibits a bifurcated geographic distribution with separate populations occurring in a narrow band along the Front Range of the Southern Rocky Mountains and separate populations occurring in western Colorado (Armstrong 1972, Armstrong et al. 1994, Fitzgerald et al. 1994, Adams 2003). This data set does not support the broader distribution hypothesis that *M. thysanodes* occurs throughout the Southern Rocky Mountains. These results suggest that the mountain ranges, mountain parks and valleys, and the Continental Divide of the Southern Rocky Mountains minimize or prevent dispersal and gene flow among populations on the eastern and western slopes of the Colorado Rockies.

In the analysis of elevational distribution of *M. thysanodes*, there were significantly different elevation mean sum of squares among reproductive classes (F value = 7.03, P = 0.0010), but not between sex classes (F value = 0.10, P = 0.7578). While there was overlap between the elevations of occurrence among all sex and reproductive classes, these results suggest that in Colorado juvenile and reproductive adult *M. thysanodes* of both sexes tend to occur at lower elevations than non-reproductive adults of both sexes.

Mountains have long been known to influence and shape the distribution of bat species. Findley (1969) discussed in some detail how mountains can influence the distribution patterns of mammals, including bats, in the southwestern and desert landscapes of North America. Armstrong (1972) developed a distribution classification scheme for mammals in North America, and that occur in Colorado, based in large part on the impacts of mountains on mammalian distribution patterns. Several researchers have emphasized the thermoregulatory constraints imposed by the general pattern of decreased ambient temperatures at the higher elevations associated with mountain ranges (McNab 1969, 1982a, 1982b; Graham 1983; Patterson et al.1996; Soriano et al. 1999; Cryan et al. 2000; McCain 2007; Willig et al. 2009; Willey 2010). Soriano et al. (1999) analyzed the biogeographic impact of the Andes in Venezuela on mammalian and bat distribution patterns, and concluded that this mountain chain has significantly influenced the speciation, distribution, and evolutionary patterns of the mammalian species associated with the Andes. McCain (2007) investigated the impacts of temperature and elevational gradients on bat species richness associated with mountains, and concluded that bat species richness is maximized when mean ambient temperatures are relatively high and when water is reliably available. McCain concluded that these patterns are due in part to thermoregulatory constraints, especially on reproductive females, and on the availability of water and food resources.

In the Southern Rocky Mountains, there are significant constraints on the distribution of *M. thysanodes* throughout this species' annual life cycle. *M. thysanodes* is not known to be a strongly migratory bat, and therefore for viable populations to persist in an area of the Colorado Rockies suitable and available hibernacula, maternity sites, water, and food, must occur within a population's annual home range. These combined factors may tend to limit the dispersal ability of *M. thysanodes*, especially over major geographic barriers such as high mountains, mountain passes, and mountain valleys and parks that often do not offer forest structure, suitable ambient temperatures for reproduction and hibernation, readily-available water resources, or predictable food supplies. As an example, consider the challenges confronting individuals of a *M. thysanodes* population attempting to disperse westward along the Cache la Poudre River corridor from the Colorado Front Range near Fort Collins over the Southern Rocky Mountains to the Yampa River corridor near Steamboat Springs and Craig in western Colorado. These bats would be confronted with the thermodynamic challenge of finding suitable roosting resources as they moved over the high peaks and passes of the Never Summer and Medicine Bow Mountains and the Rawah Range. They then would be challenged by a general lack of naturally-available roosting resources as they moved across the large, arid intermountain valley and sagebrush and steppe vegetation of North

Park. The bats would then, once again, be challenged by high peaks and mountain passes, this time associated with the Sierra Madre, Gore, Park, and Rabbit Ears Ranges, and the Continental Divide. Once over these major barriers, however, dispersing *M. thysanodes* would find plentiful roosting resources, food, and available water associated with the mid-elevation conifer forests and valleys of the west slope near Steamboat Springs and along the Yampa River corridor.

Alternatively, consider the challenges confronting individuals of a *M. thysanodes* population attempting to disperse eastward from the west slopes of the Rockies near Pagosa Springs over the San Juan Mountains to the east slopes of the Sangre De Cristo Mountains near Trinidad, Colorado. As in the previous example, these bats would be confronted with the thermodynamic challenge of finding suitable roosting resources as they moved over the rugged high peaks and passes of the San Juan Mountains. They also would be challenged by a general lack of naturally-available roosting resources as they moved east across the alluvial and salt flats of the 80 km wide San Luis Valley. These bats would then, once again, be challenged by high peaks and mountain passes, this time associated with the Sangre de Cristo Mountains and the Continental Divide. Once over these major barriers, however, dispersing *M. thysanodes* would find plentiful roosting resources, food, and available water associated with the mid-elevation conifer forests, foothills shrublands, canyons, and piñon-juniper woodlands and savannas of the eastern slope near Trinidad and along the Purgatoire River corridor.

Such dispersal patterns from east to west across the Southern Rocky Mountains, and vice versa, do not seem likely for a bat species that is not a strong disperser. A more likely route of dispersal would be around the Southern Rocky Mountains over many generations by dispersing north into Wyoming, or south into New Mexico. The distance for such dispersal would likely be much longer than dispersal for a strongly migratory species, because the bats would likely disperse along forested corridors, which would be primarily on the edges of mountain parks and valleys, making the actual dispersal distance significantly longer. Therefore, my working hypothesis is that from a dispersal and population genetics perspective the *M. thysanodes* that occur along the Colorado Front Range are more closely related to bats in central Wyoming, and to the Black Hills subspecies *M. t. pahasapensis*, than they are to the *M. thysanodes* in western Colorado. The *M. thysanodes* populations in southern Colorado near the east slopes of the Sangre de Cristo Mountains, and in southwestern Colorado near the Southern Ute and Ute Mountain Indian Reservations, are likely to be closely related to *M. thysanodes* in northern New Mexico. Additionally, I suggest that the high peaks and mountains parks and valleys of the Southern Rocky Mountains act as a set of dispersal filters, making it difficult for *M. thysanodes* to successfully move across all filters. Regular movement by *M. thysanodes* from east to west or vice versa across the Colorado Rockies seems unlikely.

The results I present here strongly support the Chihuahuan distribution hypothesis that the *M. thysanodes* distribution bifurcates around the high peaks and mountain valleys of the Southern Rocky Mountains. Thus, the area occupied by this species in Colorado is substantially less than would be occupied if *M. thysanodes* occurred throughout the Colorado Rockies. Furthermore, the *M. thysanodes* populations that occur along the eastern slopes of the Colorado Rockies coincide with the rapid urbanization that is occurring along the Front Range from Pueblo to Fort Collins. These populations are at increased risk due to human development, habitat disturbance, and fragmentation, and decreasing surface water resource availability due to increased urban and agricultural water use. The information presented here should help guide conservation and management planning efforts in the Southern Rocky Mountains, including consideration of the potential impacts of urbanization and a changing climate on this species. Future occupancy studies (MacKenzie et al. 2002, 2006) of bats using acoustic techniques in the Southern Rocky Mountains would help refine our understanding of the distribution of *M. thysanodes* in Colorado and in the Southern Rocky Mountain region.

Maternity Roost Selection

I documented reproductive female *M. thysanodes* using a variety of roosting resources as maternity sites, including abandoned mines, cabins, and rock structures. I did not find evidence of this species using tree snags as roosting habitat. Maternity colonies in tree snags were not documented during this research or in the literature and documents reviewed during this project. All lactating or post-lactating female *M. thysanodes* that were captured and radio-tracked to roost sites were roosting in crevices in rock structures. All but one of these rock features were large structures on the landscape. For example, female *M. thysanodes* were tracked to large rock faces in the Cache la Poudre canyon and to flatirons and similar large rock structures in the foothills west of Boulder and Fort Collins. All bats that could be seen were roosting with clusters of other bats. The smallest cluster observed consisted of four bats roosting in a crevice in a large boulder. All other clusters were estimated to consist of between 10 and 30 bats. These observations are consistent with those of this species' use of rock structures in other parts of the western United States (Bogan et al. 1998, Cryan et al. 2001). The largest colonies of *M. thysanodes* were observed in abandoned mines, and over 100 individuals of this species were observed in Wiggins copper mine in northeastern New Mexico and in Skull Canyon mine in southeastern Colorado.

The maternity roosts located in rock structures along the Colorado Front Range in Boulder and Laramie Counties tended to be located on landscape features with steeper grades and east, south, and southwestern aspects. Rock structures on hillsides with southerly aspects and steeper grades receive greater direct solar radiation flux in mid-summer at the latitudes in our study area (Larson et al. 2000). This increased solar radiation may result in roost microclimates that are more conducive to growth and development of prenatal and postnatal young, and such conditions may result in greater reproductive success.

Using grade and aspect provided the best landscape model for differentiating *M. thysanodes* maternity roosts from randomly selected potential roost sites. I used these two variables to develop a preliminary maternity roost suitability index for *M. thysanodes* (see Figure 2). The intention of developing the index was to provide some insight into where *M. thysanodes* maternity colonies may be more likely to occur in our study area in Boulder and Larimer Counties. As an example, this model could be used to compare multiple sites to evaluate which areas have higher likelihood, based on this data set, of containing maternity roosts. Using this model, sites with steeper slopes and more south-facing aspects are given higher values compared to areas with shallower slopes and more northerly aspects. A possible extension of this habitat suitability index is to incorporate the model into GIS software to map areas that have higher suitability indexes.

This research does not support the Warm Roost & Proximity to Water hypothesis (H1). However, although the variable "Proximity to Water" had a low cumulative AIC weight, and there is overlap between the 95% confidence intervals for proximity to water for randomly-selected potential roosts and *M. thysanodes* maternity roosts, it is possible that this species is choosing maternity roosts that tend to be, but are not significantly (in the formal statistical sense), closer to permanent surface water resources. In this data set the mean distance to a permanent water source for *M. thysanodes* maternity roosts was 546 m (95% CI: 274-817 m), whereas the mean distance to water for randomly-selected sites was 988 m (95% CI: 744-1,202 m).

O'Farrell and Studier extensively studied the ecophysiology of *M. thysanodes* in the 1970's and early 1980's (see O'Farrell and Studier 1980 for an overview of this work). Using these studies they estimated thermal neutral zones, upper and lower critical limits, and evaporative water loss rates for this and other species. O'Farrell and Studier also examined basic physiological adaptations of *M. thysanodes*. Although this species is known to be strongly associated with the basins and ranges of the Chihuahuan Desert and nearby areas, it does not appear to have kidney or other adaptations that promote water conservation and prevent evaporative and respiratory water loss. O'Farrell and Studier showed that adults of this species regularly lost about 15% of their body mass in water while roosting in day roosts inside an attic near Montezuma, New Mexico. Studier and O'Farrell's work suggests that this species has behavioral, not physiological, adaptations that promote survival with significant daily challenges to water balance. It would be reasonable to continue consideration of proximity to water in other maternity roost selection studies, including of *M. thysanodes*. It is possible that in our study area water is generally more available than in other, more arid, parts of the *M. thysanodes* range in Colorado and elsewhere in this species' range.

The roost-site analysis suggests that the average temperature and relative humidity inside maternity roosts is not statistically different from the average temperature and relative humidity in randomly-selected potential roosts on the landscape. This is a surprising result. Data logger results indicate that *M. thysanodes* maternity roosts on average are not characterized by more stable temperatures, or higher average relative humidity than randomly-selected potential roosts that are available in the same area.

Although the temperature and relative humidity variables used in the roost site analysis did not receive significant statistical support, I suspect that these variables may be important in differentiating the highest quality roosts from randomly-selected sites. Figures 10-17, for example, show the temperature and relative humidity plots of two *M. thysanodes* maternity sites: Skull Canyon mine and Murray Cabin, as well as plots for a ponderosa pine snag that was not used as a roost. Skull Canyon copper mine is the *M. thysanodes* maternity site that had the most stable temperature ($\bar{X}$ = 14.5 °C, $\sigma = 0.3$) of all sites evaluated. This site also had the lowest variability in relative humidity ($\bar{X}$ = 87.7 %RH, $\sigma = 10.9$), except for one randomly-selected north-facing rock crevice. The field survey evidence suggests that maternity colonies of *M. thysanodes* and Townsend's big-eared bat (*C. townsendii*) have likely used the Skull Canyon mine for over 30 years (Ellinwood 1978; Armstrong et al. 1994; Navo, personal communication; Hayes and Bonewell, unpublished data). This site is an abandoned copper mine that is now protected by a bat compatible gate that allows bats to use the site but prevents humans from entering the site unless they have keys to the gate. Alternatively, Murray Cabin, which is also a *M. thysanodes* maternity site, had the most variable temperature ($\bar{X} = 24.3$ °C, $\sigma = 17.6$) and relative humidity ($\bar{X} = 50.2$ %RH, $\sigma = 34.6$) of all sites evaluated. I believe this variability is in part due to where I placed the data logger. On May 27, 2009, at about 10:30 hrs, I observed numerous *M. thysanodes* roosting between the metal roof of the cabin and wood support beams in the attic of Murray Cabin. I also observed several large guano piles under this area. So, I placed two data loggers in the areas near where the bats were roosting in the south part of the cabin attic near a loft door. At the time I observed bats in this roost, the internal temperature of the roost near where the bats were was approximately 25 °C (also see Figure 16 for a 24 hour temperature plot of this site on June 1, 2009). However, it is clear from the data collected by the data loggers that the temperature and relative humidity at this site vary dramatically (see Figures 11, 14, 16, and 17). It seems likely that the *M. thysanodes* that use this roost move among several sites inside Murray Cabin to take advantage of varying temperatures in different parts of the cabin.

Several randomly-selected tree snags that were used as potential roost sites in this study had temperature and relative humidity profiles that appeared to offer potentially suitable microclimates for *M. thysanodes*. One such ponderosa snag is shown in Figures 12, 15, 16, and 17. Although these snags generally exhibited moderately variable temperature and relative humidity profiles, they exhibited short periods of stable temperatures with high humidity. In Figures 16 and 17, for example, the temperature and humidity profile for June 1, 2009, was reasonably comparable to the Skull Canyon mine roost profile, whereas the Murray Cabin roost was much more variable in temperature and humidity.

