MEXICAN SPOTTED OWL REPRODUCTION, HOME RANGE, AND HABITAT ASSOCIATIONS IN GRAND CANYON NATIONAL PARK

by

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ABSTRACT

Mexican spotted owls (*Strix occidentalis lucida*) are nocturnal avian predators that are widely distributed in the southwest U.S. and northern Mexico. In 1993, the *lucida* subspecies was listed as threatened in response to concern over the loss of forest habitats to which the owl is widely associated. However, in the northwestern corner of their range spotted owls primarily inhabit steep-walled rocky canyons. Owl populations inhabiting this region have received less attention than populations using forests, although, canyon populations are important to the persistence of the subspecies, and are subject to different environmental pressures. I investigated the breeding ecology and home range characteristics of Mexican spotted owls within Grand Canyon which supports both forest and rocky canyon habitat. During the study from 2004 – 2006, female fecundity (mean = 0.86), calculated as the number of female fledglings per paired female, was relatively high compared to values reported previously for Mexican spotted owls. Five adult male owls were radio-tracked during the breeding season. I used minimum convex polygons and fixed kernel estimates to describe home range size (mean = 356 ha and 372 ha, respectively) and generated adaptive kernels to describe areas of concentrated use within home ranges. I used GIS to describe vegetation and geology cover types associated with owl use areas. This information was used to determine if spotted owls used landscape cover types disproportionately to their availability. At a landscape level, spotted owl telemetry locations were positively correlated with piñyon-juniper vegetation that occurred within canyons as well as with the Redwall and Muav geologic layers ($p \leq 0.05$). Home ranges were located toward the heads of tributary canyons and spotted owls were rarely observed above the rim on forested plateaus. To identify nest core areas that might aid in the species conservation I delineated 40 ha "protected core areas" around spotted owl nest sites and show that these conservation zones correlated closely to areas of concentrated use I identified using an adaptive kernel (30% isopleth) home range analysis.

GENERAL INTRODUCTION

Background Information

Mexican spotted owls (*Strix occidentalis lucida*) are nocturnal avian predators that primarily consume rodents, birds, and insects (Block et al. 2005). Population declines, loss of habitat, and perceived threats from wildfire contributed to the listing of Mexican spotted owls as threatened species (Cully and Austin 1993, USDI 1995). On average, spotted owls are 44.5 cm in height with a wing span of 64 cm, and male and female combined average weight equals 610 gr (Sibley 2000). Spotted owls are generally non-migratory, although a few individuals from several populations are known to have moved up to 45 km, involving apparent shifts in elevation during winter (Ganey 1988, Verner et al. 1992, Willey 1998).

Mexican spotted owls are widely distributed in the southwest U.S. and in Mexico's Sierra Madre Occidental and Oriental mountains (Gutiérrez et al.1995). Among regions, Mexican spotted owls are associated with a variety of habitats (Ganey and Balda 1989a, Gutiérrez et al.1995). For example, in the northwestern corner of their range, near the four corners of Utah, Colorado, Arizona and New Mexico, spotted owls primarily inhabit steep-walled rocky canyons (USDI 1995). Within these canyon habitats, spotted owls are frequently detected in isolated, relatively small (<1 ha) patches of vegetation composed of mixed-conifer forest and riparian woodland (Rinkevich and Gutiérrez 1996, Willey 1998, Willey and van Riper 2007). However, pinyon-juniper woodland (*Pinus-Juniperus* spps.) and desert scrub (Brown 1982) vegetation typically dominate home ranges in rocky canyon habitats (Ganey and Balda 1989b, Willey and Van Riper 2007, Bowden et al. 2008)   In parts of Arizona, and the Gila Wilderness of New Mexico, Mexican spotted owls are detected most frequently in mixed-conifer forest, but they also occur in pine–oak forests, rocky canyonlands, and riparian forests (Ganey and Balda1989a, Ganey et al. 1999, USDI 1995). Finally, in southeastern Arizona and southwestern New Mexico south into Mexico, spotted owls are associated with Madrean pine-oak forests, Arizona cypress forests, encinal oak woodlands, and riparian gallery forests (Tarango 1994, USDI 1995).

Several habitat types are used by Mexican spotted owls for nest placement, and nesting substrates vary across regions (USDI 1995, May and Gutiérrez 2002, Rinkevich 1991, Willey 1998, Willey and Van Riper 2007). In rocky canyon habitats in Utah and northern Arizona, all nests found by researchers were located on shaded ledges or in caves on cliff faces (Rinkevich 1991, Willey 1998, Bowden et al. 2008). In mixed-conifer forests in Arizona and New Mexico, spotted owl nests were located in trees on debris platforms or stick nests built by other species and tree cavities (Seamans and Gutiérrez 1995). In the relatively open pine-oak habitat, cavities in large oak trees (*Quercus gambelii*) were frequently used for nesting (May et al. 2004). Despite floristic differences among these nesting habitats, physiognomic similarities do exist. For example, most spotted owl nesting areas show high vertical and horizontal structural complexity, have ample shade and cover for protection of the nest and adjacent roost sites

(Gutiérrez et al. 1995, USDI 1995, Rinkevich and Gutiérrez 1996, Ganey et al. 2005, Willey and Van Riper 2007).

Shade and overhead cover appear to be important components of suitable Mexican spotted owl nesting habitats (Kertell 1977, Rinkevich and Gutiérrez 1996, Willey 1998, Ganey et al 2000, Ganey 2004). Furthermore, Mexican spotted owls may be less heat tolerant than Great horned owls (*Bubo virginianus*) (Ganey et al. 1993) and thus select nest areas that are significantly cooler than surrounding environments (Willey 1998, Rinkevich and Gutiérrez 1996, Ganey 2004).

Mexican spotted owl demographic vital rates have been intensely studied (USDI 1995, Seamans and Gutiérrez 1995, Ganey et al. 2000). Mexican spotted owls do not nest every year and productivity is sporadic (Ganey 1988, Gutiérrez et al. 1995, Seamans and Gutiérrez 1995). The number of fledglings produced per successful pair ranges from one to four (Gutiérrez et al. 1995, USDI 1995), with the average number of fledglings per paired female (i.e., per capita female productivity) equal to 1.006 ($n = 695$, $SE = 0.037$) (USDI 1995). The survival of juveniles (i.e., owlets that have fledged the nest but are <1 yr old) is low, only 10-30% survive per year (Ganey et al. 1995, Seamans and Gutiérrez 1995, Willey and van Riper 2000). One to three year old spotted owls are termed "subadults", and owls ≥3yr olds are considered "adults". Feather patterns can be used to identify these age classes (Gutiérrez et al. 1995). Breeding probability is variable among regions, and territories, and there is much temporal variation (Seamans and Gutiérrez 1995). Monitoring studies have shown synchronous breeding among pairs during some years (Fletcher and Hollis 1994), and high breeding probability has been correlated with climate and prey population dynamics (USDI 1995, Seamans et al. 1999, Willey 2006).

Ganey (1988) described the breeding phenology of Mexican spotted owls nesting in Arizona, where he observed that courtship began in March, and eggs were typically laid by April. In that study, the incubation phase lasted approximately 30 days, and chicks were in nests for approximately 30 days. Males provided nearly all prey items consumed by the female and chicks during incubation and brooding phases (Ganey 1988, Willey 1998). By early to mid-June, chicks fledge but remain relatively close (often <300 m) to nest sites (Ganey et al. 1995, Willey 1998, Willey and van Riper 2000). Within three weeks of leaving the nest, fledgling owls are capable of short flights and have been observed handling prey delivered by the adults (Willey 1998, Bowden et al. 2008). Natal dispersal begins in late August and most juveniles disperse during September each year, although adult owls have been observed feeding fledglings in October (Ganey et al. 1998, Willey and Van Riper 2000).

By studying the daily and seasonal activities of Mexican spotted owls, researchers have described movement patterns and home range sizes using radio telemetry (USDI 1995, Ganey et al. 2005, Willey and Van riper 2007). Results indicate that Mexican spotted owl movement patterns were consistent with home-range models for central place foragers (Orians and Pearson 1979, Ganey et al. 2005). For example, during the breeding season, adult owls make numerous short flights radiating out from the nest site to which they return with prey items (Ganey 1988). This concentration of effort around nest sites was used as rationale to create “core areas” by the Recovery Team (USDI 1995) and represent “activity centers” of significant importance to Mexican spotted owls (Ganey 1988, Ganey et al. 2005, Willey and Van riper 2007).

During winter, when owls appear less restricted by the prey demands of juveniles, home range sizes tend to relatively large (e.g., Willey and van Riper 2007). Spotted owl seasonal movements observed between summer and winter activity centers suggest that movement corridors may account for the enlarged winter ranges described in various studies (Forsman et al. 1984, Ganey 1988, Willey and Van Riper 2007, Zwank et al. 1994). Annual and breeding season home range sizes varied widely for spotted owls, with annual home-range size ranging from 100, to greater than 2,000 ha (Ganey et al. 1999, Willey 1998, Ganey et al. 2005, Forsman et al. 2005, Willey and Van Riper 2007). Annual home range size varies in response to multiple factors, including reproductive status, season, habitat, and location (White and Garrott 1990). Ganey et al. (2005) found that owls nesting in xeric habitats had larger home ranges than owls that nested in more mesic habitats within the same mountain range, suggesting habitat quality may influence home range size (see Carey et al. 1992, Franklin et al. 2000, and Willey and Van Riper 2007). Using results from home range studies, the recovery team for the Mexican spotted owl recommended a 243-ha conservation buffer, a “protected activity center” be placed around known nest sites or roosting areas to conserve nest core areas and adjacent foraging habitats (USDI 1995).