This research tentatively supports the Rock Crevice Preference hypothesis (H2). This hypothesis proposes that where there is a suite of potential roost sites available, including rock crevices and tree snags, *M. thysanodes* maternity roosts will tend to be found in rock crevices more frequently than in other roost types. I did not have difficulty finding tree snags during this project, and there appear to be abundant snags available for roosting in most areas where I conducted field work. However, our lab group has yet to track a *Myotis* of any species to a tree snag along the Front Range. These results do not suggest that maternal *M. thysanodes* use rock crevices as roost sites because the Front Range lacks adequate refugia in ponderosa pine and Douglas-fir snags. These results suggest that rock formations may be preferred by this species to the available tree snags along the Front Range. My working hypothesis is that *M. thysanodes* likely do use tree snags when they are available, and alternative roosts that are permanent features on the landscape provide more consistent microclimates are not available. Along the Colorado Front Range, there appears to be plentiful roosting resources available in rock features. Tree snags are ephemeral roosting resources and are not structures that exist for long periods of time on the landscape (Lewis 1995). During this study one ponderosa snag in which I had installed a data logger fell down, likely due to high winds, and two other snags were cut down or significantly modified during forest treatments. Abandoned mines, caves, and refugia in rock features tend to have more permanence, and may be preferred as maternity roosting resources, when available.

It is possible that reproductive female *M. thysanodes* that use roost sites that are characterized by lower thermal entropy may tend to experience higher average reproductive rates and average pup survival rates. Thermal entropy, as I use it here, is a measure of the variability of the temperature in a site, with low thermal entropy values indicating sites that have more stable internal temperatures. It is possible that female *M. thysanodes* may have higher fidelity to maternity roosts that exhibit lower thermal entropy. To evaluate this hypothesis, I calculated a measure of thermal entropy for each *M. thysanodes* maternity roost and randomly-selected potential roost used in this study. For the thermal entropy measure, I calculated the base *e* information entropy applied to all temperature measurements collected for each site from June 1 to August 15 using Mathematica^{TM} 8.0. The average thermal entropy measure (S) for maternity roosts was 3.15 ($\sigma = 0.37$, 95% CI = 2.43-3.87) while the average for randomly-selected potential roost sites was 3.63 ($\sigma = 0.08$, 95% CI = 3.46-3.79) (Table 11). While the 95% confidence intervals overlapped for known maternity roosts and randomly-selected potential roosts, the two maternity sites in this data set that have high *M. thysanodes* fidelity and where large maternity colonies of this species have been observed have the two lowest thermal entropy values of all the sites evaluated (Skull Canyon mine, S =

0.99, Wiggins copper mine, *S* = 2.00). I propose that it may be useful to include a measure of thermal entropy in future roost site selection studies. It is possible that roosting in structures with stable temperatures provide thermally predictable environments that require lower metabolic costs to maintain basal metabolic rates. In such environments reproductive females may have more metabolic energy available to devote to growth and development of pups. In turn, pups may also grow more rapidly and reach volancy earlier than if they developed in more variable thermal environments. I predict that adult females using maternity roosts with low thermal entropy and average temperatures near a species' thermal neutral zone will have higher fecundity, and their pups will have higher first year survival, when compared to adult females using sites with higher thermal entropy.

Of the female *M. thysanodes* tracked to maternity roosts, all but two bats stayed in the same roost location until the radio failed. The two females that moved, each moved only once to a nearby roost within 500 meters of the original roost. These data suggest that *M. thysanodes* in our study area have high fidelity to maternity roost locations, once maternity roosts are established. Thus, this study supports the Rock Crevive fidelity hypothesis (H3). Additionally, maternity colonies have been observed returning to the same roost in multiple years. For example, a maternity colony has been repeatedly observed in the Der Zerkle rock face on Boulder Open Spaces and Mountain Parks property (R. Adams, personal communication). Likewise, in the Cache la Poudre canyon, I observed *M. thysanodes* returning to the same roost near Hewlett Gulch on multiple years. I suspect that along the Front Range, this species tends to establish maternity roosts in permanent rock structures and return to these rock structures (or nearby structures) year after year. I conclude that *M. thysanodes* has relatively high maternity roost site fidelity when using sites that have relatively stable microclimates and high permanence.

Population Modeling and Climate Change

In all IPCC SRES climate change scenarios used in this analysis, by year 2100 mean *Myotis* and *M. thysanodes* populations exhibited significant decreases from the original populations of 2,000 females in year 2000. The generic *Myotis* simulation using the IPCC SRES B1 climate scenario exhibited the lowest decrease in bat populations, but this scenario still resulted in a ~88% reduction in mean female bat populations by the year 2100. The IPCC SRES B1 climate change scenario family assumes that humanity will devote significantly more resources and attention over the coming decades to global environmental sustainability, and this scenario family is expected to result in the lowest overall increase in mean global surface temperatures (Nakicenovic and Swart 2000). All species-specific *M. thysanodes* simulations exhibited at least 95% reduction by year 2100 from the original populations of 2,000 female bats in year 2000 (Figure 23-26). In these *M. thysanodes* simulations, even the IPCC SRES climate change scenarios that focus on environmental sustainability resulted in decreases of over 95% compared to the original populations.

These results support the hypothesis proposed by Adams and Hayes (2008) that regional climate warming and reductions in natural surface water availability associated with a changing climate may result in significant reductions in some forest bat populations in the Southern Rocky Mountains and arid regions of western North America. The impacts of climate change in North America is expected to be more severe in the interior west where the effects of oceans and large water bodies on temperature and precipitation are reduced (Christensen and Lettenmaier 2006, Kang and Ramírez 2007, Saunders et al. 2008, Ray et al. 2008). In this analysis, *M. thysanodes* populations declined more rapidly than the generic *Myotis* simulations, suggesting that *M. thysanodes* females may be more sensitive to variation in water resources and temperature than some other forest dwelling *Myotis* species in Colorado. These results support Adams (2010) conclusion that *M. thysanodes*, and several other *Myotis* species, exhibit reduced reproductive output in females during warmer, drier years. These results also suggest that *M. thysanodes* populations may be at significant risk of local or regional extinction in the Southern Rocky Mountains over the coming 100 - 200 years, if average temperatures significantly increase and surface water resources decrease. Furthermore, in this analysis *M. thysanodes* populations decreased to close to extinction in all IPCC climate change scenarios, suggesting that wildlife biologists, resource managers, and policy makers may need to take proactive actions to support populations of this species. Suggestions for such support are outlined in the management recommendations section below.

The approach employed here of coupling regional climate change projections with statistical analysis of time series data related to female vital rates and bat population dynamics models using Monte Carlo simulations may be useful in analyzing the impacts of regional climate and ecological change on species of conservation concern in other geographic areas. This approach may also be useful in helping to prioritize bat species for limited conservation and management resources.

None of the simulations resulted in bat populations decreasing to extinction. I predict that this is because the models are not spatially explicit or density dependent, and the models do not incorporate terms to estimate the probability of females finding breeding partners. As natural population numbers decrease toward extinction, adult females often have difficulty finding breeding partners, and thus even females that are capable of breeding are unable to breed. Relationships between density and fitness are described as Allee effects (for a review, see Kramer et al. 2009). Although this analysis does not attempt to incorporate density effects on reproductive rates in female bats, it is likely that small bat populations experience Allee effects. Thus in future modeling efforts it may be useful to incorporate density dependence into some vital rates, especially female reproductive rates.

In this analysis, adult survival and fecundity in adults that were 3+ years old had the highest sensitivity values and the most affect on population growth rates (Table 15). This implies that management and conservation actions aimed at supporting and maximizing these vital rates will have the greatest impact on improving population growth rates for those that are considered to be at risk.

Future research and population modeling efforts related to bat populations in the Southern Rocky Mountains would benefit from more research in three key areas. First, there is a lack of long-term mark-recapture data related to *Myotis* species in the Southern Rocky Mountains. Collecting high quality mark-recapture data and developing estimates of species specific survival and fecundity rates would improve on the modeling effort I have presented here. The multi-year mark-recapture data and analysis related to *E. fuscus* in Fort Collins, Colorado (O'Shea et al. 2004, 2010) provides a framework for developing vital rate estimates in natural *Myotis* populations. A multi-year project similar to the O'Shea et al. Fort Collins project, but conducted in a forested area of the Front Range, would greatly improve our knowledge of *Myotis* populations in the Southern Rocky Mountains. Additionally, although I have not addressed the issue in this research, high quality mark-recapture information would allow the evaluation of co-variation among vital rates.

A second area of research that would improve on the modeling I present here, would be to develop capture probability estimates of *Myotis* species related to reproductive status. Adams and Hayes (2008) found that reproductive female *M. thysanodes* visited a water resource near a maternity roost significantly more often than non-reproductive females of the same species. This suggests that, because reproductive females visit water resources more frequently than non-reproductive females, we may be more likely to capture reproductive females in mist nets, and thus the field capture based fecundity estimates used in this analysis may be higher than exhibited by the natural population.

A third area of research that would improve our knowledge of forest bat populations in the Southern Rocky Mountains would be the continuation, and development of additional, long-term survey projects such as the forest bat monitoring project that Rick Adams has conducted in the Boulder County Front Range. Turchin (Turchin 2003, and references therein) has emphasized that multi-decade empirical time series data is needed to analyze the complex population dynamics of animal populations. Such long-term survey and capture data would complement rigorously collected mark-recapture data and allow a theoretical-empirical synthesis of forest bat population dynamics in the Southern Rocky Mountains.

Management Recommendations

An improved understanding of the distribution, use of maternity roost sites, and population trends in forested areas of western North America (Barclay and Brigham 1996, Pierson 1998, Hutson et al. 2001) and under key climate change scenarios (Adams and Hayes 2008, Adams 2010) will help biologists and managers protect *M. thysanodes* populations in the Southern Rocky Mountains. In Colorado, the distribution of this species exhibits a bifurcated geographic distribution with separate populations occurring in a narrow band along the Front Range of the Southern Rocky Mountains and separate populations occurring in western Colorado. Reproductive female *M. thysanodes* use a variety of roosting resources as maternity sites, including abandoned mines, cabins, and rock crevices. I did not find evidence of this species using tree snags as roosting habitat. In this analysis *M. thysanodes* populations decreased to close to extinction in all IPCC climate change scenarios within 100 years, suggesting that wildlife biologists, resource managers, and policy makers, may need to take proactive actions to support populations of this species. These action may include, but are not limited to: working with public land management agencies and private land-owners to identify and protect key roost and water resources used by this species; minimizing human disturbance and predation at key maternity roosts, for example by installing bat gates where appropriate; taking action to prevent the spread of bat diseases, such as White Nose Syndrome, into key maternity and other roost sites; protecting, and when appropriate, enhancing foraging habitat associated with forest and riparian areas near key roost sites; minimizing or preventing disruptive human activity, such as recreational rock climbing and noisy forest treatment procedures near maternity sites during the late spring and summer months.

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APPENDIX A

CODE USED TO PROGRAM TWO OF THE MONTE CARLO SIMULATIONS USED IN THIS RESEARCH

Appendix A. Code used to program two of the Monte Carlo simulations: the stable climate and *M. thysanodes* IPCC SRES B1 Scenario. Wolfram Mathematica® 8.0 mathematical software was used to perform the Monte Carlo simulations.

Mathematica® code for the stable climate scenario:

```
SFmin := .4

SFmax := .55

SFave := .475

SAmin := .75

SAmax := .84

SAave := .795

B1min := 0.295

B1max := 0.405

B1ave := .35

B2min := .395

B2max := .49

B2ave := .4425
```

```
B3min := .42

B3max := .49

B3ave := .455

Npups := 600

Nne := 290

Ntwo := 230

Nthree := 880

runs := 100000;

j := 0;

MonteCarlo := Table[Npups := 600; Nne := 290; Ntwo := 230; Nthree := 880;

i := 1; While[i < 100,

Npups = (Nne*(RandomReal[TriangularDistribution[{B1min, B1max}]])) +
(Ntwo*(RandomReal[TriangularDistribution[{B2min, B2max}]])) +
(Nthree*(RandomReal[TriangularDistribution[{B3min, B3max}]]));

Nne = (Npups*(RandomReal[TriangularDistribution[{SFmin, SFmax}]]));

Ntwo = (Nne*(RandomReal[TriangularDistribution[{SAmin, SAmax}]]));
```

```
Nthree = (Ntwo*(RandomReal[TriangularDistribution[{SAmin, SAmax}]])) +
(Nthree*(RandomReal[TriangularDistribution[{SAmin, SAmax}]]));
Ntotal = Npups + Nne + Ntwo + Nthree;
i = i + 1;]; j = j + 1; Ntotal, {runs}]; k := 0;
N[Mean[Round[MonteCarlo]]]
N[StandardDeviation[Round[MonteCarlo]]]
N[Min[Round[MonteCarlo]]]
N[Max[Round[MonteCarlo]]]
Hist = Round[MonteCarlo, 50];
Histogram[Hist, BaseStyle -> {FontSize -> 14}, ImageSize -> 400,
PlotLabel -> StringJoin["100-year populations after ", ToString[runs],
" simulations.", "(TriDist)" ], AxesLabel -> {"Population", "Frequency"}]
```

Mathematica® code for the *M. thysanodes* IPCC SRES B1 scenario:

```
aRepro := {0.41, 0.39, 0.39, 0.40, 0.41, 0.40, 0.40, 0.39, 0.39, 0.41, 0.39, 0.40, 0.38, 0.40,
0.42, 0.39, 0.41, 0.39, 0.39, 0.40, 0.38, 0.40, 0.39, 0.40, 0.41, 0.40, 0.39, 0.39, 0.41, 0.41,
0.39, 0.39, 0.41, 0.41, 0.39, 0.39, 0.41, 0.38, 0.38, 0.37, 0.39, 0.37, 0.39, 0.38, 0.38, 0.36,
0.37, 0.37, 0.38, 0.39, 0.39, 0.37, 0.38, 0.38, 0.38, 0.38, 0.36, 0.36, 0.37, 0.36, 0.37, 0.39,
```

```
0.36, 0.37, 0.35, 0.37, 0.39, 0.38, 0.35, 0.39, 0.37, 0.38, 0.38, 0.37, 0.39, 0.35, 0.38, 0.35,
0.36, 0.34, 0.35, 0.35, 0.37, 0.35, 0.36, 0.34, 0.36, 0.37, 0.37, 0.34, 0.34, 0.35, 0.35, 0.33,
0.34, 0.36, 0.35, 0.36, 0.33, 0.34, 0.33, 0.35, 0.32, 0.34, 0.32, 0.34, 0.35, 0.35, 0.35, 0.35,
0.34, 0.35, 0.35}

jRepro := {0.31, 0.29, 0.29, 0.30, 0.31, 0.30, 0.30, 0.29, 0.29, 0.31, 0.29, 0.30, 0.28, 0.30,
0.32, 0.29, 0.31, 0.29, 0.29, 0.30, 0.28, 0.30, 0.29, 0.30, 0.31, 0.30, 0.29, 0.29, 0.31, 0.31,
0.29, 0.29, 0.31, 0.31, 0.29, 0.29, 0.31, 0.28, 0.28, 0.27, 0.29, 0.27, 0.29, 0.28, 0.28, 0.26,
0.27, 0.27, 0.28, 0.29, 0.29, 0.27, 0.28, 0.28, 0.28, 0.28, 0.26, 0.26, 0.27, 0.26, 0.27, 0.29,
0.26, 0.27, 0.25, 0.27, 0.29, 0.28, 0.25, 0.29, 0.27, 0.28, 0.28, 0.27, 0.29, 0.25, 0.28, 0.25,
0.26, 0.24, 0.25, 0.25, 0.27, 0.25, 0.26, 0.24, 0.26, 0.27, 0.27, 0.24, 0.24, 0.25, 0.25, 0.23,
0.24, 0.26, 0.25, 0.26, 0.23, 0.24, 0.23, 0.25, 0.22, 0.24, 0.22, 0.24, 0.25, 0.25, 0.25, 0.25,
0.24, 0.25, 0.25}

SFmin := .4

SFmax := .55

SFave := .475

SAmin := .75

SAmax := .84

SAave := .795

runs := 100000;
```

```
j := 0;
MonteCarlo := Table[ Npups := 600; Nne := 290; Ntwo := 230; Nthree := 880;
i := 1; While [i < 100, Ntotal = Npups + Nne + Ntwo + Nthree;
Nthree = (Ntwo*(RandomReal [TriangularDistribution[{SAmin,
SAmax}]])) + (Nthree*(RandomReal[TriangularDistribution[{SAmin, SAmax}]]));
Ntwo = (Nne*(RandomReal[TriangularDistribution[{SAmin, SAmax}]])); Nne =
(Npups*(RandomReal[TriangularDistribution[{SFmin, SFmax}]])); Npups =
(Nne*(jRepro[[i]])) + (Ntwo*(aRepro[[ i]])) + (Nthree*(aRepro[[i]]));
i = i + 1;]; j = j + 1; Ntotal, {runs}]; k := 0;
Hist = Round[MonteCarlo, 5];
N[Mean[Round[MonteCarlo]]]
N[StandardDeviation[MonteCarlo]]
N[Min[MonteCarlo]]
N[Max[MonteCarlo]]
Histogram[Hist, BaseStyle -> {FontSize -> 14}, ImageSize -> 400,
 PlotLabel -> StringJoin["100-year populations after ", ToString[runs],
   " simulations.", "(TriDist)" ], AxesLabel -> {"Population", "Frequency"}]
```

APPENDIX B

DETAILS OF ALL CAPTURE AND OCCURANCE RECORDS OF *MYOTIS THYSANODES* COMPILED DURING THIS RESEARCH FROM COLORADO

Appendix B. Details of *M. thysanodes* records from Colorado compiled during this research. "Location" indicates the geogrphic location of the capture or occurence record; "County" is the county of occurence; "elevation" is the estimated elevation of occurence; "date" is the collection or occurence date; "name or citation" is a brief indication of the person or citation that reported the occurence; "sex" is listed as M (male), F (female), or U unknown); age is A (adult) or J (juvenile); "repro" is reproductive status and is listed as NR (non-reproductive), P (pregnant), L (lactating), S (scrotal), I (inguinal), or U (unknown); "Zone", "Easting", and "Northing" are GPS coordinates in NAD 84, if known. A blank cell indicates that the data associated with that cell was not listed in the record or citation.

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
1	Murray Cabin	Archuleta	2256	7/9/97	BIMP	F	A	P	13	334148	4112610
2	Murray Cabin	Archuleta	2256	7/9/97	BIMP	F	A		13	334148	4112610
3	Murray Cabin	Archuleta	2256	7/9/97	BIMP	F	A	P	13	334148	4112610
4	Murray Cabin	Archuleta	2256	7/9/97	BIMP	F	A	P	13	334148	4112610
5	Murray Cabin	Archuleta	2256	7/9/97	BIMP	U			13	334148	4112610
6	Murray Cabin	Archuleta	2256	7/9/97	BIMP	U			13	334148	4112610

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
7	Murray Cabin	Archuleta	2256	10/3/97	BIMP	M			13	334148	4112610
8	Murray Cabin	Archuleta	2256	5/27/09	Hayes	F	A	UNK	13	334148	4112610
9	Murray Cabin	Archuleta	2256	5/27/09	Hayes	F	A	UNK	13	334148	4112610
10	Murray Cabin	Archuleta	2256	5/27/09	Hayes	F	A	UNK	13	334148	4112610
11	Murray Cabin	Archuleta	2256	5/27/09	Hayes	F	A	UNK	13	334148	4112610
12	Murray Cabin	Archuleta	2256	5/27/09	Hayes	F	A	UNK	13	334148	4112610
13	Murray Cabin	Archuleta	2256	5/27/09	Hayes	F	A	UNK	13	334148	4112610
14	Murray Cabin	Archuleta	2256	5/27/09	Hayes	F	A	UNK	13	334148	4112610
15	Skull Mine	Baca	1409	9/14/77	Ellinwood	U			13	673713	4104862
16	Skull Mine	Baca	1409	9/14/77	Ellinwood	U			13	673713	4104862
17	Skull Mine	Baca	1409	9/21/01	Navo	F	A	PL	13	673713	4104862
18	Skull Mine	Baca	1409	7/23/07	Hayes, Navo, Bonewell	F	J		13	673713	4104862
19	Skull Mine	Baca	1409	7/23/07	Hayes, Navo, Bonewell	M	J		13	673713	4104862

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
20	Skull Mine	Baca	1409	7/23/07	Hayes, Navo, Bonewell	M	J		13	673713	4104862
21	Skull Mine	Baca	1409	9/6/09	Hayes, Bonewell			~75 MYTH	13	673713	4104862
22	2nd Flatiron	Boulder	1951		Adams	F			13	475190	4426510
23	Abbey Pond	Boulder	1789	7/8/95	Adams	F	A	P	13	477520	4423780
24	Abbey Pond	Boulder	1789	8/26/95	Adams	M	A	ND	13	477520	4423780
25	Abbey Pond	Boulder	1789	8/1/96	Adams	M	A	S	13	477520	4423780
26	Abbey Pond	Boulder	1789	8/23/96	Adams	M	J	NS	13	477520	4423780
27	Abbey Pond	Boulder	1789	8/23/96	Adams	M	J	NS	13	477520	4423780
28	Abbey Pond	Boulder	1789	8/12/97	Adams	F	A	L	13	477520	4423780
29	Abbey Pond	Boulder	1789	8/19/98	Adams	F	J	NLNP	13	477520	4423780
30	Abbey Pond	Boulder	1789	8/7/01	Navo/CNHP	M	A	NB	13	477520	4423780
31	Abbey Pond	Boulder	1789	8/7/01	Navo/CNHP	F	A	L	13	477520	4423780
32	Abbey Pond	Boulder	1789	8/8/05	Kiser	F	A	L	13	477520	4423780

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
33	Abbey Pond	Boulder	1789	8/8/05	Kiser	F	A	L	13	477520	4423780
34	Abbey Pond	Boulder	1789	8/8/05	Kiser	F-SA	A	NL	13	477520	4423780
35	Abbey Pond	Boulder	1789	8/8/05	Kiser	M	A	S	13	477520	4423780
36	Abbey Pond	Boulder	1789	8/8/05	Kiser	F	A	L	13	477520	4423780
37	Bear Creek	Boulder	1883	8/16/95	Adams	F	A	L	13	475761	4424529
38	Bear Creek	Boulder	1883	8/16/95	Adams	F	A	L	13	475761	4424529
39	Bear Creek	Boulder	1883	8/16/95	Adams	F	A	L	13	475761	4424529
40	Bear Creek	Boulder	1883	8/16/95	Adams	M	A	S	13	475761	4424529
41	Bear Creek	Boulder	1883	5/30/96	Adams	F	A	NLNP	13	475761	4424529
42	Bear Creek	Boulder	1883	5/30/96	Adams	F	A	NLNP	13	475761	4424529
43	Bear Creek	Boulder	1883	5/30/96	Adams	M	A	NS	13	475761	4424529
44	Bear Creek	Boulder	1883	7/2/96	Adams	F	A	P	13	475761	4424529
45	Bear Creek	Boulder	1883	7/2/96	Adams	M	A	NS	13	475761	4424529

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
46	Bear Creek	Boulder	1883	7/16/96	Adams	F	A	L	13	475761	4424529
47	Bear Creek	Boulder	1883	8/11/96	Adams	M	A	A	13	475761	4424529
48	Bear Creek	Boulder	1883	8/11/96	Adams	F	J	NLNP	13	475761	4424529
49	Bear Creek	Boulder	1883	8/11/96	Adams	F	A	L	13	475761	4424529
50	Bear Creek	Boulder	1883	8/11/96	Adams	F	A	NLNP	13	475761	4424529
51	Bear Creek	Boulder	1883	8/11/96	Adams	M	A	S	13	475761	4424529
52	Bear Creek	Boulder	1883	8/11/96	Adams	M	J	NS	13	475761	4424529
53	Bear Creek	Boulder	1883	6/4/97	Adams	F	A	UNK	13	475761	4424529
54	Bear Creek	Boulder	1883	6/4/97	Adams	M	A	NS	13	475761	4424529
55	Bear Creek	Boulder	1883	6/4/97	Adams	F	A	P	13	475761	4424529
56	Bear Creek	Boulder	1883	6/4/97	Adams	F	A	P	13	475761	4424529
57	Bear Creek	Boulder	1883	6/4/97	Adams	F	A	P	13	475761	4424529
58	Bear Creek	Boulder	1883	6/4/97	Adams	M	A	NS	13	475761	4424529
59	Bear Creek	Boulder	1883	6/18/97	Adams	M	A	NS	13	475761	4424529

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
60	Bear Creek	Boulder	1883	6/18/97	Adams	M	A	NS	13	475761	4424529
61	Bear Creek	Boulder	1883	6/18/97	Adams	M	A	NS	13	475761	4424529
62	Bear Creek	Boulder	1883	6/18/97	Adams	F	A	P	13	475761	4424529
63	Bear Creek	Boulder	1883	6/18/97	Adams	UNK	A	UNK	13	475761	4424529
64	Bear Creek	Boulder	1883	7/21/97	Adams	F	A	L	13	475761	4424529
65	Bear Creek	Boulder	1883	7/21/97	Adams	F	A	L	13	475761	4424529
66	Bear Creek	Boulder	1883	7/21/97	Adams	F	A	L	13	475761	4424529
67	Bear Creek	Boulder	1883	8/15/97	Adams	F	A	L	13	475761	4424529
68	Bear Creek	Boulder	1883	8/15/97	Adams	M	J	NS	13	475761	4424529
69	Bear Creek	Boulder	1883	8/15/97	Adams	M	A	NS	13	475761	4424529
70	Bear Creek	Boulder	1883	8/23/97	Adams	F	J	NLNP	13	475761	4424529
71	Bear Creek	Boulder	1883	8/23/97	Adams	F	A	L	13	475761	4424529
72	Bear Creek	Boulder	1883	5/30/98	Adams	M	A	NS	13	475761	4424529

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
73	Bear Creek	Boulder	1883	5/30/98	Adams	M	A	NS	13	475761	4424529
74	Bear Creek	Boulder	1883	6/25/98	Adams	F	A	NLNP	13	475761	4424529
75	Bear Creek	Boulder	1883	6/25/98	Adams	F	A	L	13	475761	4424529
76	Bear Creek	Boulder	1883	6/25/98	Adams	M	A	NS	13	475761	4424529
77	Bear Creek	Boulder	1883	6/25/98	Adams	M	A	NS	13	475761	4424529
78	Bear Creek	Boulder	1883	6/25/98	Adams	M	A	NS	13	475761	4424529
79	Bear Creek	Boulder	1883	8/8/98	Adams	F	J	NPNL	13	475761	4424529
80	Bear Creek	Boulder	1883	8/8/98	Adams	F	A	L	13	475761	4424529
81	Bear Creek	Boulder	1883	8/8/98	Adams	F	A	L	13	475761	4424529
82	Bear Creek	Boulder	1883	8/8/98	Adams	F	A	L	13	475761	4424529
83	Bear Creek	Boulder	1883	8/8/98	Adams	F	A	L	13	475761	4424529
84	Bear Creek	Boulder	1883	8/8/98	Adams	F	J	NLNP	13	475761	4424529
85	Bear Creek	Boulder	1883	8/8/98	Adams	F	J	NLNP	13	475761	4424529
86	Bear Creek	Boulder	1883	8/8/98	Adams	M	J	NS	13	475761	4424529

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
87	Bear Creek	Boulder	1883	8/8/98	Adams	M	A	S	13	475761	4424529
88	Bear Creek	Boulder	1883	5/26/99	Adams	F	A	L	13	475761	4424529
89	Bear Creek	Boulder	1883	5/26/99	Adams	F	A	L	13	475761	4424529
90	Bear Creek	Boulder	1883	5/26/99	Adams	M	A	NS	13	475761	4424529
91	Bear Creek	Boulder	1883	5/26/99	Adams	M	A	NS	13	475761	4424529
92	Bear Creek	Boulder	1883	5/26/99	Adams	F	A	P	13	475761	4424529
93	Bear Creek	Boulder	1883	7/5/99	Adams	F	A	P	13	475761	4424529
94	Bear Creek	Boulder	1883	7/5/99	Adams	F	A	L	13	475761	4424529
95	Bear Creek	Boulder	1883	7/5/99	Adams	F	A	L	13	475761	4424529
96	Bear Creek	Boulder	1883	7/5/99	Adams	M	A	NS	13	475761	4424529
97	Bear Creek	Boulder	1883	8/24/99	Adams	F	A	PL	13	475761	4424529
98	Bear Creek	Boulder	1883	8/24/99	Adams	M	A	S	13	475761	4424529
99	Bear Creek	Boulder	1883	8/24/99	Adams	M	A	S	13	475761	4424529
100	Bear Creek	Boulder	1883	8/24/99	Adams	M	A	NS	13	475761	4424529