Study Area

Grand Canyon National Park is located 124 kilometers northeast of Flagstaff, in northern Arizona (Fig. 1.1). The landscapes within Grand Canyon National Park are dominated by steep rocky canyons rimmed by high forested plateaus and isolated mesas. The Grand Canyon is 446 kilometers in length and averages 1,220 meters in depth. At its deepest the Canyon exceeds 1,800 m and is as wide as 24 kilometers (Grand Canyon National Park, Nature and Science 2007). The Canyon's topography varies with relatively low elevations on the east and west ends and higher elevations in the east-central portion where the uplifted Kaibab Plateau bisects the Park along a north-south gradient (Stevens 1983). Elevations within the National Park along the Colorado River range from 940 meters on the northeastern boundary at Lee's Ferry to 366 meters on the western boundary at Lake Mead. The highest elevation in the park is 2,784 meters on the Kaibab Plateau (Grand Canyon National Park GIS Server, DEM 10-m resolution 2006). During my study, total annual precipitation averaged 39.4 cm per year, and temperatures ranged seasonally from -17.2 to 36.10 C (U.S. Weather Bureau, Climate and Precipitation Summaries, Arizona).

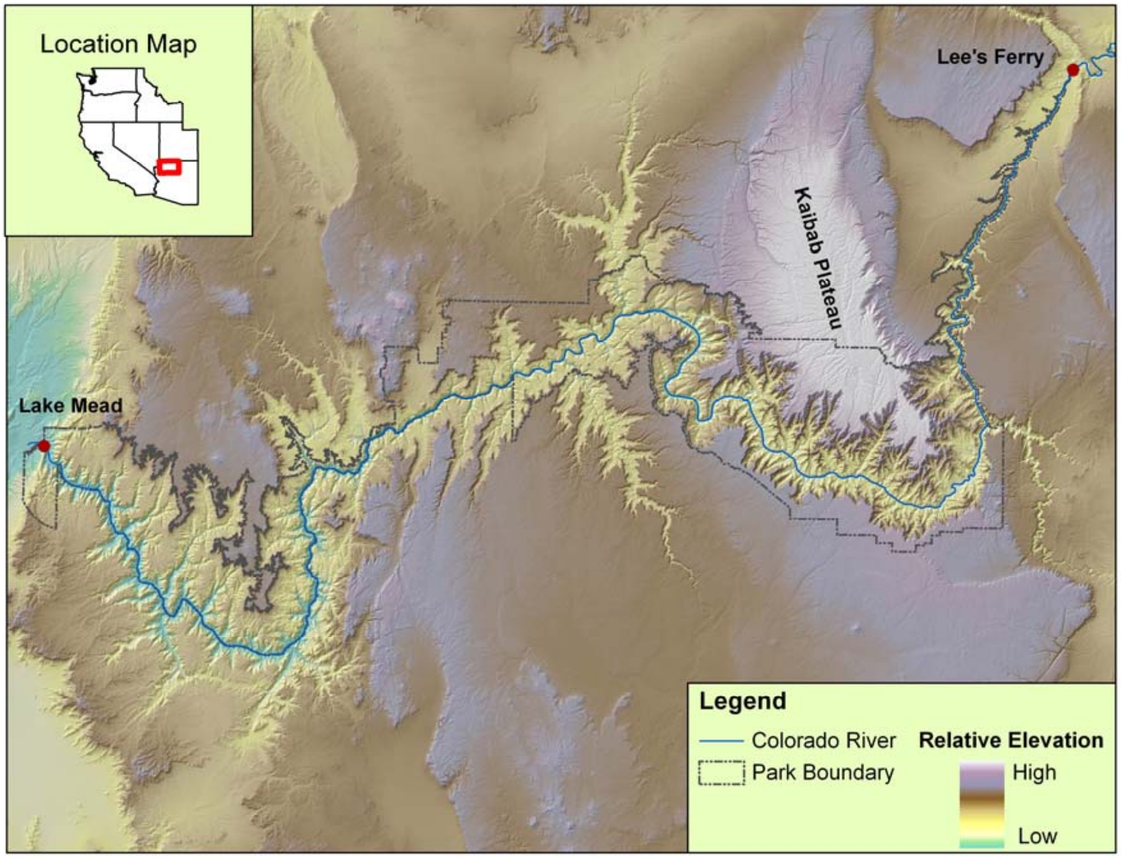


Figure 1.1 Location and digital elevation model of Grand Canyon National Park in northwest Arizona, USA. The study area is contained by the Park boundary, 2004 – 2006.

Three North American Deserts converge within the lower elevations of the Grand Canyon National Park, host to more than 1,750 plant species and seven life zones (Huisinga et al. 2006). The Colorado River flows along the lowest elevations within the Park and supports the Riparian life zone, comprised of hydrophilic species such as Cottonwood (*Populus fremontii*), Coyote willow (*Salix exigua*), Tamarisk (*Tamarix ramosissima*), Arrow-weed (*Pluchea sericea*), and Horsetail (*Equisetum ferrissii*) (Huisinga et al. 2006). Increasing in elevation and distance from the river are the

Desertscrub life zones. The Mojave Desertscrub life zone occurs in the west portion of the Park between approximately 400 – 1200 m (Huisinga et al. 2006). Heat tolerant species such as Joshua Tree (*Yucca brevifolia*), Creosotebush (*Larrea tridentata*), and Cholla (*Cylindropuntia sp.*) occur in the Mojave Desertscrub (Huisinga et al. 2006). The central portion of the Park between approximately 600 – 1200 m is dominated by the Sonoran Desertscrub life zone (Huisinga et al. 2006). The Sonoran Desertscrub life zone is comprised of species such as Honey mesquite (*Prosopis glandulosa*), Catclaw acacia (*Acacia greggii*), Prickly-pear cactus (*Opuntia basilaris*), and brittlebush (*Encelia farinosa*) (Huisinga et al. 2006). Cold-tolerant species of the Great Basin Desertscrub life zone such as Utah century plant (*Agave utahensis*), Blackbrush (*Coleogyne ramosissima*), Four-wing saltbush (*Atriplex canescens*), and Ephedra (*Ephedra fasciculata*) extend north to Lee's Ferry in the northeastern portion of the Park and occupy elevations between approximately 1200 – 1500 m (Huisinga et al. 2006). Upland slopes within canyons at elevations between 1500 – 2000 m are dominated by the Piñon-Juniper Woodland life zone which is comprised of species such as Piñon pine (*Pinus edulis*), One-seed juniper (*Juniperus monosperma*), and Banana yucca (*Yucca baccata*) (Huisinga et al. 2006). The Ponderosa Pine Forest life zone occurs on plateaus and mesas at elevations between 2000 – 2400 m and is dominated by Ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), and Gambel oak (*Quercus gambellii*) (Huisinga et al. 2006). Above 2400 m the Spruce-Fir Forest life zone dominates (Huisinga et al. 2006). The Spruce-Fir life zone contains species such as Engelmann spruce (*Picea engelmannii*), Subalpine fir (*Abies lasiocarpa*), and Aspen (*Populus tremuloides*) (Huisinga et al. 2006).

Research Objectives

The research presented in this thesis was designed to investigate breeding ecology and home range characteristics of Mexican spotted owls within Grand Canyon National Park. Grand Canyon provides forest and rocky canyon habitats designated as critical habitat by the U.S. Fish and Wildlife Service for recovery of Mexican spotted owls (USDI 2004). While spotted owls have been seen in Grand Canyon since the 1930's (McKee 1932), formal surveys within the park did not begin until the 1990's and reproduction was not documented until 2001 (Willey and Ward 2003). Since the late 1990s, over 40 distinct spotted owl territories have been located within canyons of the Park (Willey et al. 2003). However, lacking were information concerning the location and characteristics of suitable nesting habitat, including vegetation and rock strata associated with nest sites, and furthermore, no previous information on home range characteristics have been recorded for spotted owls in Grand Canyon. Therefore, the objectives of my research were to: 1) locate roost and nest sites to identify habitat features that might be important to spotted owls; 2) monitor nesting status of known territories to assess reproductive output; 3) identify prey items within pellets collected in roost areas; 4) estimate home range size and shape during the breeding season for a sample of adult males with established territories; and 5) assess nocturnal foraging locations to determine if adult spotted owls utilize more classical forests that exist above the canyon rims of the Grand Canyon.

NEST SITE LAND COVER ASSOCIATIONS AND REPRODUCTIVE OUPUT OF MEXICAN SPOTTED OWLS IN GRAND CANYON NATIONAL PARK

Introduction

For many avian species, the ability to find nest sites has affected production and breeding densities (Newton 1979). This may be particularly true for raptor species that actively defend nesting areas and exhibit high nest-site fidelity (Kruger 2002). Nest areas that provide protection from predators (Martin 1995) and inclement weather (Morrison et al. 2007) have higher productivity than more exposed nest areas. The proximate selection of nest site may be influenced by habitat structure (Reynolds et al. 1982), inter-specific interactions (Hakkarainen et al. 2004), predator avoidance (Sergio et al. 2003), and prey availability (Robinson 1994). Ultimately, nest site selection will have important consequences for bird species as differences in nest site quality can affect occupancy and reproduction rates (Hildén 1965, Newton 1979, Gutiérrez et al. 1995, Kruger 2002).