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
101	Bear Creek	Boulder	1883	8/24/99	Adams	M	A	S	13	475761	4424529
102	Bear Creek	Boulder	1883	6/17/01	Adams	M	A	NS	13	475761	4424529
103	Bear Canyon	Boulder	NL	6/23/04	Kiser	F	A	P	13	475761	4424529
104	Bear Canyon	Boulder	NL	6/23/04	Kiser	M	A	NS	13	475761	4424529
105	Bear Canyon	Boulder	NL	6/23/04	Kiser	M	A	NS	13	475761	4424529
106	Bear Canyon	Boulder	NL	6/23/04	Kiser	M	A	NS	13	475761	4424529
107	Bear Canyon	Boulder	NL	8/4/04	Kiser	F	A	L	13	475761	4424529
108	Bear Canyon	Boulder	NL	8/4/04	Kiser	F	A	L	13	475761	4424529
109	Bear Canyon	Boulder	NL	7/12/05	Kiser	F	A	L	13	475761	4424529
110	Bear Canyon	Boulder	NL	8/6/05	Kiser	F	A	L	13	475761	4424529
111	Bear Canyon	Boulder	NL	8/6/05	Kiser	F-SA	A	NL	13	475761	4424529
112	Bear Canyon	Boulder	NL	8/6/05	Kiser	F-SA	A	NL	13	475761	4424529
113	Bear Canyon	Boulder	NL	8/6/05	Kiser	SA	A	NL	13	475761	4424529

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
114	Bear Canyon	Boulder	NL	6/7/06	Kiser	F	A	L	13	475761	4424529
115	Bear Canyon	Boulder	NL	6/7/06	Kiser	F	A	NR	13	475761	4424529
116	Bear Canyon	Boulder	NL	6/7/06	Kiser	F	A	P	13	475761	4424529
117	Bear Canyon	Boulder	NL	6/7/06	Kiser	F	A	P	13	475761	4424529
118	Bear Canyon	Boulder	NL	6/7/06	Kiser	F	A	P	13	475761	4424529
119	Bear Canyon	Boulder	NL	7/13/06	Kiser	F	A	NR	13	475761	4424529
120	Bear Canyon	Boulder	NL	7/13/06	Kiser	M	A	NS	13	475761	4424529
121	Bear Creek Pond	Boulder	1883	7/14/08	Adams	F	A	NR	13	475761	4424529
122	Bear Creek Pond	Boulder	1883	7/14/09	Adams	F	A	P	13	475761	4424529
123	Boulder CO OS Barns	Boulder		8/10/95	Ingersoll	F	A	L			
124	Boulder Mountain J3	Boulder	2048	9/27/01	Piaggio	M	A	TENL	13	468650	4439680

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
125	Buckingham Park Creek	Boulder	1790	7/14/96	Adams	F	A	L	13	473832	4440131
126	Buckingham Park Creek	Boulder	1790	7/14/96	Adams	F	A	L	13	473832	4440131
127	Buckingham Park Creek	Boulder	1790	7/14/96	Adams	F	A	L	13	473832	4440131
128	Buckingham Park Creek	Boulder	1790	7/14/96	Adams	F	A	L	13	473832	4440131
129	Buckingham Park Creek	Boulder	1790	1996	Adams	F			13	473832	4440131
130	Dakota Ridge	Boulder		7/31/01	Adams	F	A	L			
131	Der Zerkle	Boulder	2012		Adams	F			13	475448	4424740
132	Douglas Fir 1	Boulder		6/17/99	Adams	M	A	NS			
133	Douglas Fir 1	Boulder		6/17/99	Adams	F	A	P			
134	Douglas Fir 10	Boulder		8/7/99	Adams	M	A	NS			
135	Douglas Fir 3	Boulder		8/6/99	Adams	M	A	NS			

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
136	Douglas Fir 4	Boulder		8/6/99	Adams	F	A	NLNP			
137	Douglas Fir 5	Boulder		8/6/99	Adams	M	J	NS			
138	Douglas Fir 6	Boulder		8/7/99	Adams	F	A	PL			
139	Douglas Fir 7	Boulder		8/7/99	Adams	F	J	NLNP			
140	Douglas Fir 8	Boulder		8/7/99	Adams	F	J	NLNP			
141	Douglas Fir 9	Boulder		8/7/99	Adams	M	A	NS			
142	Eldorado Mtn. Roost	Boulder	2022		Adams	F			13	475860	4417570
143	Geer Canyon	Boulder	1830	8/12/05	Kiser	F-SA	A	NLNP	13	473970	4443780
144	Geer Canyon	Boulder	1830	8/15/05	Kiser	F	A	PL	13	473970	4443780
145	Geer Canyon	Boulder	1830	6/14/07	Adams	F	A	NLNP	13	473970	4443780
146	Geer Canyon	Boulder	1830	6/14/07	Adams	F	A	NLNP	13	473970	4443780
147	Geer Canyon	Boulder	1830	6/14/07	Adams	F	A	P	13	473970	4443780
148	Geer Canyon	Boulder	1830	6/25/07	Adams	M	A	S	13	473970	4443780

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
149	Geer Canyon Road	Boulder	1830	8/6/03	Adams	M	J	S	13	473970	4443780
150	Geer Canyon Road	Boulder	1830	8/6/03	Adams	F	A	L	13	473970	4443780
151	Geer Canyon roost	Boulder	1875		Adams				13	473900	4443940
152	Golden Age CG17	Boulder	2097	6/12/95	BIMP	M	A	UNKN	13	470170	4439900
153	Good Friday ST-19	Boulder	2504	6/10/97	BIMP	M	A	NONB	13	462126	4431143
154	Good Friday ST-8	Boulder	2379	8/17/04	BIMP	M	A	NONB	13	462878	4431358
155	Gregory Canyon Pond	Boulder	1820	7/13/98	Adams	M	A	NS	13	475150	4427620
156	Gregory Canyon Pond	Boulder	1820	7/13/1998	Adams	F	A	L	13	475150	4427620
157	Greg. Can Pond	Boulder	1820	7/13/98	Adams	M	A	NS	13	475150	4427620

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
158	Gregory Canyon Pond	Boulder	1820	7/13/98	Adams	F	A	NLNP	13	475150	4427620
159	Gregory Canyon Pond	Boulder	1820	8/5/98	Adams	M	J	NS	13	475150	4427620
160	Gregory Canyon Pond	Boulder	1820	8/5/98	Adams	F	A	L	13	475150	4427620
161	Gregory Canyon Pond	Boulder	1820	8/20/98	Adams	F	A	PL	13	475150	4427620
162	Gregory Canyon Pond	Boulder	1820	8/20/98	Adams	M	J	NS	13	475150	4427620
163	Gregory Canyon Roost	Boulder	1820	8/6/98	Adams	F	A	UNK	13	475150	4427620
164	Gregory Canyon	Boulder	1820	6/14/06	Kiser	M	A	NS	13	475150	4427620
165	Gregory Canyon	Boulder	1820	7/16/06	Kiser	F	A	L	13	475150	4427620
166	Greg. Canyon	Boulder	1820	6/22/09	Hayes	M	A	NR	13	475150	4427620

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
167	Harmon Cave	Boulder	2051			F			13	475590	4424130
168	Ingersol Quarry	Boulder	2073	8/31/02	Adams	F	A	L	13	474093	4447142
169	Ingersol Quarry	Boulder	2073	8/31/02	Adams	F	A	L	13	474093	4447142
170	Ingersol Quarry	Boulder	2073	8/31/02	Adams	F	A	L	13	474093	4447142
171	Ingersol Quarry	Boulder	2073	8/31/02	Adams	F	A	L	13	474093	4447142
172	Ingersol Quarry	Boulder	2073	7/28/03	Adams	M	A	NS	13	474093	4447142
173	Ingersol Quarry	Boulder	2073	7/28/03	Adams	F	A	L	13	474093	4447142
174	Ingersol Quarry	Boulder	2073	7/28/03	Adams	M	A	NS	13	474093	4447142
175	Ingersol Quarry	Boulder	2073	7/10/04	Adams	M	A	NS	13	474093	4447142
176	Ingersol Quarry	Boulder	2073	7/10/04	Adams	M	A	NS	13	474093	4447142
177	Ingersol Quarry	Boulder	2073	8/12/04	Adams	F	A	L	13	474093	4447142
178	Ingersol Quarry	Boulder	2073	8/12/04	Adams	F	A	L	13	474093	4447142
179	Ingersol Quarry	Boulder	2073	9/11/04	Adams	F	A	PL	13	474093	4447142
180	Ingersol Quarry	Boulder	2073	7/28/05	Adams	M	A	S	13	474093	4447142

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
181	Ingersol Quarry	Boulder	2073	7/28/05	Adams	M	A	NS	13	474093	4447142
182	Ingersol Quarry	Boulder	2073	7/28/05	Adams	M	A	NS	13	474093	4447142
183	Ingersol Quarry	Boulder	2073	8/18/05	Adams	M	A	S	13	474093	4447142
184	Ingersol Quarry	Boulder	2073	8/18/05	Adams	F	A	PL	13	474093	4447142
185	Ingersol Quarry	Boulder	2073	8/18/05	Adams	F	A	PL	13	474093	4447142
186	Ingersol Quarry	Boulder	2073	8/18/05	Adams	F	A	PL	13	474093	4447142
187	Ingersol Quarry	Boulder	2073	9/4/05	Adams	F	J	NLNP	13	474093	4447142
188	Ingersol Quarry	Boulder	2073	6/24/06	Adams	M	A	NS	13	474093	4447142
189	Ingersol Quarry	Boulder	2073	6/24/06	Adams	M	A	NS	13	474093	4447142
190	Ingersol Quarry	Boulder	2073	7/19/06	Adams	F	A	L	13	474093	4447142
191	Ingersol Quarry	Boulder	2073	7/19/06	Adams	F	A	L	13	474093	4447142
192	Ingersol Quarry	Boulder	2073	7/19/06	Adams	M	A	NS	13	474093	4447142
193	Ingersol Quarry	Boulder	2073	7/19/06	Adams	M	A	NS	13	474093	4447142
194	Ingersol Quarry	Boulder	2073	6/13/07	Adams	F	A	NLNP	13	474093	4447142

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
195	Ingersol Quarry	Boulder	2073	6/13/07	Adams	M	A	NS	13	474093	4447142
196	Ingersol Quarry	Boulder	2073	6/13/07	Adams	M	A	NS	13	474093	4447142
197	Ingersol Quarry	Boulder	2073	6/26/07	Adams	M	A	S	13	474093	4447142
198	Ingersol Quarry	Boulder	2073	8/8/07	Adams	M	A	NS	13	474093	4447142
199	Ingersol Quarry	Boulder	2073	8/8/07	Adams	F	A	PL	13	474093	4447142
200	Ingersol Quarry	Boulder	2073	8/20/07	Adams	M	A	NS	13	474093	4447142
201	Ingersol Quarry	Boulder	2073	8/20/07	Adams	M	A	S	13	474093	4447142
202	Ingersol Quarry	Boulder	2073	9/21/07	Adams	M	A	NS	13	474093	4447142
203	Ingersol Quarry	Boulder	2073	9/21/07	Adams	M	A	NS	13	474093	4447142
204	Ingersol Quarry	Boulder	2073	10/4/07	Adams	M	A	S	13	474093	4447142
205	Ingersol Quarry	Boulder	2073	7/10/08	Adams	F	A	NR	13	474093	4447142
206	Ingersol Quarry	Boulder	2073	7/17/09	Adams	M	A	NS	13	474093	4447142
207	Ingersol Quarry	Boulder	2073	7/17/09	Adams	M	A	NS	13	474093	4447142
208	Ingersol Quarry	Boulder	2073	7/17/09	Adams	M	A	NS	13	474093	4447142

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
209	Ingersol Quarry	Boulder	2073	7/17/09	Adams	M	A	NS	13	474093	4447142
210	Ingersol Quarry	Boulder	2073	7/17/09	Adams	F	A	L	13	474093	4447142
211	Ingersol Quarry	Boulder	2073	8/12/09	Adams	F	A	L	13	474093	4447142
212	Ingersol Quarry	Boulder	2073	8/12/09	Adams	M	A	NS	13	474093	4447142
213	Ingersol Quarry	Boulder	2073	8/12/09	Adams	M	A	NS	13	474093	4447142
214	Ingersol Quarry	Boulder	2073	8/12/09	Adams	M	A	NS	13	474093	4447142
215	Ingersol Quarry	Boulder	2073	8/12/09	Adams	M	A	NS	13	474093	4447142
216	Ingersol Quarry	Boulder	2073	8/12/09	Adams	M	A	NS	13	474093	4447142
217	Ingersol Quarry	Boulder	2073	7/12/10	Adams	M	A	NS	13	474093	4447142
218	Ingersol Quarry	Boulder	2073	8/12/10	Adams	F	A	L	13	474093	4447142
219	Lindsey Pond	Boulder	1784	8/12/09	Adams	M	A	L	13	477887	4419450
220	Lindsey Pond	Boulder	1784	7/21/96	Adams	F	A	L	13	477887	4419450skull
221	Lindsey Pond	Boulder	1784	7/25/99	Adams	F	A	L	13	477887	4419450

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
222	Lindsey Pond	Boulder	1784	7/25/99	Adams	F	A	L	13	477887	4419450
223	Lindsey Pond	Boulder	1784	7/25/99	Adams	F	A	L	13	477887	4419450
224	Lindsey Pond	Boulder	1784	7/25/99	Adams	F	A	L	13	477887	4419450
225	Lindsey Pond	Boulder	1784	7/25/99	Adams	F	A	L	13	477887	4419450
226	Lindsey Pond	Boulder	1784	7/25/99	Adams	F	A	L	13	477887	4419450
227	Lindsey Pond	Boulder	1784	7/7/04	Kiser	F	A	NR	13	477887	4419450
228	Lindsey Pond	Boulder	1784	7/2/07	Hayes/Adams	F	A	P	13	477887	4419450
229	Long Canyon	Boulder	2066	7/11/04	Kiser	F	A	L	13	473740	4426880
230	Long Canyon	Boulder	2066	7/11/04	Kiser	F	A	L	13	473740	4426880
231	Long Canyon	Boulder	2066	6/13/06	Kiser	M	A	NS	13	473740	4426880
232	Long Canyon	Boulder	2066	6/29/06	Kiser	F	A	P	13	473740	4426880
234	Long Canyon	Boulder	2066	6/29/06	Kiser	M	A	NS	13	473740	4426880
235	Long Canyon	Boulder	2066	7/28/08	Adams	M	A	NS	13	473740	4426880
236	Long Canyon	Boulder	2066	7/28/08	Adams	F	A	PL	13	473740	4426880

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
237	Long Canyon	Boulder	2066	7/6/09	Adams/Hayes	M	A	NS	13	473740	4426880
238	Long Canyon Roost	Boulder	2080		Adams	F			13	474900	4427240
239	Lower Geer	Boulder	1833	7/24/06	Adams	F	A	L	13	474170	4443810
240	Lower Geer	Boulder	1833	7/24/06	Adams	F	A	L	13	474170	4443810
241	Lower Geer	Boulder	1833	7/24/06	Adams	F	A	L	13	474170	4443810
242	Lower Geer	Boulder	1833	7/24/06	Adams	F	A	NLNP	13	474170	4443810
243	Lower Geer	Boulder	1833	7/24/06	Adams	F	A	L	13	474170	4443810
244	Lower Geer	Boulder	1833	5/20/07	Adams	F	A	P	13	474170	4443810
245	Lower Geer Canyon	Boulder	1833	7/29/02	Adams	F	A	L	13	474170	4443810
246	Lower Geer Canyon	Boulder	1833	7/29/02	Adams	M	A	NS	13	474170	4443810
247	Lower Geer Canyon	Boulder	1833	7/29/02	Adams	M	A	NS	13	474170	4443810

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
248	Lower Geer Canyon	Boulder	1833	8/4/02	Adams	F	A	L	13	474170	4443810
249	Lower Geer Canyon	Boulder	1833	8/4/02	Adams	F	A	L	13	474170	4443810
250	Lower Geer Canyon	Boulder	1833	8/4/02	Adams	M	J	NS	13	474170	4443810
251	Lower Geer Canyon	Boulder	1833	8/4/02	Adams	F	A	PL	13	474170	4443810
252	Lower Geer Canyon	Boulder	1833	8/4/02	Adams	F	J	NLNP	13	474170	4443810
253	Lower Geer Canyon	Boulder	1833	8/4/02	Adams	F	J	NLNP	13	474170	4443810
254	Lower Geer Canyon	Boulder	1833	8/24/04	Adams	F	J	NLNP	13	474170	4443810
256	Lower Geer Canyon	Boulder	1833	7/13/06	Adams	F	A	L	13	474170	4443810
257	Low. Geer	Boulder	1833	7/13/06	Adams	F	A	L	13	474170	4443810

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
258	Lower Geer Canyon	Boulder	1833	7/13/26	Adams	F	A	L	13	474170	4443810
259	Lower Geer Canyon	Boulder	1833	7/13/06	Adams	F	A	L	13	474170	4443810
260	Lower Geer Canyon	Boulder	1833	7/13/06	Adams	F	A	L	13	474170	4443810
261	Lower Geer Canyon	Boulder	1833	7/13/06	Adams	F	A	L	13	474170	4443810
262	Lower Geer Canyon	Boulder	1833	7/13/06	Adams	F	A	L	13	474170	4443810
263	Lower Geer Canyon	Boulder	1833	7/13/06	Adams	M	A	NS	13	474170	4443810
264	Lower Geer Canyon	Boulder	1833	7/13/06	Adams	F	A	L	13	474170	4443810
265	Lower Geer Canyon	Boulder	1833	7/13/06	Adams	F	A	L	13	474170	4443810
266	Lower Geer	Boulder	1833	7/13/06	Adams	F	A	L	13	474170	4443810

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
267	Lower Geer Canyon	Boulder	1833	7/13/06	Adams	F	A	L	13	474170	4443810
268	Lower Geer Canyon	Boulder	1833	7/15/06	Adams	F	A	UNK	13	474170	4443810
269	Lower Geer Canyon	Boulder	1833	7/15/06	Adams	M	A	NS	13	474170	4443810
270	Lower Geer Canyon	Boulder	1833	7/15/06	Adams	F	A	L	13	474170	4443810
271	Lower Geer Canyon	Boulder	1833	7/15/06	Adams	F	A	L	13	474170	4443810
272	Lower Geer Canyon	Boulder	1833	7/15/06	Adams	F	A	NLNP	13	474170	4443810
273	Lower Geer Canyon	Boulder	1833	7/15/06	Adams	F	A	L	13	474170	4443810
274	Lower Geer Canyon	Boulder	1833	7/15/06	Adams	F	A	L	13	474170	4443810
275	Lower Geer	Boulder	1833	7/15/06	Adams	F	A	NLNP	13	474170	4443810

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
276	Lower Geer Canyon	Boulder	1833	7/18/06	Adams	F	A	L	13	474170	4443810
277	Lower Geer Canyon	Boulder	1833	7/18/06	Adams	M	A	NS	13	474170	4443810
278	Lower Geer Canyon	Boulder	1833	7/18/06	Adams	F	A	NLNP	13	474170	4443810
279	Lower Geer Canyon (HVR)	Boulder	1833	7/26/06	Hayes	F	A	NR	13	474170	4443810
280	Lower Geer Canyon (HVR)	Boulder	1833	7/26/06	Hayes	F	A	L	13	474170	4443810
281	Lower Geer Canyon (HVR)	Boulder	1833	7/26/06	Hayes	F	A	L	13	474170	4443810
282	Lower Geer Canyon (HVR)	Boulder	1833	8/8/06	Hayes	M	J		13	474170	4443810
283	Lower Geer Canyon (HVR)	Boulder	1833	8/8/06	Hayes	M	A	NS	13	474170	4443810
284	Lower Long	Boulder	1833	6/1/01	Adams	F	A	P	13	473740	4426880

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
285	Lower Long Canyon	Boulder	1833	7/27/01	Adams	F	A	PL	13	473740	4426880
286	Maiden I	Boulder		7/29/01	Adams	M	A	NS			
287	Maiden I	Boulder		7/29/01	Adams	M	A	NS			
288	Mallory Cave	Boulder	2083		Adams	F			13	475333	4424705
289	Middle Geer Canyon	Boulder	1830	8/2/03	Adams	M	J	NS	13	473950	4443790
290	Middle Geer Canyon	Boulder	1830	8/2/03	Adams	M	J	NS	13	473950	4443790
291	Middle Geer Canyon	Boulder	1830	8/2/03	Adams	M	J	NS	13	473950	4443790
292	Middle Geer Canyon	Boulder	1830	8/2/03	Adams	F	J	NLNP	13	473950	4443790
293	Middle Geer Canyon	Boulder	1830	8/2/03	Adams	F	J	NLNP	13	473950	4443790
294	Middle Geer Canyon	Boulder	1830	8/13/03	Adams	F	A	L	13	473950	4443790

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
295	Middle Geer Canyon	Boulder	1830	8/13/03	Adams	M	J	NS	13	473950	4443790
296	Middle Geer Canyon	Boulder	1830	8/13/03	Adams	M	J	NS	13	473950	4443790
297	Middle Geer Canyon	Boulder	1830	8/13/03	Adams	M	J	NS	13	473950	4443790
298	Middle Geer Canyon	Boulder	1830	8/13/03	Adams	M	J	NS	13	473950	4443790
299	Middle Geer Canyon	Boulder	1830	6/7/04	Adams/Kiser	F	A	P	13	473950	4443790
300	Middle Geer Canyon	Boulder	1830	6/7/04	Adams/Kiser	M	A	P	13	473950	4443790
301	Middle Geer Canyon	Boulder	1830	6/7/04	Adams	F	A	P	13	473950	4443790
302	Middle Geer Canyon	Boulder	1830	6/7/04	Adams	F	A	P	13	473950	4443790
303	Middle Geer	Boulder	1830	7/6/04	Adams	F	A	P	13	473950	4443790

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
304	Middle Geer Canyon	Boulder	1830	7/8/04	Kiser	F	A	L	13	473950	4443790
305	Middle Geer Canyon	Boulder	1830	7/9/04	Adams	F	A	L	13	473950	4443790
306	Middle Geer Canyon	Boulder	1830	7/9/04	Kiser	F	A	L	13	473950	4443790
307	Middle Geer Canyon	Boulder	1830	8/12/05	Adams	F	J	NLNP	13	473950	4443790
308	Middle Geer Canyon	Boulder	1830	8/25/05	Kiser	F	SA	NR	13	473950	4443790
309	Middle Geer Canyon	Boulder	1830	8/12/05	Adams	F	A	PL	13	473950	4443790
310	Middle Geer Canyon	Boulder	1830	9/13/05	Adams	M	J	NS	13	473950	4443790
311	Middle Geer Canyon	Boulder	1830	9/13/05	Adams	F	A	NLNP	13	473950	4443790
312	Mt. Sanitas	Boulder	1896		Adams	F			13	474130	4431370

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
313	NE of Mallory Cave	Boulder	2075	6/7/98	Adams	F	A	UNK	13	475448	4424741
314	NE of Mallory Cave	Boulder	2075	6/22/98	Adams	F	A	UNK	13	475448	4424741
315	North Eldorado Roost	Boulder	2131		Adams	F			13	475400	4421220
316	North Shanahan Trail Pond	Boulder	1802	8/14/96	Adams	M	J	NS	13	477518	4423786
317	North Shanahan Trail Pond	Boulder	1802	7/2/97	Adams	M	A	NS	13	477518	4423786
318	North Shanahan Trail Pond	Boulder	1802	6/2/98	Adams	F	A	P	13	477518	4423786
319	North Shanahan Trail Pond	Boulder	1802	7/5/98	Adams	F	A	L	13	477518	4423786
320	North Shanahan Trail Pond	Boulder	1802	7/5/98	Adams	F	A	L	13	477518	4423786
321	North Shanahan	Boulder	1802	8/22/98	Adams	M	A	NS	13	477518	4423786

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
322	North Shanahan Trail Pond	Boulder	1802	8/22/98	Adams	F	J	NLNP	13	477518	4423786
323	North Shanahan Trail Pond	Boulder	1802	6/8/99	Adams	M	A	NS	13	477518	4423786
324	North Shanahan Trail Pond	Boulder	1802	8/13/99	Adams	F	A	L	13	477518	4423786
325	North Shanahan Trail Pond	Boulder	1802	8/13/99	Adams	M	A	NS	13	477518	4423786
326	North Shanahan Trail Pond	Boulder	1802	8/13/99	Adams	M	A	S	13	477518	4423786
327	North Shanahan Trail Pond	Boulder	1802	8/13/99	Adams	F	A	PL	13	477518	4423786
328	North Shanahan Trail Pond	Boulder	1802	8/13/99	Adams	F	A	L	13	477518	4423786
329	North Shanahan Trail Pond	Boulder	1802	8/13/99	Adams	F	A	L	13	477518	4423786
330	North Shanahan	Boulder	1802	8/13/99	Adams	F	J	NLNP	13	477518	4423786

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
331	North Shanahan Trail Pond	Boulder	1802	8/13/99	Adams	F	A	L	13	477518	4423786
332	North Shanahan Trail Pond	Boulder	1802	8/4/08	Adams	M	A	S	13	476896	4423808
333	North Shanahan Trail Pond	Boulder	1802	8/4/08	Adams	M	A	NS	13	476896	4423808
334	North Shanahan Trail Pond	Boulder	1802	8/4/08	Adams	M	A	S	13	476896	4423808
335	North Shanahan Trail Pond	Boulder	1802	8/7/09	Adams	F	A	P	13	476896	4423808
336	Plumely Canyon (Site 1)	Boulder	1913	6/16/03	Adams	F	A	P	13	474040	4445940
337	Pollywag Pond	Boulder	1772	6/27/95	Adams	M	A	NS	13	477610	4423710
338	Pollywag Pond	Boulder	1772	6/27/95	Adams	M	A	NS	13	477610	4423710
339	Quarry 2	Boulder		6/1/04	Adams	F	A	P			
340	Roadway Waterhole	Boulder		6/18/05	Adams	F	A	P			

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
341	Roadway Waterhole (HVR)	Boulder		6/18/05	Adams	F	A	P			
342	Roadway Waterhole (HVR)	Boulder		6/18/05	Adams	F	A	P			
343	Roadway Waterhole (HVR)	Boulder		6/18/05	Adams	F	A	P			
344	Schneider Pond	Boulder		7/13/96	Adams	M	A	NS			
345	Shadow Canyon	Boulder	1996	5/27/98	Adams	M	A	NS	13	477382	4421239
346	Shadow Canyon	Boulder	1996	5/27/98	Adams	M	A	NS	13	477382	4421239
347	Shadow Canyon	Boulder	1996	5/27/98	Adams	M	A	NS	13	477382	4421239
348	Shadow Canyon	Boulder	1996	5/27/98	Adams	M	A	NS	13	477382	4421239

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
349	Shadow Canyon	Boulder	1996	6/11/98	Adams	M	A	NS	13	477382	4421239
350	Shadow Canyon	Boulder	1996	6/11/98	Adams	M	A	NS	13	477382	4421239
351	Shadow Canyon	Boulder	1996	7/19/98	Adams	M	A	NS	13	477382	4421239
352	Shadow Canyon	Boulder	1996	6/18/99	Adams	M	A	NS	13	477382	4421239
353	Shadow Canyon	Boulder	1996	6/18/99	Adams	M	A	NS	13	477382	4421239
354	Shadow Canyon	Boulder	1996	6/18/99	Adams	M	A	NS	13	477382	4421239
355	Shadow Canyon	Boulder	1996	6/18/99	Adams	M	A	NS	13	477382	4421239
356	Shadow Canyon	Boulder	1996	6/18/99	Adams	M	A	NS	13	477382	4421239
357	Shadow Can.	Boulder	1996	6/18/99	Adams	M	A	NS	13	477382	4421239