Mexican spotted owls appear to be highly selective in choosing nest and breeding-season roost locations (Ganey et al. 2000, Ganey 2004). Further, the amount and distribution of suitable breeding habitats may be a limiting factor for the sub-species (USDI 1995). In 1993, the Mexican spotted owl was listed as threatened in response to concerns over the loss of forest habitats (Cully and Austin 1993) to which the owl is widely associated within the southwestern US and northern Mexico. In forest habitats, nests and roost sites are placed within a restricted set of forest types (distinguished by species composition and structural characteristics) in comparison to the wide range of forest types that are used for foraging (Ganey and Dick 1995, Ganey et al. 2000). If spotted owls can accept a wider range of habitat conditions for foraging than nesting, then identifying specific components of nest and roost areas is central to our conservation effort and our understanding of habitats that support the *lucida* sub-species (USDI 1995, Ganey et al. 2000).

Habitats selected for nesting and roosting vary regionally across the range of Mexican Spotted Owls (Gutiérrez et al. 1995, USDI 1995). In southern Utah, owls always established nests and located roost sites on shaded cliff ledges or in caves in steep rocky canyons (Rinkevich and Gutiérrez 1996, Willey 1998). In Arizona and New Mexico, spotted owls placed nests in large diameter trees on debris platforms, or stick nests built by other species (Seamans and Gutiérrez 1995). Spotted owls also use oak cavities in pine-oak forests (*Pinus ponderosa – Quercus gambellii*) (May et al. 2004). Previous research has identified nest site selection given local availability of forest and woodland habitats or rocky-canyon habitats. In contrast, Grand Canyon National Park contains both classic-forest and rocky-canyon habitats, and spotted owls in the Park may have a choice among several distinct nesting habitats (Willey and Spotskey 2000, USDI 2004). Thus, the Grand Canyon provides a landscape where preference among disparate nesting habitats can be distinguished. However there is currently little information on spotted owl nest behavior and status in Grand Canyon (Willey and Ward 2003).

My research investigated nest and roost habitat, reproductive output, and diet of Mexican spotted owls in Grand Canyon National Park. In this region, steep cliffs below high elevation plateaus create a layered terrain that supports a diversity of vegetation communities and provides structural characteristics that may be suitable for spotted owl nesting (Willey and Spotskey 2000). Therefore, my research question is: What is the breeding ecology (nest location, reproductive output, and land cover associations) of spotted owls within the Grand Canyon? The objectives of my research were to 1) locate nest and roost areas, 2) monitor reproductive output, 3) describe physical characteristics of roost and nest sites, 4) identify land cover associated with nest and roost areas, and 5) identify prey items within pellets collected in roost areas.

Methods

Locating Spotted Owl Territories

I identified an area along the South Rim of the Grand Canyon, and several outlying areas of the park, as my primary study areas (Fig. 2.1). Within these study areas, I selected tributary canyons as sites to conduct spotted owl investigations. Sites were selected based on accessibility, proximity to South Rim management activities, and isolation from human influences. Once a tributary canyon was selected, observers approached the areas on foot and spotted owls were located by mimicking spotted owl vocalizations from survey points placed along survey routes at night (Forsman 1983, USDI 2003, Willey et al. 2003). In addition, observers listened for spotted owls throughout the night from survey stations and from prominent points within the canyons to detect unsolicited, i.e. voluntary, owl vocalizations and movements. Once owls were located, additional visits to the study sites were conducted to locate roost and nest areas. For consistency, I refer to study sites that contained spotted owls as “territories”, although I did not evaluate defensive behavior during this research (Burt 1949). While conducting nest searches, observers relied primarily on voluntary vocalizations by the owls to minimize disturbance to nesting owls. Within suspected nest areas, observers used dusk and dawn visual sightings of owls and subsequent owl behavior to locate the position of nests and roosts. Consecutive night surveys were often required to locate owls and nests, or roosts, within territories. Roost and nest locations were plotted using a Global Positioning System (Garmin GPS 5.0) and USGS 7.5 minute topographical maps.

Core Areas and Reproductive Monitoring

During the breeding season, spotted owls concentrate their time in portions of the home range that contain nest and roost sites, these areas are referred to as "core areas" (Ganey 1988, USDI 1995, Willey and van Riper 2007). I identified core areas based on the presence of nest or roost sites (USDI 1995, Ward and Salas 2000). I searched the core areas for regurgitated pellets to describe prey consumed by spotted owls. Not >30 min was spent searching for pellets below roost sites to minimize disturbance to roosting or nesting owls. Pellets were also collected as they were encountered while searching for roost or nest locations. All pellets were stored for dissection and analysis of prey remains. Pellets were dried and sorted by study site then dissected to identify Genus, Family, and sometimes Order (Arthropoda) of prey items (DeRosier and Ward 1994).

I measured the following habitat characteristics in core areas: roost or nest type, surface geology, elevation, canyon width at roost or nest height, roost and nest substrates, and habitat type in the vicinity of the nest or roost area. Visual and auditory observations were used to determine roost type (male, female, juvenile, roost, nest). Geologic strata, canyon width at roost height, roost substrate (cave, ledge, tree, shrub), and habitat type (forest, woodland, riparian, desert scrub) were visually estimated. Positional data (UTM coordinates) and elevation were collected using a hand held global positioning system (Garmin GPS 5.0). Owl, roost, nest and pellet locations were also plotted on 1:24,000 scale field maps using ArcView 3.3 (ESRI, Redlands, California).

I investigated Mexican spotted owl breeding rates by counting the maximum number of fledgling owls detected at each monitored territory during multiple visits throughout the breeding season (MAR-AUG). For this analysis, I defined "fledgling" as an owlet that was observed on rock ledges or vegetation within the vicinity of an adult pair's nest or roost site during the breeding season. Core areas I located in the Grand Canyon did not have spatial overlap, so incorrectly assigning fledglings to a neighbor territory was not likely. Because I was not able to detect nesting failures I did not estimate breeding probability or nest success. Territories with owls where no young were observed were considered inactive breeders. To count fledglings, I arrived at nesting areas prior to dusk and scanned the areas using 10 x 42 binoculars. I often remained in the core area until midnight listening for juvenile begging calls. I also returned pre-dawn to listen for vocalizations and visually confirm the number of fledglings within the nesting area. I calculated fecundity following established methods for spotted owls (Franklin et al. 1996), where annual fecundity is calculated as the number of female fledglings per paired female per year, with an assumed 1:1 sex ratio (Ganey et al. 2005). To estimate the reproductive contribution of territories over the course of the study, average productivity was estimated as the number of observed fledglings/territory/ number of years of observation (Franklin et al. 1996).

Core Area Habitat Analysis

To identify habitat within core areas I used Grand Canyon National Park's Geographic Information System (GIS) and the computer software ArcGIS 9.2 (ESRI, Redlands, CA) to draw 40-ha buffers around nest sites or locations where owlets were observed. If nests or owlets were not seen, I centered the 40-ha circle to include the greatest number of roost sites. I selected a 40 ha spatial area because this is the size specified as a "core area" in the Recovery Plan (USDI 1995).

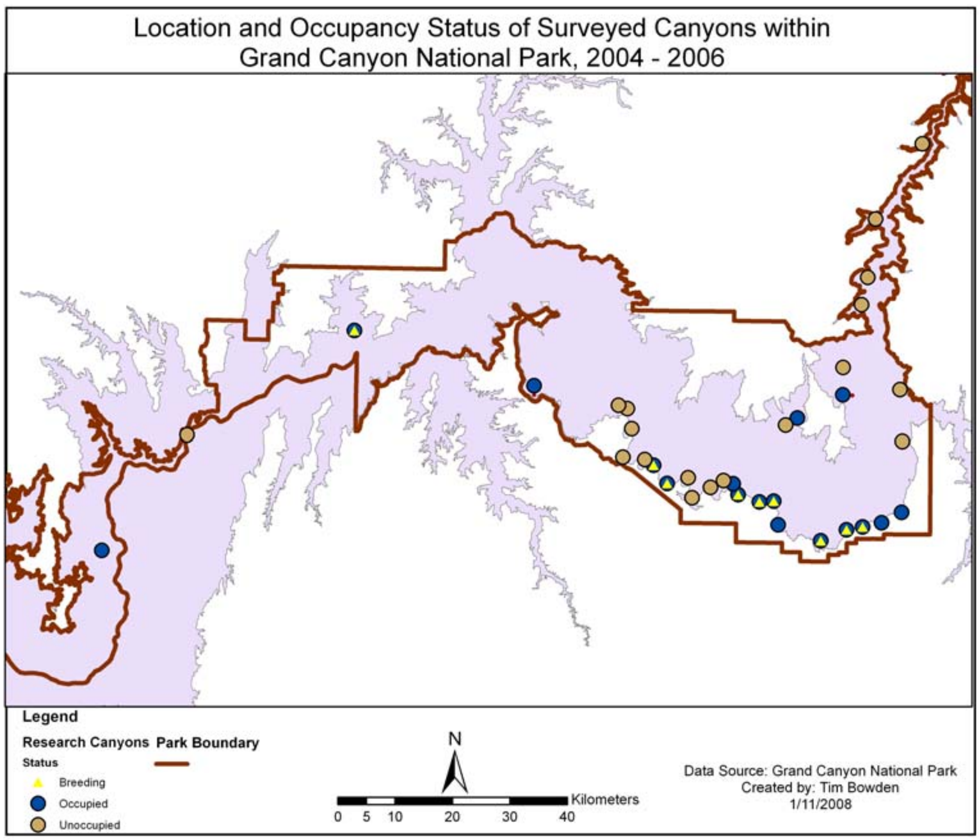
To quantify percent composition of land cover types present in spotted owl core areas, I used pre-existing vector data acquired from the National Park Service, Grand Canyon Science Center (unpublished, database). The land cover data consisted of vegetation and geology cover types. The vegetation cover types (1:62,500 map scale) were based on a park-wide vegetation study (Warren et al. 1982) that categorized vegetation into various ecological plant communities (Brown et al. 1979). Vegetation type boundaries were drawn based on aerial photo interpretation at 1:24000 scale, field verification occurred at over 1,500 sites, and the boundaries were re-drawn onto a 1:62,500 scale map. The geologic cover type was based on a 1:62,500 scale map of the geologic surface formations within the park (USGS 1962). I used the NPS land cover data to create base landscape layers over which core area buffers were intersected for vector analysis of percent vegetation type composition. The results of the spatial intersect were used to describe owl habitat within nesting core areas using both geologic and vegetation variables.