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
358	Shadow Canyon	Boulder	1762	7/20/99	Adams	M	A	I	13	477382	4421239
359	Shadow Canyon	Boulder	1762	7/1/04	Kiser	M	A	NS	13	477382	4421239
360	Shadow Canyon	Boulder	1762	7/1/04	Kiser	M	A	NS	13	477382	4421239
361	Shadow Canyon	Boulder	1762	8/15/04	Kiser	M	A	NS	13	477382	4421239
362	Shadow Canyon	Boulder	1762	5/19/05	Kiser	M	A	NS	13	477382	4421239
363	Shadow Canyon	Boulder	1762	5/19/05	Kiser	M	A	NS	13	477382	4421239
364	Shadow Canyon	Boulder	1762	7/13/05	Kiser	M	A	NS	13	477382	4421239
365	Shanahan Ridge Pond	Boulder	1798	7/29/95	Adams	M	A	S	13	477638	4423634
366	Shanahan R.P.	Boulder	1798	7/29/95	Adams	M	A	S	13	477638	4423634

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
367	Shanahan Ridge Pond	Boulder	1798	7/29/95	Adams	F	A	L	13	477638	4423634
368	Shanahan Ridge Pond	Boulder	1798	6/6/96	Adams	M	A	NS	13	477638	4423634
369	South Shanahan Trail Pond	Boulder	1769	8/19/98	Adams	M	J	NS	13	477638	4423634
370	South Shanahan Trail Pond	Boulder	1769	8/27/98	Adams	M	J	NS	13	477638	4423634
371	Stockton Cabin Pool	Boulder	1766	7/12/95	Adams	M	SA	NS	13	477382	4421239
372	Stockton Cabin Pool	Boulder	1766	7/12/95	Adams	M	A	S	13	477382	4421239
373	Stockton Cabin Pool	Boulder	1766	7/12/95	Adams	M	A	NS	13	477382	4421239
374	Stockton Cabin Pool	Boulder	1766	8/12/96	Adams	M	A	A	13	477382	4421239
375	Stockton Cabin	Boulder	1766	8/12/96	Adams	M	A	S	13	477382	4421239

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
376	Stockton Cabin Pool	Boulder	1766	8/12/96	Adams	M	A	S	13	477382	4421239
377	Stockton Cabin Pool	Boulder	1766	8/12/96	Adams	M	A	S	13	477382	4421239
378	Stockton Cabin Pool	Boulder	1766	8/12/96	Adams	M	A	S	13	477382	4421239
379	Stockton Cabin Pool	Boulder	1766	6/11/97	Adams	M	A	NS	13	477382	4421239
380	Stockton Cabin Pool	Boulder	1766	6/11/97	Adams	M	A	NS	13	477382	4421239
381	Stockton Cabin Pool	Boulder	1766	6/11/97	Adams	M	A	NS	13	477382	4421239
382	Stockton Cabin Pool	Boulder	1766	6/19/97	Adams	M	A	NS	13	477382	4421239
383	Stockton Cabin Pool	Boulder	1766	6/19/97	Adams	M	A	NS	13	477382	4421239
384	Stockton Cabin	Boulder	1766	6/30/97	Adams	M	A	NS	13	477382	4421239

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
385	Stockton Cabin Pool	Boulder	1766	8/1/97	Adams	M	A	NS	13	477382	4421239
386	Stockton Cabin Pool	Boulder	1766	8/1/97	Adams	M	A	S	13	477382	4421239
387	Stockton Cabin Pool	Boulder	1766	8/1/97	Adams	M	A	S	13	477382	4421239
388	Stockton Cabin Pool	Boulder	1766	8/1/97	Adams	M	A	S	13	477382	4421239
389	Stockton Cabin Pool	Boulder	1766	8/1/97	Adams	M	A	S	13	477382	4421239
390	Stockton Cabin Pool	Boulder	1766	8/1/97	Adams	M	A	S	13	477382	4421239
391	Stockton Cabin Pool	Boulder	1766	8/1/97	Adams	M	A	S	13	477382	4421239
392	Stockton Cabin Pool	Boulder	1766	8/1/97	Adams	M	A	S	13	477382	4421239
393	Stockton Cabin	Boulder	1766	8/14/97	Adams	M	A	NS	13	477382	4421239

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
394	Stockton Cabin Pool	Boulder	1766	8/22/97	Adams	M	A	S	13	477382	4421239
395	Stockton Cabin Pool	Boulder	1766	8/22/97	Adams	M	J	NS	13	477382	4421239
396	Stockton Cabin Pool	Boulder	1766	7/28/01	Adams	M	A	NS	13	477382	4421239
397	Stockton Cabin Pool	Boulder	1766	7/28/01	Adams	M	A	NS	13	477382	4421239
398	Stockton Cabin Pool	Boulder	1766	7/28/01	Adams	M	A	NS	13	477382	4421239
399	Stockton Cabin Pool	Boulder	1766	7/28/01	Adams	M	A	NS	13	477382	4421239
400	Tank 1, HVR	Boulder		6/22/03	Adams	M	A	NS	13	474490	4447490
401	Tank 2, HVR	Boulder		7/1/03	Adams	M	A	NS	13	474240	4447630
402	Tank 2, HVR	Boulder		7/1/03	Adams	F	A	P	13	474240	4447630
403	Thinned 3	Boulder		7/29/04	Adams	F	A	L			

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
404	Thinned 3	Boulder		7/29/04	Adams	M	A	NS			
405	Tucker B1	Boulder	2316	9/19/00	BIMP	M	J	NONB	13	465041	4428043
406	Tucker L2	Boulder	1768	6/24/00	BIMP	F	A	NONB	13	473988	4453563
407	Tucker L2	Boulder	1768	6/24/00	BIMP	F	A	LACT	13	473988	4453563
408	Tucker L2	Boulder	1768	6/24/00	BIMP	F	A	LACT	13	473988	4453563
409	Tucker L2	Boulder	1768	6/24/00	BIMP	F	A	LACT	13	473988	4453563
410	Tucker L2	Boulder	1768	9/16/00	BIMP	F	A	POST	13	473988	4453563
411	Tucker L2	Boulder	1768	9/16/00	BIMP	F	A	PREG	13	473988	4453563
412	Tucker mine L2	Boulder	1768	6/24/00	BIMP	F	A	NONB	13	473988	4453563
413	Tucker mine L2	Boulder	1768	6/24/00	BIMP	F	A	L	13	473988	4453563
414	Tucker mine L2	Boulder	1768	6/24/00	BIMP	F	A	L	13	473988	4453563
415	Tucker mine L2	Boulder	1768	6/24/00	BIMP	F	A	L	13	473988	4453563
416	Tucker mine L2	Boulder	1768	9/16/00	BIMP	F	A	PL	13	473988	4453563
417	Tucker mine L2	Boulder	1768	9/16/00	BIMP	F	A	PL	13	473988	4453563

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
418	Upper Geer	Boulder	1826	8/8/06	Adams	M	A	NS	13	473460	4443790
419	Upper Geer	Boulder	1826	8/8/06	Adams	M	J	NS	13	473460	4443790
420	Upper Geer Canyon	Boulder	1826	6/27/02	Adams	F	A	L	13	473460	4443790
421	Upper Geer Canyon	Boulder	1826	6/27/02	Adams	M	A	NS	13	473460	4443790
422	Upper Geer Canyon	Boulder	1826	7/5/02	Adams	M	A	NS	13	473460	4443790
423	Upper Geer Canyon	Boulder	1826	7/30/02	Adams	F	J	NLNP	13	473460	4443790
424	Upper Geer Canyon	Boulder	1826	7/13/03	Adams	F	A	L	13	473460	4443790
425	Upper Geer Canyon	Boulder	1826	7/1/09	Hayes	M	A	NR	13	473460	4443790
426	Upper Gregory Canyon	Boulder	1826	6/5/01	Adams	F	A	P	13	473460	4443790
427	Gregory Can.	Boulder	1820	6/22/09	Hayes	M	A	NR	13T	474856	4427333

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
428	Gregory Canyon (Boulder OSMP)	Boulder	1820	6/22/09	Hayes	M	A	NR	13T	474856	4427333
429	Heil Valley Ranch, Lower Geer Canyon	Boulder	1832	6/16/09	Hayes	M	A	NR	13T	473962	4443775
430	Heil Valley Ranch, Upper Geer Canyon	Boulder	1826	7/1/09	Hayes	M	A	NR	13T	473170	4443935
431	Chicago Creek 236	Clear Creek	2420	6/16/01	BIMP	M	A	NONB	13	453846	4398332
432	Red Elephant 17	Clear Creek	2755	9/19/04	BIMP	M	A	TENL	13	446357	4402541
433	Dutch Flat 126	Custer	2569	7/25/03	BIMP	M	A	NONB	13	489402	4219795
434	Robinson118	Custer	2788	8/25/01	BIMP	M	A	NONB	13	469294	4218289
435	Junction Pond USFS	Dolores		7/16/05	BIMP	M	A		12	690093	4197520

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
436	North Pines	Dolores	2345	8/19/06	Hayes	F	A	PL			
437	North Pines	Dolores	2345	8/19/06	Hayes	F	A	PL			
438		El Paso			DMNS	F					
439	6 mi. N, 1 mi. W Colorado Springs	El Paso			Barbour and Davis, 1969						
440	5 Sisters 6	Fremont	1764	9/27/04	BIMP	M	A	TENL	13	484049	4244539
441	5 Sisters 6	Fremont	1764	9/27/04	BIMP	M	A	TENL	13	484049	4244539
442	Grape Creek GC-4	Fremont	1857	5/20/06	BIMP	F	A	UNKN	13	471162	4249075
443	Sunset City roost	Fremont	2214	7/23/07	Hayes	F	A	LACT	13	460321	4248898
444	Sunset City 2	Fremont	2214	5/28/09	Hayes	F	A	UNK	13	460321	4248898
445	Sunset City 2	Fremont	2214	5/28/09	Hayes	F	A	UNK	13	460321	4248898
446	Sunset City 2	Fremont	2214	5/28/09	Hayes	F	A	UNK	13	460321	4248898

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
447	Sunset City 2	Fremont	2210	7/28/05	BIMP	F	A	LACT	13	460320	4248900
448	Sunset City 2	Fremont	2210	7/28/05	BIMP	F	A	LACT	13	460320	4248900
449	Sunset City 2	Fremont	2210	7/28/05	BIMP	F	A	LACT	13	460320	4248900
450	Sunset City 2	Fremont	2210	7/28/05	BIMP	F	A	LACT	13	460320	4248900
451	Sunset City 2	Fremont	2210	7/28/05	BIMP	F	A	LACT	13	460320	4248900
452	Sunset City 2	Fremont	2210	7/28/05	BIMP	F	A	LACT	13	460320	4248900
453	Sunset City 2	Fremont	2210	7/28/05	BIMP	F	A	LACT	13	460320	4248900
454	Sunset City 2	Fremont	2210	7/8/05	BIMP	F	A	UNKN	13	460320	4248900
455	Sunset City 2	Fremont	2210	7/8/05	BIMP	U	U	UNKN	13	460320	4248900
456	Sunset City 2	Fremont	2210	7/8/05	BIMP	F	U	UNKN	13	460320	4248900
457	Sunset City 2	Fremont	2210	7/8/05	BIMP	F	U	UNKN	13	460320	4248900
458	Sunset City 2	Fremont	2210	7/8/05	BIMP	F	U	UNKN	13	460320	4248900
459	Sunset City 2	Fremont	2210	7/8/05	BIMP	F	A	UNKN	13	460320	4248900
460	Sunset City 2	Fremont	2210	7/8/05	BIMP	F	A	UNKN	13	460320	4248900

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
461	Sunset City 2	Fremont	2210	7/8/05	BIMP	F	A	UNKN	13	460320	4248900
462	Sunset City 2	Fremont	2210	7/8/05	BIMP	F	A	UNKN	13	460320	4248900
463	New Castle	Garfield									
464	Jeffco BC-1	Jefferson	1885	5/17/05	BIMP	F	A	PREG	13	482144	4389173
465	Jeffco JCOS -4	Jefferson	1902	8/26/93	BIMP	M	J	UNKN	13	486540	4376840
466	DRG Burnwell 1	La Plata	2271	8/23/93	BIMP	F	A	NONB	12	757400	4127190
467	DRG Old Peacock East	La Plata	2347	6/18/92	Freeman	F	A	NONB	12	758100	4127540
468	DRG Old Peacock East	La Plata	2347	8/31/94	BIMP	F	A	POST	12	758100	4127540
469	DRG Old Peacock East	La Plata	2347	8/31/94	BIMP	M	U	NONB	12	758100	4127540
470	DRG Old Peacock East	La Plata	2347	7/31/00	BIMP	M	A	NONB	12	758100	4127540
471	Peacock West	La Plata	2347	8/21/91	BIMP	M	A	TENL	12	758090	4127540

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
472	DRG Old Peacock West	La Plata	2347	8/02/92	Freeman	M	A	NONB	12	758090	4127540
473	Peacock Mine, sec. 29, T35N, R11W	La Plata			Freeman and Adams, 1992						
474	1.5 mi. S., 5.6 mi. W Livermore, SE 1/4 sec. 5, T9N R71W	Larimer	2012	8/30/81	Riddle & Svoboda	F			13	469852	4513102
475	2939 N County Road 31-D	Larimer	1615		Armstrong						
476	Cow Camp, Sylvan Dale Guest Ranch, Cedar Creek	Larimer	1890		Armstrong						
477	Dutch George	Larimer	1982	9/23/04	USGS	M	A	Not	13t	462332	4504965
478	Gateway Confluence	Larimer	1660	9/4/03	USGS	F	A	Post	13t	479612	4505680

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
479	Gateway Mountain Park	Larimer	1641	9/4/04	USGS	F	A				
480	Hewlett Gulch Pond	Larimer	1830	7/4/06	Hayes	M	A		13	473610	4506490
481	Hewlett Gulch Pond	Larimer	1830	8/10/06	Hayes	M	A		13	473610	4506490
482	Hewlett Gulch Pond	Larimer	1830	8/10/06	Hayes	F	A	NR	13	473610	4506490
483	Hewlett Gulch Pool	Larimer	1830	8/11/08	Hayes	F	A	L	13T	473588	4506512
484	Hewlett Gulch Pool	Larimer	1830	8/11/08	Hayes	M	A	NR	13T	473588	4506512
485	Hewlett Gulch, Sara's Crossing	Larimer	1778	6/27/08	Hayes	M	A	NR	13T	473403	4505318
486	Hewlett Gulch, Sara's Crossing	Larimer	1778	6/27/08	Hayes	F	A	L	13T	470650	4503880
487	Sara's Crossing	Larimer	1778	7/27/08	Hayes	F	A	L	13T	473403	4505318

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
488	Hewlett Gulch, Sara's Crossing	Larimer	1778	7/27/08	Hayes	F	A	L	13T	473403	4505318
489	Hewlett Gulch, Sara's Crossing	Larimer	1778	7/27/08	Hayes	F	A	L	13T	473403	4505318
490	Manhattan SM19	Larimer	2304	8/29/98	BIMP	M	A	NONB	13	449010	4504400
491	Manhattan SM19	Larimer	2304	8/29/98	BIMP	M	A	TENL	13	449010	4504400
492	Manhattan SP1	Larimer	1864	7/14/01	BIMP	M	A	NONB	13	467646	4503550
493	mouth of Sulzer Gulch, T5N, R71W, sec. 3, 5280'	Larimer	1609	9/3/90	Armstrong	M			13	482161	4474709
494	Old Flowers Pond	Larimer	2632	7/17/03	USGS	F	A	Not	13t	457748	4496615
495	Old Flowers Pond	Larimer	2632	7/17/03	USGS	M	A	Scro	13t	457748	4496615

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
496	Pamige Ranch Pond	Larimer	2129	9/9/04	USGS	M	J	Not	13t	468415	4500434
497	Phantom Canyon, North Fork Poudre River	Larimer	1920		Armstrong				13	475100	4521600
498	Picnic Rock	Larimer	1598	8/5/03	USGS	F	A	Lact	13t	480553	4502405
499	Picnic Rock	Larimer	1598	8/5/03	USGS	F	A	Lact	13t	480553	4502405
500	Picnic Rock	Larimer	1598	8/5/03	USGS	M	A	Not	13t	480553	4502405
501	Picnic Rock	Larimer	1598	9/1/03	USGS	M	J	Not	13t	480553	4502405
502	Redstone Pool	Larimer	1816	8/20/07	USGS	F	A	PL	13	480877	4490339
503	Redstone Pool	Larimer	1816	8/20/07	USGS	F	A	PL	13	480877	4490339
504	Redstone Pool	Larimer	1816	8/20/07	USGS	F	A	PL	13	480877	4490339
505	Redstone Pool	Larimer	1816	8/20/07	USGS	F	A	PL	13	480877	4490339
506	Redstone Pool	Larimer	1816	8/20/07	USGS	F	A	PL	13	480877	4490339

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
507	Redstone Pool	Larimer	1816	8/20/07	USGS	M	A		13	480877	4490339
508	Redstone Pool	Larimer	1816	8/20/07	USGS	M	J		13	480877	4490339
509	Redstone Pool	Larimer	1816	8/20/07	USGS	M	J		13	480877	4490339
510	Redstone Pool	Larimer	1816	8/20/07	USGS	M	J		13	480877	4490339
511	RFRD A100	Larimer	2402	9/24/94	BIMP	M	A	TENL	13	449400	4507350
512	Sara's Crossing (Hewlett Gulch)	Larimer	6000	6/30/06	Hayes	F	A	L	13	473452	4505086
513	Sara's Crossing (Hewlett Gulch)	Larimer	6000	6/30/06	Hayes	F	A	L	13	473452	4505086
514	Sara's Crossing (Hewlett Gulch)	Larimer	6000	6/30/06	Hayes	F	A	L	13	473452	4505086
515	Sylvan Dale Ranch, 6.5 mi W Loveland	Larimer	1609	5/22/93	Armstrong	F			13	481626	4475514

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
516	Triolos Ponds	Larimer		8/6/03	USGS	M	A	Scro	13t	474021	4499619
517	Young's Gulch	Larimer	1782	7/18/08	Hayes	F	A	PL	13T	473403	4505318
518	Young's gulch	Larimer	1797	6/30/09	Hayes	M	A	NS	13T	470681	4503932
519	4 mi. S, 3 3/4 mi. W Gulnare	Las Animas			J. R. Choate, pers. comm.						
520	Burro Canyon, T32S R66W, Sec 18	Las Animas	2316	8/15/81	Finley & Riddle	F					
521	junction Plum and Chacuacu (sp. Chacuacu) creeks	Las Animas	1524	7/22/77		M			13	621420	4150930
522	Wooten	Las Animas	2308	6/16/68	Findley	F					
523	Amethyst Queen 9	Mesa	1987	8/25/95	BIMP	M	A	NONB	12	711970	4301590
524	Calamity FP2	Mesa	1963	7/30/97	BIMP	F	A	LACT	12	687845	4275583
525	Dominguez	Mesa	1463		Allard	F			12	722590	4464610

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
526	Dominguez Recreation Site, ca. 3 mi (by rd) NW Dominguez Recreation Site	Mesa	1463		Valdez	F			12	722590	4464610
527	Little Dolores Canyon	Mesa		6/24/98	BIMP	M	A	NB	13	150634	4325722
528	Lumsden 87 Mag.	Mesa	2073	10/3/00	BIMP	M	J	NONB	12	671640	4279190
529	Outlaw Mesa Dixie 2	Mesa	1890	9/22/98	BIMP	M	A	TENL	12	687205	4275697
530	Outlaw Mesa 30	Mesa	2036	6/4/97	BIMP	M	A	NONB	12	689523	4276110
531	Outlaw Mesa	Mesa	2006	6/25/97	BIMP	F	A	UNKN	12	686972	4276190
532	Outlaw Mesa A2	Mesa	1993	6/5/97	BIMP	F	A	PREG	12	686684	4276420
533	Outlaw Mesa	Mesa	2006	6/6/97	BIMP	F	A	PREG	12	686439	4276708

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
534	Outlaw Mesa 59	Mesa	2006	6/6/97	BIMP	F	A	PREG	12	686439	4276708
535	Outlaw Mesa 59	Mesa	2006	6/6/97	BIMP	F	A	PREG	12	686439	4276708
536	Outlaw Mesa 60	Mesa	2006	6/6/97	BIMP	F	A	PREG	12	686374	4276722
537	Outlaw Mesa 60	Mesa	2006	6/6/97	BIMP	F	A	PREG	12	686374	4276722
538	Outlaw Mesa 61 D2	Mesa	1951	9/22/98	BIMP	F	A	NONB	12	686435	4277097
539	Outlaw Mesa 64D1	Mesa	2006	6/6/97	BIMP	F	A	PREG	12	686226	4276840
540	Outlaw Mesa 64D1	Mesa	2006	6/697	BIMP	F	A	PREG	12	686226	4276840
541	Outlaw Mesa 64D3	Mesa	2006	6/6/97	BIMP	F	A	PREG	12	686257	4276907
542	Outlaw 64D3	Mesa	2006	9/20/97	BIMP	F	A	NONB	12	686257	4276907

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
543	Outlaw Mesa 65	Mesa	1999	6/19/97	BIMP	F	A	PREG	12	686005	4276955
544	Outlaw Mesa 65	Mesa	1999	9/20/97	BIMP	U	U	UNKN	12	686005	4276955
545	Outlaw Mesa 66D1	Mesa	1993	10/1/97	BIMP	M	A	NONB	12	685593	4276271
546	Outlaw Mesa 73A1	Mesa	1993	9/27/98	BIMP	F	A	NONB	12	687355	4273080
547	Tenderfoot Mesa 14B	Mesa	2006	8/1/97	BIMP	M	A	NONB	12	687355	4273080
548	Tenderfoot Mesa 15A	Mesa	1981	10/3/95	BIMP	M	A	NONB	12	681200	4277900
549	Tenderfoot Mesa 3	Mesa	2042	6/24/95	BIMP	M	A	NONB	12	680720	4281720
550	Tenderfoot Mesa 6A	Mesa	2042	8/3/97	BIMP	F	J	NONB			
551	Ute Canyon	Mesa	1402		Adams						

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
552	Ute Canyon, T12S R2W	Mesa	1402								
553	West Creek, 4 mi. NE Gateway, T15S R103W	Mesa			Freeman						
554	About 1.1 mi N of Massey Cabin	Moffat		7/13/90	Bogan	M					
555	Elk Springs, 5 mi. SE of Elk Springs, T5N R98W	Moffat	1890	9/12/81	Freeman	M					
556	Elk Springs, 5 mi. SE of Elk Springs, T5N R98W	Moffat	1890								
557	Green River, Dinosaur NM	Moffat			BIMP						

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
558	Holland Draw, 6 mi SW Greystone, T7N R101W	Moffat		7/2/79		F			12	688024	4493876
559	Holland Draw, 6 mi SW Greystone, T7N R101W	Moffat		7/2/79		F		L	12	688024	4493876
560	Holland Draw, 6 mi SW Greystone, T7N R101W	Moffat		7/2/79		F		NL	12	688024	4493876
561	Pool creek ranch, Dinosaur National Monument	Moffat	1551	8/12/88	Fisher	F					
562	Pool creek ranch, Dinosaur National Monument	Moffat	1551	6/20/89	Bogan	F					

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
563	Pool creek ranch, Dinosaur National Monument	Moffat	1551	6/20/89	Bogan	F					
564	Pot Creek, Dinosaur National Monument	Moffat		7/17/90	BIMP	M	M		13	166701	4505267
565	Pot Creek, Dinosaur National Monument	Moffat		7/17/90	BIMP	M	J		13	166701	4505267
566	right bank Yampa River, river mile 24, Big Joe Campground	Moffat	1615	7/20/82	Bogan	F					
567	0.1 mi. jct Spruce Canyon & Spruce Tree	Montezuma	1914	8/29/92	Bogan	M					

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
568	1 mi SSE Rock Springs, Mesa Verde National Park	Montezuma		8/2/91	Bogan	F					
569	1 mi SSE Rock Springs, Mesa Verde National Park	Montezuma		8/2/91	Valdez	M					
570	1 mi SSE Rock Springs, Mesa Verde National Park	Montezuma		8/2/91	Valdez	F					
571	1 mi SSE Rock Springs, Mesa Verde National Park	Montezuma		8/2/91	Valdez	F					
572	1 mi SSE Rock Springs, Mesa Verde National Park	Montezuma		8/2/91	Valdez	F					

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
573	Mesa Verde Park "Lower Sites"	Montezuma	≤2,165	2006	O'Shea et al. 2011	F					
574	Mesa Verde Park "Lower Sites"	Montezuma	≤2,165	2006	O'Shea et al. 2011	F					
575	Mesa Verde Park "Lower Sites"	Montezuma	≤2,165	2006	O'Shea et al. 2011	F					
576	Mesa Verde Park "Lower Sites"	Montezuma	≤2,165	2006	O'Shea et al. 2011	F					
577	Mesa Verde Park "Lower Sites"	Montezuma	≤2,165	2006	O'Shea et al. 2011	M					
578	Mesa Verde Park "Lower Sites"	Montezuma	≤2,165	2006	O'Shea et al. 2011	M					
579	Mesa Verde	Montezuma	≤2,165	2006	O'Shea et al.	M					

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
580	Mesa Verde Park "Higher Sites"	Montezuma	≥2,311	2006	O'Shea et al. 2011	F					
581	Mesa Verde Park "Higher Sites"	Montezuma	≥2,311	2006	O'Shea et al. 2011	F					
582	Mesa Verde Park "Higher Sites"	Montezuma	≥2,311	2006	O'Shea et al. 2011	F					
583	Mesa Verde Park "Higher Sites"	Montezuma	≥2,311	2006	O'Shea et al. 2011	M					
584	Mesa Verde Park "Higher Sites"	Montezuma	≥2,311	2006	O'Shea et al. 2011	M					
585	Mesa Verde Park "Higher Sites"	Montezuma	≥2,311	2006	O'Shea et al. 2011	M					
586	Mesa Verde	Montezuma	≥2,311	2006	O'Shea et al.	M					

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
587	Mesa Verde Park "Higher Sites"	Montezuma	≥2,311	2006	O'Shea et al. 2011	M					
588	Mesa Verde Park "Higher Sites"	Montezuma	≥2,311	2006	O'Shea et al. 2011	M					
589	Mesa Verde Park "Higher Sites"	Montezuma	≥2,311	2006	O'Shea et al. 2011	M					
590	Mesa Verde Park "Higher Sites"	Montezuma	≥2,311	2006	O'Shea et al. 2011	M					
591	Mesa Verde Park "Higher Sites"	Montezuma	≥2,311	2006	O'Shea et al. 2011	M					
592	Mesa Verde Park "Lower Sites"	Montezuma	≤2,165	2007	O'Shea et al. 2011	F					
593	Mesa Verde	Montezuma	≤2,165	2007	O'Shea et al.	F					

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
594	Mesa Verde Park "Lower Sites"	Montezuma	≤2,165	2007	O'Shea et al. 2011	F					
595	Mesa Verde Park "Lower Sites"	Montezuma	≤2,165	2007	O'Shea et al. 2011	F					
596	Mesa Verde Park "Lower Sites"	Montezuma	≤2,165	2007	O'Shea et al. 2011	F					
597	Mesa Verde Park "Lower Sites"	Montezuma	≤2,165	2007	O'Shea et al. 2011	F					
598	Mesa Verde Park "Lower Sites"	Montezuma	≤2,165	2007	O'Shea et al. 2011	F					
599	Mesa Verde Park "Lower Sites"	Montezuma	≤2,165	2007	O'Shea et al. 2011	F					
600	Mesa Verde	Montezuma	≤2,165	2007	O'Shea et al.	F					

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
601	Mesa Verde Park "Lower Sites"	Montezuma	≤2,165	2007	O'Shea et al. 2011	F					
602	Mesa Verde Park "Lower Sites"	Montezuma	≤2,165	2007	O'Shea et al. 2011	F					
603	Mesa Verde Park "Lower Sites"	Montezuma	≤2,165	2007	O'Shea et al. 2011	F					
604	Mesa Verde Park "Lower Sites"	Montezuma	≤2,165	2007	O'Shea et al. 2011	F					
605	Mesa Verde Park "Lower Sites"	Montezuma	≤2,165	2007	O'Shea et al. 2011	F					
606	Mesa Verde Park "Lower Sites"	Montezuma	≤2,165	2007	O'Shea et al. 2011	M					
607	Mesa Verde	Montezuma	≤2,165	2007	O'Shea et al.	M					