Results

Surveys for Mexican spotted owls were completed in 36 tributary canyons of the Colorado River in Grand Canyon National Park during 2004-2006 (Fig. 3). An average of 14.1 hours (±13.9 SD) was spent searching for owls per canyon. Spotted owls were detected in 18 canyons, and 34 distinct roost sites were observed in 13 of the canyons (Table 2.1). Eight nests were located in eight tributary canyons during the study. The nest and roost sites I located during the field surveys were positioned toward the heads of tributary canyons. All eight nests were placed in the Redwall Limestone geologic layer. The majority of roosts were also found in the Redwall layer, however, in TER9 and TER11 (occupied by single male owls), roost sites were found in Tapeats Sandstone and Muav Limestone, respectively.

Within the core areas I identified, twenty-six roost sites. All 8 nests were located in caves (n = 6) or on ledges (n = 2) on steep rock cliffs (Fig. 2.2). Roost sites locations varied, with eight roost sites in live trees including: Western red bud (*Cercis occidentalis*), single leaf ash (*Fraxinus anomala*), pinyon pine (*Pinus edulis*), Utah juniper (*Juniperus osteosperma*), and catclaw acacia (*Acacia greggii*). Across all roosts, average roost height was 14.4 meters but varied widely (±11.5 SD). Average roost height in trees (8.3 ±7.2 SD) was lower than the average rock roost height (15.9 ±11.6). Canyon width at roost height averaged 46.2 meters and also varied widely (±40.9 SD). Elevation of roosts ranged from 814 – 1512 m (mean = 1342; ±162 SD). The presence of shade was common in the core areas I identified and roosting owls were observed moving apparently to seek shade.

Figure 2.1. Location and status of 36 canyons surveyed for spotted owls in Grand Canyon.



Nest Productivity

During reproductive follow-up visits I observed juvenile spotted owls in nine of eighteen territories, and across 3 study years, a total of 32 fledgling spotted owls were observed, resulting in an estimated fecundity of 0.84 (±0.28 SE) female owlets produced per breeding female (n =19 observations of reproduction) (Table 2.2). The number of fledglings per territory varied from 1 to 4 (Table 1), and two sites (TER4, and TER5) produced fledglings each year of the study. The 2006 field season showed highest number of fledglings counted during the surveys, and the greatest number of apparent nesting attempts (Table 2.1, Table 2.2).

Habitat Associations in Spotted Owl Core Areas

Ten vegetation communities and 12 geologic strata (Figs. 2.3 and 2.4) were included in the 40-ha spotted owl core areas (n=13). The 13 core areas were dominated by the Juniper/Pinyon/Mormon Tea/Greasebush vegetation community, which composed 64.63% of core areas overall. The Snakeweed/Mormon Tea/Utah Agave community totaled 11% of core areas, and was the next most dominant cover type, followed by the Pinyon scrub Oak vegetation community (Fig 2.3). In addition, three vertically sequential geologic strata, Muav Limestone, Redwall Limestone, and Supai Group, accounted for >80% of the rock cover within core areas (Fig. 2.4). All core areas occurred below the canyon rims in habitats dominated by Pinyon-Juniper Woodland.

Table 2.1. Occupancy and reproductive status of 18 active Mexican spotted owl territories studied during 2004-2006, in Grand Canyon National Park.

Territory	2004	2005	2006
TER1	NS	NS	M
TER2	NS	M	
TER3	NS	P-3	P
TER4	P-3	P-2	P-4
TER5	P-1	P-2	P-3
TER6	M	NS	P
TER7	P-1	P-2	P
TER8			P
TER9	M	NS	NS
TER10			M
TER11	M	NS	M
TER12	M		P
TER13			P-1
TER14	M	M	P-3
TER15	M		
TER16	NS	M	P-2
TER17	P-3		P-1
TER18	NS	M	P

Symbols:

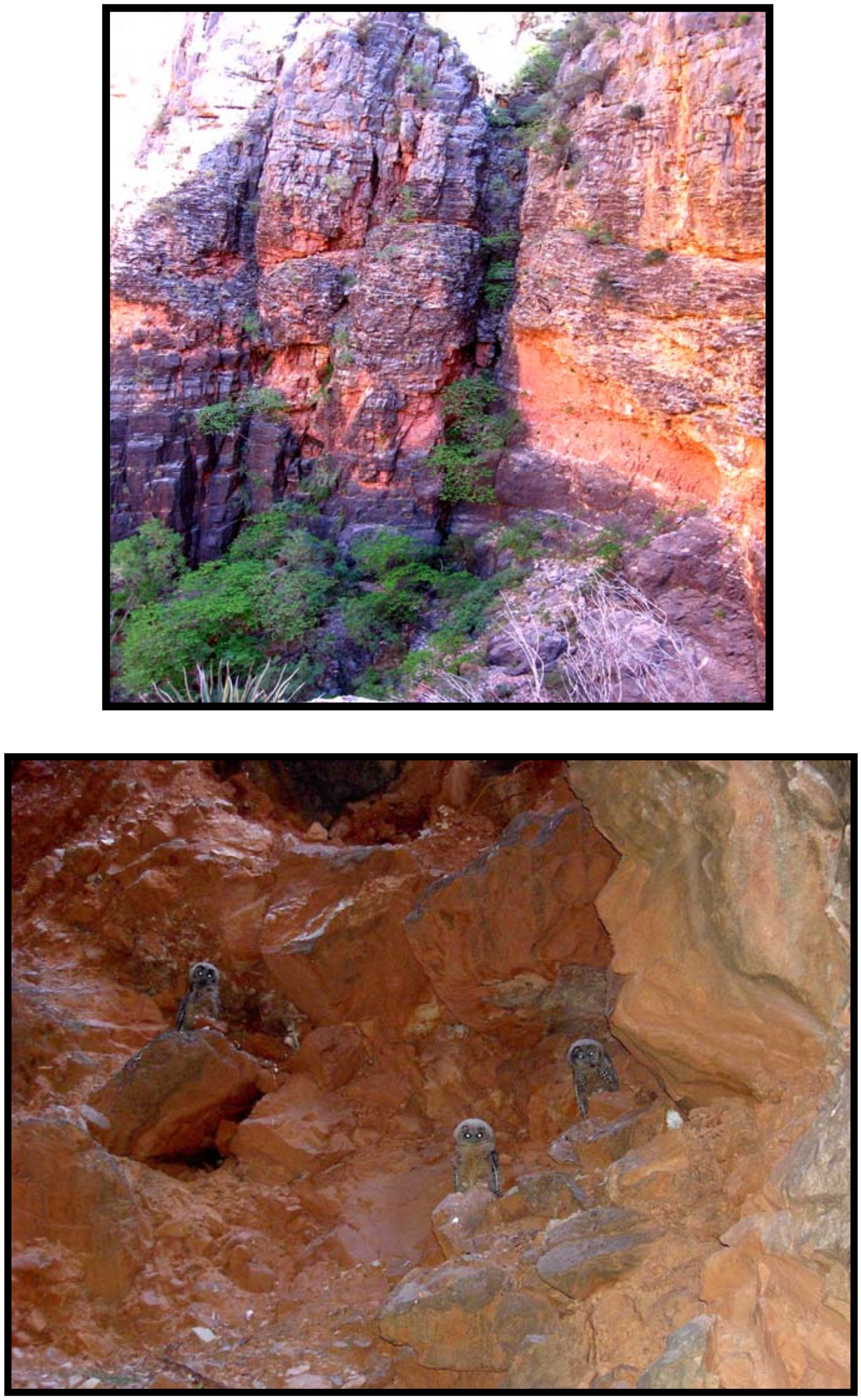
M Male spotted owl.

P Pair of spotted owls observed.

NS No survey

-# Number of juveniles observed; ·no owls observed.

Figure 2.2. (A) TER12 nest core area; and (B) TER4 nest site for Mexican spotted owls in Grand Canyon National Park (June 2006).



A

B

Table 2.2. Maximum number of fledgling spotted owls counted, site productivity, and annual fecundity estimates from 9 territorial canyons during 2004-2006, Grand Canyon.

Territory	**2004**	**2005**	**2006**	***Site Prod***
TER3	NS	3*	0	*1.5*
TER4	3	2	4	*3*
TER5	1	2*	3	*2*
TER7	1	2	0	*1*
TER12	NF	NF	1	*0.33*
TER13	NF	NF	1	*0.33*
TER14	NF	NF	3	*1*
TER16	NS	0	2	*1*
TER17	3	0	1	*1.33*
Annual Fecundity	*1*	*0.75*	*0.83*	
Adult females (n)	*4*	*6*	*9*	
SE	*0.29*	*0.25*	*0.24*	

NS No Survey.
NF No Female detected.
* 1 fledgling died during the breeding season.

Figure 2.3. Vegetation Communities present in spotted owl core areas within Grand Canyon National Park, 2004 – 2006.

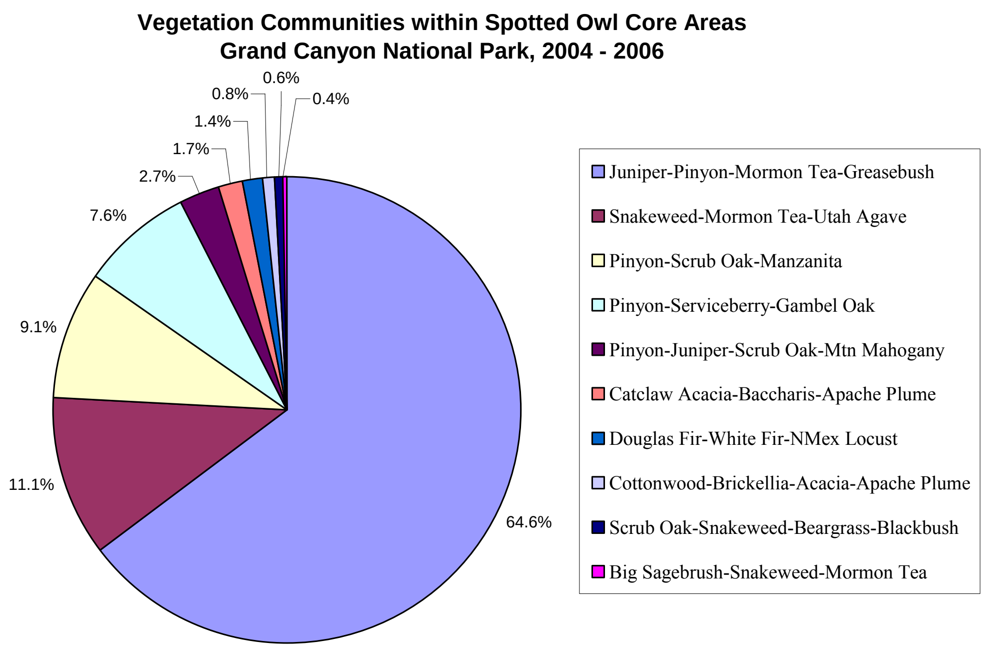
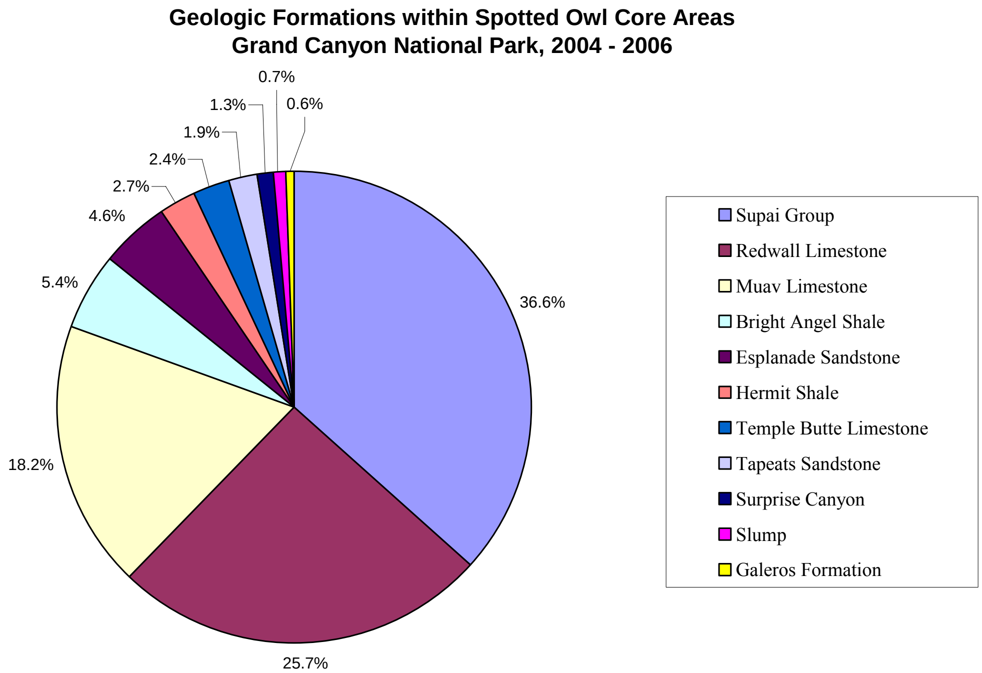


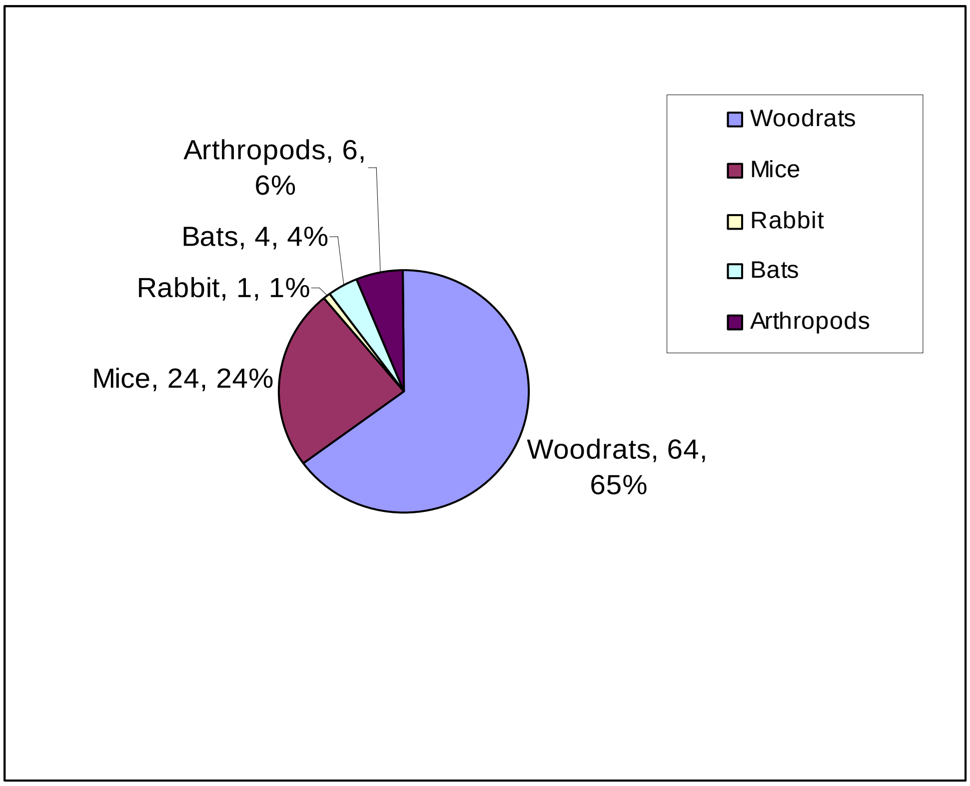
Figure 2.4. Geologic composition of nest core areas for Mexican spotted owls in Grand Canyon National Park, Arizona.



Spotted Owl Diet in Grand Canyon

Pellet analysis to describe spotted owl diet was completed for 69 dissected pellets gathered from nine territories, but with a majority from TER4 and TER17. Ninety-eight distinct individual small mammals were identified in the pellets (Fig. 2.5). Woodrats (primarily *Neotoma albigula* or *N. cinereus* based on dentary bone structure) were the most common prey type found in the diet (64 individuals; 70% of all mammals). Mice (*Peromyscus* spps.) were the next most abundant prey type (25%), with 24 distinct individuals. A single *Sylvilagus auduboni* skull was identified, and four bat (*Myotis)* skulls. In addition, various Arthropoda were identified, including a Coleopteran, several Stenopalmatidae, and several Scorpionids (Fig. 2.5).

Figure 2.5. Percent of total number of individuals identified in spotted owl pellet dissections from sites in Grand Canyon, 2004 2006.