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
608	Mesa Verde Park "Lower Sites"	Montezuma	≤2,165	2007	O'Shea et al. 2011	M					
609	Center	Montezuma		8/20/00	BIMP	F	A	PL	13	189799	4128973
610	Lower Morfield Canyon, Mesa Verde National Park	Montezuma		8/3/89	Ramotnik	M					
611	Lower Morfield Canyon, Mesa Verde National Park	Montezuma		8/4/89	Ramotnik	F					
612	Mesa Verde NP	Montezuma		1989-1994	Chung-MacCaubry and Bogan	F	A				
613	Mesa Verde NP	Montezuma		1989-1994	Chung-MacCaubry and Bogan	F	A				
614	Mesa Verde NP	Montezuma		Same	Same	F	A				

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
615	Mesa Verde NP	Montezuma		1989-1994	Chung-MacCaubry and Bogan	F	A				
616	Mesa Verde NP	Montezuma		1989-1994	Chung-MacCaubry and Bogan	F	A				
617	Mesa Verde NP	Montezuma		1989-1994	Chung-MacCaubry and Bogan	F	A				
618	Mesa Verde NP	Montezuma		1989-1994	Chung-MacCaubry and Bogan	M	?				
619	Mesa Verde NP	Montezuma		1989-1994	Chung-MacCaubry and Bogan	M	?				
620	Mesa Verde NP	Montezuma			Chung-Mac.	M	?				
621	Mesa Verde NP	Montezuma		1989-1994	USGS						

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
622	Rock Springs, Mesa Verde National Park	Montezuma	2256	8/23/56	S. Anderson	F	A				
623	Rock Springs, Mesa Verde National Park	Montezuma	2256	8/3/91	Bogan	F					
624	Cashin Mine W1	Montrose,		8/5/02	BIMP	M	J	NB	13	154600	4247498
625	Cashin Mine W2 Ladder	Montrose,		7/31/98	BIMP	F	A	L	13	154583	4247472
626	Cashin Mine W2 Ladder	Montrose,		7/31/98	BIMP	M	A	NB	13	154583	4247472
627	EAST BULL CANYON 580A1	Montrose,		9/8/04	BIMP	F	A	POST			
628	Grizzly Gulch	Montrose,									
629	GYPSUM 451A1	Montrose,	1739	7/7/02	BIMP	F	A	LACT	12	678225	4227297

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
630	GYPSUM 455A1	Montrose,	1757	9/23/02	BIMP	M	A	TENL	12	678381	4227642
631	GYPSUM 465A1	Montrose,	1701	9/10/96	BIMP	F	J	NONB	12	679458	4226446
632	GYPSUM 469A1	Montrose,	1654	9/27/03	BIMP	F	A	POST	12	678359	4230103
633	GYPSUM 469A1	Montrose,	1654	9/27/03	BIMP	F	A	POST	12	678359	4230103
634	HIEROGLYPHIC 1547	Montrose,	1674	9/12/03	BIMP	M	A	NONB	12	699119	4246624
635	HIEROGLYPHIC 1553A1	Montrose,	1652	6/8/05	BIMP	F	A	LACT	12	697322	4247664
636	HIEROGLYPHIC 1555	Montrose,	1667	6/8/05	BIMP	F	A	LACT	12	697051	4247477
637	Irwin Field	Montrose,	1512	7/11/96	BIMP	M	A	NB	12	160832	4247976
638	LA SAL CREEK # 2	Montrose,		7/25/97	BIMP	F	A	L	12	154621	4247520

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
639	PARADOX 1288A1	Montrose,	1851	9/16/01	BIMP	F	A	POST	12	700974	4237706
640	PARADOX 1290A1	Montrose,	1932	7/11/96	BIMP	M	A	NONB	12	699077	4239460
641	PARADOX 1290A1	Montrose,	1932	7/12/96	BIMP	F	A	NONB	12	699077	4239460
642	PARADOX 1290A1	Montrose,	1932	9/4/96	BIMP	F	J	NONB	12	699077	4239460
643	PARADOX 1291A1	Montrose,	1945	9/4/96	BIMP	M	A	TENL	12	699422	4239221
644	PARADOX 1292A1	Montrose,	1958	9/14/01	BIMP	F	J	NONB	12	699406	4239225
645	PARADOX 1292A1	Montrose,	1958	9/14/01	BIMP	F	A	POST	12	699406	4239225
646	PARADOX 1292A1	Montrose,	1958	9/14/01	BIMP	M	J	NONB	12	699406	4239225
647	PARADOX	Montrose,	1958	9/14/01	BIMP	F	A	POST	12	699406	4239225

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
648	PARADOX 1292A1	Montrose,	1958	9/14/01	BIMP	F	A	POST	12	699406	4239225
649	PARADOX 1292A1	Montrose,	1958	9/14/01	BIMP	F	J	NONB	12	699406	4239225
650	PARADOX 1293A1	Montrose,	1962	9/1/01	BIMP	F	A	POST	12	699362	4239165
651	PARADOX 1293A2	Montrose,	1962	9/1/01	BIMP	F	A	POST	12	699362	4239165
652	PARADOX 278X	Montrose,	2002	9/13/01	BIMP	F	A	POST	12	697052	4240671
653	PARADOX 278X	Montrose,	2002	9/13/01	BIMP	F	A	POST	12	697052	4240671
654	PARADOX 278X	Montrose,	2002	9/13/01	BIMP	F	A	POST	12	697052	4240671
655	PARADOX 278X	Montrose,	2002	9/13/01	BIMP	F	A	POST	12	697052	4240671
656	PARADOX	Montrose,	2002	9/13/01	BIMP	M	J	NONB	12	697052	4240671

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
657	PARADOX 278X	Montrose,	2002	9/13/01	BIMP	F	J	NONB	12	697052	4240671
658	PARADOX 278X	Montrose,	2002	9/13/01	BIMP	U	U	UNKN	12	697052	4240671
659	PARADOX 278X	Montrose,	2002	6/22/02	BIMP	F	A	LACT	12	697052	4240671
660	PARADOX 278X	Montrose,	2002	6/22/02	BIMP	F	A	LACT	12	697052	4240671
661	PARADOX 278X	Montrose,	2002	6/22/02	BIMP	F	A	LACT	12	697052	4240671
662	PARADOX 278X	Montrose,	2002	6/22/02	BIMP	F	A	LACT	12	697052	4240671
663	PARADOX 278X	Montrose,	2002	6/22/02	BIMP	F	A	LACT	12	697052	4240671
664	PARADOX 278X	Montrose,	2002	6/22/02	BIMP	M	A	NONB	12	697052	4240671
665	PARADOX	Montrose,	2002	6/22/02	BIMP	F	A	LACT	12	697052	4240671

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
666	PARADOX 278X	Montrose,	2002	6/22/02	BIMP	F	A	LACT	12	697052	4240671
667	PARADOX 278X	Montrose,	2002	6/22/02	BIMP	F	A	LACT	12	697052	4240671
668	PARADOX 278X	Montrose,	2002	6/22/02	BIMP	F	A	LACT	12	697052	4240671
669	PARADOX 278X	Montrose,	2002	6/22/02	BIMP	F	A	NONB	12	697052	4240671
670	Paradox Canyon	Montrose,	1512	7/10/96	BIMP	M	A	NB	13	165857	4252574
671	Redd Pond	Montrose,	1527	8/23/01	BIMP	F	A	PL	13	161268	4250034
672	SPUD PATCH 1500A1	Montrose,	1644	10/11/96	BIMP	M	A	TENL	12	698100	4249650
673	TRAMP 524	Montrose,		7/6/02	BIMP	M	A	NONB	12	695305	4243570
674	TRAMP 524	Montrose,		9/10/02	BIMP	M	A	NONB	12	695305	4243570
675	TRAMP 527	Montrose,	1948	7/6/02	BIMP	F	A	LACT	12	695305	4243570

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
676	TRAMP 527	Montrose,	1948	7/6/02	BIMP	M	A	NONB	12	695305	4243570
677	Umetco Teapot Dome	Montrose,	1896	9/3/93	BIMP	F	J	NONB	12	693060	4228420
678	WEST MONTROSE 2	Montrose,	1622	9/24/99	BIMP	F	A	POST	12	689330	4254060
679	WEST MONTROSE 2	Montrose,	1622	9/24/99	BIMP	U	U	UNKN	12	689330	4254060
680	WEST MONTROSE 2	Montrose,	1622	9/24/99	BIMP	U	U	UNKN	12	689330	4254060
681	WEST MONTROSE 67	Montrose,	1847	9/25/99	BIMP	M	A	TENL	12	686890	4252530
682	WEST MONTROSE 67	Montrose,	1847	9/25/99	BIMP	U	U	UNKN	12	686890	4252530
683	WEST MONTROSE 68	Montrose,	1914	5/31/99	BIMP	F	A	UNKN	12	686360	4252720

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
684	WEST MONTROSE 69	Montrose,	1914	5/31/99	BIMP	U	U	UNKN	12	686380	4252720
685	WEST MONTROSE 69	Montrose,	1914	5/31/99	BIMP	U	U	UNKN	12	686380	4252720
686	Wiggins Copper Mine	Oklahoma, New Mexico lorado tri-state area	1577	8/16/86	Dalquest et al.	F	A & YOY		13s	673516	4089851
687	Wiggins Copper Mine	Oklahoma, New Mexico lorado tri-state area	1577	7/24/07	Hayes	F	A	L	13s	673516	4089851
688	BOOMER 103B	PARK	2615	9/5/97	BIMP	M	U	TENL	13		
689	BOOMER 110	PARK	2804	9/6/97	BIMP	M	A	TENL	13		
690	Stone City Mines	Pueblo	1570	8/2/08	BIMP	F	A	PL	13	512397	4255739

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
691	Stone City Mines	Pueblo	1570	8/2/08	BIMP	F	A	PL	13	512397	4255739
692	Stone City Mines	Pueblo	1570	8/2/08	BIMP	F	A	PL	13	512397	4255739
693	Stone City Mines	Pueblo	1570	8/2/08	BIMP	F	A	PL	13	512397	4255739
694	Stone City Mines	Pueblo	1570	8/2/08	BIMP	F	A	PL	13	512397	4255739
695	Stone City Mines	Pueblo	1570	8/2/08	BIMP	F	A	PL	13	512397	4255739
696	Stone City Mines	Pueblo	1570	8/2/08	BIMP	F	A	PL	13	512397	4255739
697	Stone City Mines	Pueblo	1570	8/2/08	BIMP	F	A	PL	13	512397	4255739
698	Stone City Mines	Pueblo	1570	8/2/08	BIMP	F	A	PL	13	512397	4255739
699	Stone City	Pueblo	1570	8/2/08	BIMP	F	A	PL	13	512397	4255739

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
700	Stone City Mines	Pueblo	1570	8/2/08	BIMP	F	A	PL	13	512397	4255739
701	Stone City Mines	Pueblo	1570	8/2/08	BIMP	F	A	PL	13	512397	4255739
702	Stone City Mines	Pueblo	1570	8/2/08	BIMP	F	A	PL	13	512397	4255739
703	Stone City Mines	Pueblo	1570	8/2/08	BIMP	F	A	PL	13	512397	4255739
704	Stone City Mines	Pueblo	1570	8/2/08	BIMP	F	A	PL	13	512397	4255739
705	Stone City Mines	Pueblo	1570	8/2/08	BIMP	F	A	PL	13	512397	4255739
706	Stone City Mines	Pueblo	1570	8/2/08	BIMP	F	A	PL	13	512397	4255739
707	Stone City Mines	Pueblo	1570	8/2/08	BIMP	M	A	NS	13	512397	4255739
708	Stone City	Pueblo	1570	8/2/08	BIMP	M	A	NS	13	512397	4255739

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
709	Stone City Mines	Pueblo	1570	8/2/08	BIMP	F	J	NLNP	13	512397	4255739
710	Stone City Mines	Pueblo	1570	7/19/10	Hayes, Navo, Bonewell			MYTH cluster	13	512397	4255739
711	11 mi W Meeker, 0.5 mi S Hwy 64, Hay Gulch Road. T1N, R69W, sec 36.	Rio Blanco		8/17/78	Freeman	M			12	750087	4409647
712	11 mi W Meeker, 0.5 mi S Hwy 64, Hay Gulch Road. T1N, R69W, sec 36.	Rio Blanco		8/17/78	Freeman	M			12	750087	4409647
713	6 mi. SW of Meeker, T1N R95W	Rio Blanco			Freeman						
714	Meeker	Rio Blanco			Freeman						

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
715	GYPSUM 416A1	SAN MIGUEL	1649	9/10/96	BIMP	M	J	TENL	12	687725	4219960
716	GYPSUM 416A1	SAN MIGUEL	1649	9/10/96	BIMP	M	A	TENL	12	687725	4219960
717	GYPSUM 493I2	SAN MIGUEL	1646	9/23/03	BIMP	M	A	TENL	12	684057	4224397
718	JOE DAVIS 519 A3	SAN MIGUEL	1847	6/5/02	BIMP	M	A	NONB	12	689830	4206400
719	SPUD PATCH 616A1	SAN MIGUEL	2257	7/9/96	BIMP	M	J	TENL	12	686408	4203144
720	TAILHOLT 431A2	SAN MIGUEL	1990	9/30/96	BIMP	M	A	TENL	12	679386	4212741
721	UPPER GROUP 3	SAN MIGUEL	1768	10/2/00	BIMP	M	A	TENL	12	686410	4209690
722	WEDDING BELL 906A1	SAN MIGUEL	1911	6/26/05	BIMP	M	A	NONB	12	689799	4225406
723	WB 906A1	S.MIGUEL	1911	6/26/05	BIMP	M	A	NONB	12	689799	4225406

No.	Location	County	Elev (m)	Date	Name or Citation	Sex	Age	Repro	Zone	Easting	Northing
724	WEDDING BELL 906A3	SAN MIGUEL	1911	8/25/05	BIMP	M	A	NONB	12	689799	4225406
725	WEDDING BELL 906A3	SAN MIGUEL	1911	8/25/05	BIMP	M	A	TENL	12	689799	4225406
726	GB 504f	TELLER	2853	9/13/95	BIMP	M	A	NONB	13	484990	4286570
727	PIKES PEAK 103	TELLER	2502	7/4/97	BIMP	M	A	NONB	13	491354	4322441
728	Pawnee Buttes	Weld	1570	8/85	Fitzgerald et al. 1989	F	A	L	13	588600	4516200
729	Pawnee Buttes	Weld	1570	6/88	Fitzgerald et al. 1989	M	A		13	583500	4519500
730	Wiggins copper Mine	Union, NM	1378	9/6/09	Hayes, Bonewell			~100 MYTH	13S	0673516	4089851