Discussion

Mexican spotted owls were widely distributed in steep rocky tributary canyons of the Colorado River in Grand Canyon National Park (Table 2.1). I detected spotted owls in fifty percent (18) of the canyons I surveyed, and nine territories produced 36 young during the study (Tables 2.1 and 2.2). Fecundity in the Grand Canyon (mean = 0.84 fledgling female/adult territorial female, SE = 0.28, n = 19 observations of reproduction) was significantly higher than fecundity reported for Mexican spotted owls in the Coconino Forest of northern Arizona (mean = 0.494 fledgling female/adult territorial female, SE = 0.043, n = 139 observations of reproduction) (Seamens et al. 1999). Fecundity estimates for the Grand Canyon were also higher than average annual fecundity estimates reported for southern New Mexico in mesic and xeric forests (mean = 0.38 ± 0.11 & 0.13 ± 0.08 fledgling female/territorial female/year, n = 6 females, respectively) (Ganey et al. 2005).

In contrast to Mexican spotted owls, during an 18 yr demographic study of 14 northern spotted owl (*S. o. caurina*) populations, mean fecundity was 0.372 female fledglings/adult territorial female (SE = 0.029, n = 10,902 observations of reproduction) (Anthony et al. 2006). For the California spotted owl (*S. o. occidentalis*), mean fecundity was estimated at 0.345 female fledglings/adult territorial female (SE = 0.028, n = 768 females) during a 12 year study (LaHaye et al. 2004). Estimates of fecundity can fluctuate widely among years (Burnham et al. 1996), and I recognize that the high fecundity estimates I report for Grand Canyon reflect annual variation, a small sample size, and my estimates should be treated cautiously. The results of my research do provide a starting point to compare with future monitoring efforts in Grand Canyon. If fecundity estimates continue at the current rate, this might highlight the Grand Canyon as an important reserve for spotted owl reproduction.

In the Grand Canyon, I found nest and roost areas in canyons where the Redwall Limestone formed vertical and overhanging cliffs that included ledges and caves that provided numerous potential nest and roost sites for spotted owls. Although spotted owls used trees as roost sites, it was rare, and all nests I found were placed in caves or on ledges of cliffs. Using caves and ledges for nest sites in canyonlands terrain has been documented in other studies (Wagner et al. 1982, Rinkevich 1991, Willey 1998) and appears to be the primary behavior in these habitats. No spotted owl roosts, nests or owlets were observed outside the rocky canyons.

Piñyon-juniper woodland with an understory of Mormon tea and greasebush was the primary vegetation present within the core areas I identified. Mexican spotted owl prey items in Grand Canyon were dominated by woodrats (*Neotoma*) and Piñyon-juniper woodlands and desert scrub habitats support up to five species of *Neotoma* in the Grand Canyon (NPS 2007). In these environments, *Neotoma* feed on Mormon tea, prickly pear, juniper berries, piñyon nuts and other succulent plants and seeds (Oelhafen and Yahnke 2004).

My results support a concept I refer to as “habitat substitution”, where rocky cliffs with cavers and ledges provide habitat structure similar to mature forest stands with high canopy closer; providing shelter and thermal relief for roosts and nests (Ganey and Balda 1989a, Willey 1998). In the Grand Canyon, the steep Redwall cliffs, and the abundance of caves and cliffs above the canyon floor, may provide protection from both avian and mammalian predators as well as cooler, shaded post fledging areas. Spotted owls are known to establish nest sites in areas with cooler microclimate than surrounding areas (Rinkevich and Gutiérrez 1996, Willey 1998, Ganey 2004), and I observed spotted owls routinely moving among roosts to obtain shade. Furthermore, in one of the monitored canyons, adults and young moved from the initial nesting area in late June, when daytime temperatures were reaching 38° C, to a new roosting area approximately 1200 m down canyon nearby a water source. On two occasions adults were observed drinking from the pool at the base of the seep. In another canyon, a spotted owl roost area included an isolated pool, and owls were observed perched at the edge of the pool.

Great horned owls (*Bubo virginianus*) were frequently observed while conducting spotted owl surveys in the Grand Canyon and it is possible that interactions with this species may influence spotted owl nest site selection. Habitat partitioning has been observed between great horned owls and Mexican spotted owls in forest habitat in northern Arizona (Ganey et al. 1997). Interactions with barred owls (*Strix varia*) appear to reduce the occupancy rate of northern spotted owl (*S.o. caurina*) nest areas in the Pacific Northwest (Kelly et al. 2003). During a 13 year study in Finland, Hakkarainen et al. (2004) demonstrated the impact of interspecific interactions on nest site selection for three raptor species. Within the Grand Canyon, overlapping vocalizations and apparent counter calling between great horned and spotted owls were observed during this study. The importance of these interactions is unknown however the potential for competition exits among raptors that occupy Grand Canyon National Park (Hakkarainen et al. 2004).

Management Considerations

Spotted owl reproductive measures varied among territories within the Grand Canyon during this study (Table 2.2). The TER4 territory produced young each year of the study, including 4 owlets during 2006 (Table 2.1), while TER12 and TER13 territories produced only a single owl during the three years. The ultimate source of the observed variation may be related to several factors, including habitat quality (Ganey et al. 2005), local prey availability (Carey et al. 1992, Willey 2006), or individual variation (Franklin et al. 1996), among others. Identifying the source of this variation was beyond the scope of my research, but it is interesting that the TER4 territory was highly productive during the study. One possible explanation for the high productivity could be a frequently used human trail passes through the this territory, close to the nest, and humans may provide supplemental food for the rodent population. Subsequent increases in rodent density could provide an indirect benefit to owl reproduction, however, further research would be required to address these impacts on spotted owl reproduction.

In the Grand Canyon, habitat located within the heads of tributary canyons and associated with the Redwall geologic layer was consistently used for nesting during this study, and health of these habitats is likely important for spotted owl reproduction (USDI 1995). Management activities in these areas should be planned carefully with consideration for spotted owl nesting. Given current estimates of spotted owl fecundity below the South Rim developed area, human activities located along the rim may have minimal effects on spotted owl reproduction. Biologists should note, however, that spotted owls did occasionally use rim forests at night, thus management activities in these areas should be planned with attempts made to preserve snags, mature trees, and a diversity of mammalian prey habitats (Carey et al. 1992, USDI 1995, Ganey et al. 2005). Finally, the Park's continued effort to locate and monitor spotted owl nesting areas will provide population trend data to support long-term management for spotted owls in the region (USDI 1995).

HOME RANGE AND HABITAT USE OF MEXICAN SPOTTED OWLS IN GRAND CANYON NATIONAL PARK

Introduction

The Mexican spotted owl inhabits a variety of environments from southern Utah and Colorado, south to the Occidental mountain ranges of Mexico (Ganey and Balda 1989a, Gutiérrez et al. 1995, USDI 1995). In the northern portion of its range, the owl is primarily associated with rocky canyons (Willey and Van Riper 2007, Rinkevich and Gutiérrez 1996, USDI 1995) that rarely contain classic forest conditions (Forsman et al. 1984, Ganey 1988). In the central and southern portion of their range, where spotted owls primarily nest and roost in mixed-coniferous forests, concern regarding habitat loss led to the listing of the Mexican spotted owl as threatened in 1993 (Cully and Austin 1993).

Spotted owls that inhabit rocky canyons primarily roost and nest on rock ledges (Rinkevich and Gutiérrez 1996, Willey 1998) where they are less likely to be affected by loss of mature forest to timber harvest or catastrophic fire. Spotted owl populations in arid rocky canyon habitats have received less attention than populations using forests (Willey and Van Riper 2007), however, canyon populations are important to the persistence of the subspecies, and they are subject to different environmental pressures (USDI 1995). While habitat use studies concerning spotted owls in forest settings have been numerous, investigation into spotted owl habitat use within arid rocky canyons is relatively limited, and further investigation will help expand our understanding of the habitat characteristics that support spotted owl populations across their range.

In northern Arizona, the Grand Canyon National Park is host to a large population of spotted owls (Willey and Ward 2003) however, information regarding home ranges and habitat use within the park is lacking. This research was designed to bridge that gap and provide information regarding spotted owls that nest in rocky canyon environments outside of Utah. Specifically, I address the following research questions: what is the home range size for spotted owls in Grand Canyon, what land cover habitat variables are associated with spotted owl home ranges in the Grand Canyon, and do spotted owls select or avoid land cover types within home ranges or within the study area? The objectives of this research were to 1) estimate home range size and shape during the breeding season for a sample of owl territories, 2) identify relevant habitat features within home ranges, and in nest core areas, and 3) determine if adult spotted owls nest or forage above canyon rims in the more classical forest habitat and, if so, to what extent they use forest vs. rocky canyon habitats.

Methods

Locating Spotted Owl Territories

Tributary canyons along the South Rim between Bass Creek and Desert View canyons were targeted for my research investigations (Fig. 3.1). Owl presence and activity was assessed by mimicking spotted owl vocalizations from survey points placed along transects within canyons and on canyon rims at night (Forsman 1983, USDI 2003, Willey et al. 2003). Once owls were located, additional visits were conducted to locate roost and nest areas.

Capture and Radio Telemetry

Mexican spotted owls were trapped during evening hours when owls were vocal and ambient temperatures mild (Willey 1998). At potential trap sites (typically a nesting area or frequently used roost area), trappers imitated a variety of spotted owl calls (Ganey 1990) to illicit a response and pinpoint an owl's location. Once an owl was located, they were trapped using Bal Chatry traps, by hand, or using a noose pole (Forsman 1983, Willey 1998). Once an owl was trapped, it was gently restrained in hand, hooded, and readied for tail-mounted radio attachment (Kenward 1987). Radio transmitters (Holohil Systems Ltd., Ontario, Canada), weighing 5.5-6.0 gm with an average signal life of 12 ± 6 month S.D., were attached to the central retrices using quick-set epoxy and un-waxed dental floss. Radio signals were received using R1000 receivers and handheld Yagi antennas (Telonics Inc., Mesa, Arizona.).

Nocturnal owl locations were obtained by triangulation of simultaneous compass bearings from $\geq$2 permanent tracking stations. The Maximum Likelihood Lenth Estimator (Lenth 1981), available in program LOAS 4.0a (Ecological Software Solutions) was used to estimate locations using the field bearings. If the MLE algorithm failed to converge, then Best Biangulation was used to estimate locations (LOAS 4.0a). In addition, accuracy tests were conducted within each territory by estimating the location of test transmitters placed 20 times throughout each territory (White and Garrott

1990). Test transmitters were sampled from tracking stations using three bearings to triangulate a test position, and repeated for each of the 20 test locations within a territory. To reduce potential bias, observers on the rim did not know the location of test transmitters while testing the telemetry system. I present the mean and standard deviation of bearing errors and area of confidence ellipses to describe signal errors (Saltz 1994).

The sampling scheme for nocturnal tracking periods followed methods described by Willey and Van Riper (2007). I attempted to track each owl once per week using tracking sessions that lasted from 30 minutes before sunset until 30 minutes after sunrise. Observers attempted to locate the focal owl every 30 min during the tracking sessions. Despite efforts to maintain even sampling among owls, the sampling effort was not even due to occasional inability to locate an owl due to signal bounce, weather, and transmitter molt. The time interval between individual fixes per focal owl ranged from 30-m to 4-h during night tracking periods.

Home Range Characteristics

Cumulative breeding season (March-September) home range size was estimated using minimum convex polygon ("MCP"), fixed kernel (“FK”), and adaptive kernel ("AK") home range models (White and Garrott 1990, Worton 1989). Only those owl point locations derived from telemetry with error ellipses <25.0 ha were used to generate breeding season home range estimates. Sheer rock faces within deep tributary canyons caused radio signal bounce and reduced accuracy of estimated locations. This resulted in many estimated locations being dropped from the analysis. The 25-ha cut off value that I selected was a balance between sample size and accuracy. One hundred percent MCP and 90% FK estimates were generated to estimate cumulative breeding season home range size. To identify areas of concentrated use by owls within their home ranges, i.e., "activity centers" (USDI 1995), I generated 75%, 50%, and 30% AK isopleths. I also generated 95% AK estimates for comparison with pertinent literature (Ganey et al. 2005, Willey and VanRiper 2007). Seaman and Powell (1996) compared various methods of home range estimation and found that fixed kernel estimates using the least-squares-cross-validation provided the most accurate estimate of simulated home ranges. The adaptive kernel model provides the best density estimates within home ranges (Silverman 1986), e.g., to identify core areas of use, while fixed kernels provide better estimates of home range size (Seaman and Powell 1996). All MCP, FK, and AK estimates were calculated using ArcGIS 9.2 (ESRI, Redlands, California) with the Home Range Tool (Rodgers et al. 2007). I used the least-squares cross-validation method to guide the selection of the smoothing parameter, H (Seaman and Powell 1996). Home range estimates for each tracked owl were based on $\geq$ 60 locations per territory.

Autocorrelation has been a concern with home range estimation in that the statistical properties of home range models require that individual locations are independent (Swihart and Slade 1986). Although the owl tracking intervals in my study may have created autocorrelated data, the minimum time waited between subsequent telemetry locations was sufficient to allow a focal owl to traverse its entire home range, thus I think my approached provided biological independence, and reduced the incidence of autocorrelation (Ganey 1988, Otis and White 1999). Autocorrelation was further reduced by using locations that were separated by more than the minimum 30 min time frame (Forsman et al. 2005, Ganey et al. 2005, Willey and Van Riper 2007). To the degree that autocorrelation was present, home range size may be underestimated (Swihart and Slade 1986).

Core Area Delineation

Following the recommendations of Ward and Salas (2000), I defined a "core area" as a 40 ha circle centered on the nest site, or primary roost area, or where owlets were observed. Forty hectares is the amount of habitat specified as a core area in the Mexican spotted owl recovery plan (USDI 1995). Core area buffers were delineated using ArcGIS 9.2 in the five canyons targeted for my home range study.

Habitat Description and Statistical Analysis

I investigated land cover associated with the 90% FK and 75%, 50%, and 30% AK home range areas for five radio-tagged male spotted owls during 2004-2006. Land cover attributes associated with spotted owl home range isopleths were described using ArcGIS 9.2. Pre-existing vector land cover data (Unpublished, Grand Canyon National Park GIS database), were used to create a base landscape layer over which home range isopleth boundaries were intersected using ArcGIS9.2. This vector analysis resulted in the percent of home range isopleths that were represented by the various land cover categories.

The land cover data consisted of vegetation and geologic strata themes (Unpublished, Grand Canyon National Park GIS database). The vegetation theme described cover types (1:62,500 map scale) that were based on a park-wide vegetation study (Warren et al. 1982) that categorized vegetation into various ecological plant communities (Brown et al. 1979). The geologic theme described cover types that were based on a 1:62,500 scale map of the geologic surface formations within the park (USGS 1962).

Habitat Selection Analysis: I investigated habitat selection within home ranges (90% FK isopleths) by addressing the research question: Do male spotted owls use vegetation communities and rock strata disproportionately to their availability within their estimated home range during the breeding season? I tested the null hypothesis that spotted owls use vegetation communities and rock strata (habitat covariates) in proportion to availability within the defined area (Fig 3.2). This level of habitat selection analysis is considered third order (Johnson 1980) or design III (Mannly et al. 2002) use vs available habitat selection. My analysis was exploratory, and I did not make *a priori* hypotheses regarding selection. Furthermore, I made the assumption that there were no physical or ecological barriers that prevented spotted owls from using the habitat covariates within home ranges. Thus, I used nearly all habitat covariates that occurred within home ranges (Table 3.1). I analyzed each home range individually by comparing the distribution of habitat covariates that were associated with telemetry locations for a focal owl to the distribution of habitat covariates that were available within the focal home range. For this comparison, I used the data cloning and maximum likelihood estimate procedures and software provided in Lele (in press) to obtain regression coefficients and likelihood values for the logistic, log-log, and probit regression models. I used Akaike's information criterion (AIC) values to determine the model that best fit my data (Mannly 2002, Lele in press). I used *Tukey's test for multiple comparisons* to compare coefficients among home ranges to determine if spotted owl habitat selection differed among home ranges (Sokal and Rohlf 1995). As selection did not differ significantly among home ranges for any coefficient, I pooled all home range data and ran regression analyses with the pooled data. This provided a larger sample for estimation. I conducted a one sample *t-test* to determine if coefficients differed significantly from 0 (Sokal and Rohlf 1995). Habitat covariates that did not differ significantly from zero were not distinguishable from the null hypothesis that use was proportional to availability.

To collect data for the habitat selections analysis, I assigned an eight hectare buffer around each telemetry location used to generate home range estimates. Eight hectares were used as a buffer because this was the average size of the confidence ellipses for point estimates of owl locations in my study. Thus, I believed that this was the smallest resolution that my data could support. At this resolution, all habitat covariates within a 160 m radius of point estimates were sampled. To describe available habitat, each home range was saturated with randomly placed 8-ha buffers to estimate the distribution of habitat covariates within the specified area.

Percent composition of habitat covariates within the eight hectare buffers was quantified using ArcGIS 9.2. Using the Spatial Analyst extension available for ArcGIS, I converted the base landscape layers (vegetation and geology) into raster format at 30-m resolution. I then created a raster "index layer" for each habitat covariate (7 rock strata and 3 vegetation communities) that occurred within home ranges. An index layer is a raster surface in which all pixels are assigned a value of 1 or 0; if the selected habitat covariate occurs within a pixel a value of 1 is assigned otherwise a value of 0 is assigned. Using the "focal mean" function within the ArcGIS Spatial Analysis Toolbox, and a single index layer, I calculated the mean value of all pixels that occurred within the 8 hectare buffers for used and available points within home ranges. This process was repeated for each of the 12 habitat covariates. The mean value of the pixels within an 8 hectare buffer of an index layer is equal to the percent composition of the selected habitat covariate within that buffer (William Huber pers. comm. 2007). These data were compiled into a single .txt file and entered into the software programs R and Winbugs following the methods described in Lele (in press).

I also investigated habitat selection at a broader scale by comparing use data to the distribution of habitat covariates that occurred within the landscape surrounding home ranges. This level of habitat selection analysis is considered second order (Johnson 1980) or design II (Mannly et al. 2002) use vs available habitat selection. For this analysis, all habitat covariates that occurred within the South Rim study area, which I defined as the area that surrounded home ranges and was bounded to the north by the Colorado River and to the south by the Park boundary (Fig 3.1), were assumed available for selection by spotted owls (Table 3.1; *Second Order*). I compared the distribution of habitat covariates that were associated with telemetry locations for all five male owls (n = 343) to the distribution of habitat covariates that were available within the study area. I collected and analyzed the data following the same methods described above for the design III habitat selection.

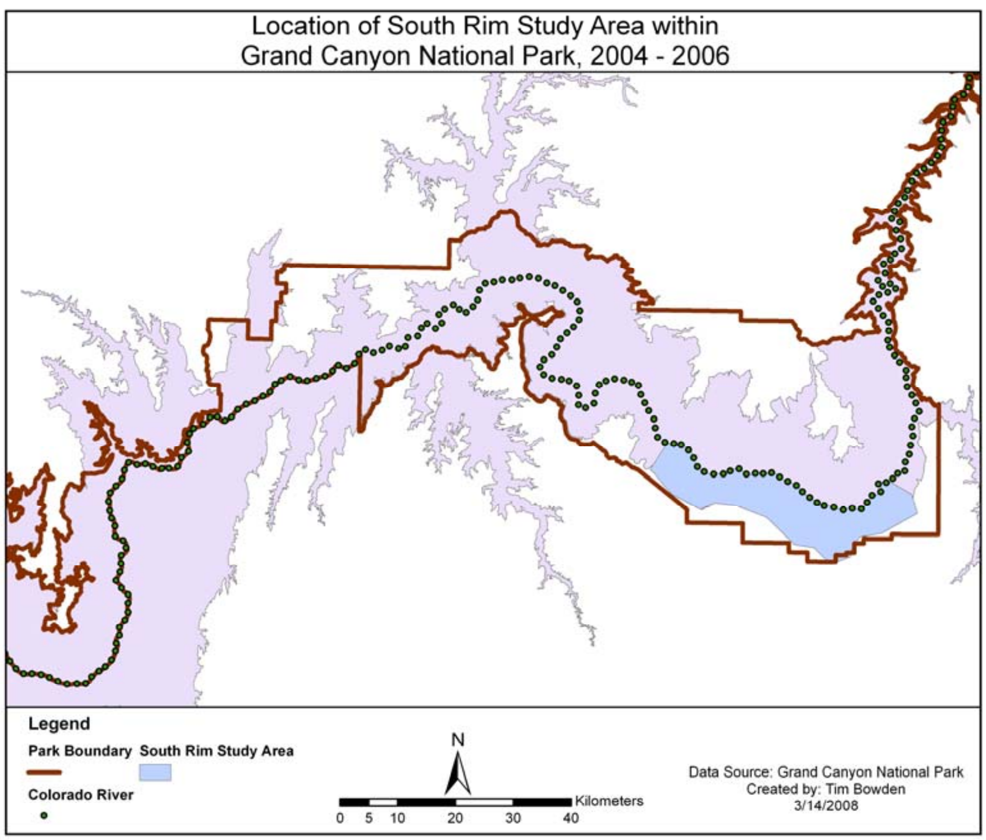


Figure 3.1. Location of the South Rim study area where Mexican spotted owl home range and habitat use studies occurred within Grand Canyon National Park

Table 3.1. Habitat covariates for the Design III and II habitat selection analyses.

Parameter	Name	Description
Third Order Habitat Selection:		
B_1	Kaibab	Kaibab geologic layer
B_2	Hermit	Hermit geologic layer
B_3	Esplanade	Esplanade geologic layer
B_4	Supai	Supai geologic layer
B_5	Redwall	Redwall geologic layer
B_6	Muav	Muav geologic layer
B_7	Other Rock	Coconino, Bright Angel, Temple Butte, Hakatai, Surprise, Tapeats, Bass, Shinumo, Diabase, and Slump geologic layers
B_8	Desert Scrub	Snakeweed-Mormon Tea-Agave vegetation
B_9	Piñyon-Juniper	Juniper-Piñyon-MT-Greasebush vegetation
B_{10}	Other Vegetation	Ponderosa-Pinyon-Gambel Oak-Juniper, Juniper-Big Sagebrush-Pinyon, Catclaw Acacia-Baccharis-Apache Plume, Mormon Tea Snakeweed Wolfberry, Cottonwood-Brickellia-Acacia-Apache Plume vegetation communities
Second Order Habitat Selection:		
B_1	Upper Rock	Kaibab, Coconino, Hermit, Esplanade, Supai geologic layers
B_2	Redwall	Redwall geologic layer
B_3	Muav	Muav geologic layer
B_4	Lower Rock	Coconino, Bright Angel, Temple Butte, Hakatai, Surprise, Tapeats, Bass, Shinumo, Diabase, Slump, Nankoweap, Dox, Cardenas, Granite, and Vishnu geologic layers
B_5	Desert Scrub	Snakeweed-Mormon Tea-Agave vegetation
B_6	Piñyon-Juniper	Juniper-Piñyon-MT-Greasebush vegetation
B_7	Other Vegetation	Ponderosa-Pinyon-Gambel Oak-Juniper, Juniper-Big Sagebrush-Pinyon, Catclaw Acacia-Baccharis-Apache Plume, Mormon Tea-Snakeweed-Wolfberry, Cottonwood-Brickellia Acacia-Apache Plume vegetation communities

Results

Home Range Characteristics

Five adult male spotted owls were radio-tracked using a ground-based telemetry system during March 2004 through August 2006 (Fig 3.2, Table 3.2, Appendix 1). The mean bearing error estimated from the error analysis from test triangulations was 8.43° (±6.23° SD, n = 432 bearings). Confidence ellipses around telemetry locations showed mean area of 8.12 ha (±5.10 SD, n = 293). The average 100% MCP area was 355.70 ha (±68.35 SD). The average estimate for the 90% FK home range area was 371.93 ha (±59.56 SD), and average 95% AK home range area was estimated at 561.93 ha (±83.76 SD).

Spotted owl home ranges appeared to be centered in the upper reaches of canyons and the majority of relocations of owls occurred within the canyons rather than areas outside the canyon rims, e.g., on adjacent plateaus and ridge-tops. Spotted owls did use areas outside of the canyon environments, with just over 3% of home range area plotted on plateaus above the canyon rims. Additionally, three telemetry locations, and 9 visual observations by researchers, confirmed that owls occasionally used areas on plateaus above the rim.

Figure 3.2. Locations of spotted owl home ranges studied within Grand Canyon National park, Arizona (2004-2006).

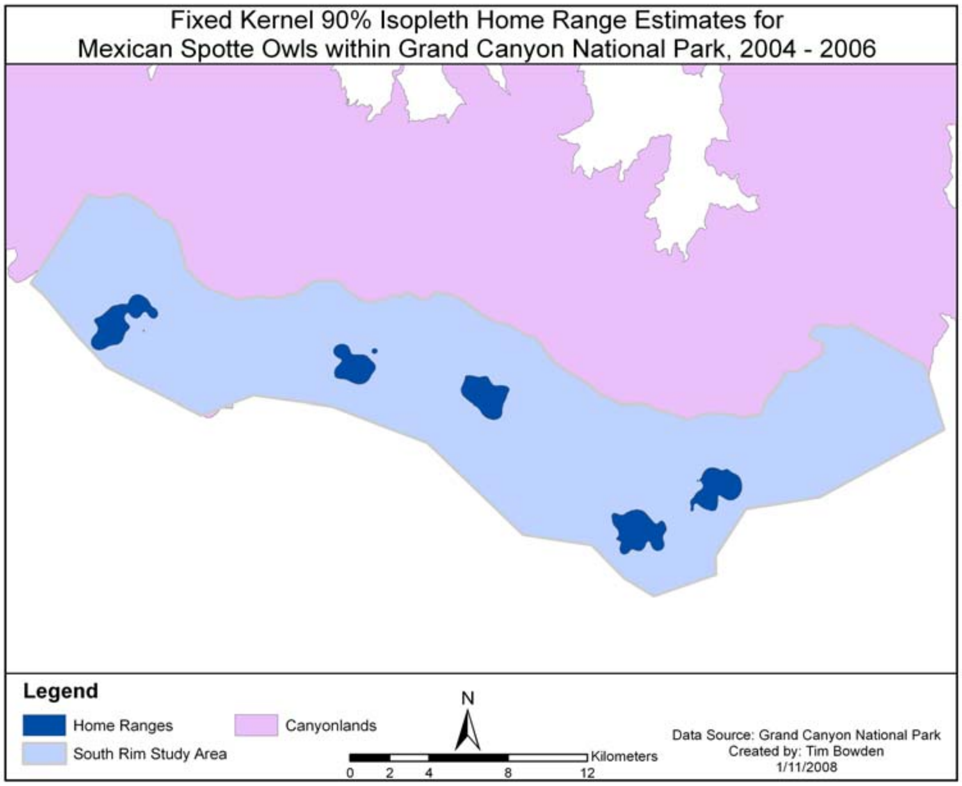


Table 3.2. Estimates of breeding season home range size (ha) for individual Mexican Spotted Owls in Grand Canyon National Park, Arizona, 2004 – 2006. Shown are the 100% minimum convex polygon (MCP), the 90% isopleth of the fixed kernel (FK), and 95% isopleth of the adaptive kernel (AK) home range models (*N* = no. relocations).

Territory	**Tracking Period**	***N***	**MCP**	**FK90%**	**AK 95%**
TER3	4/11/05 – 5/26/05	61	407	429	644
TER4	3/17/04 – 5/27/04	69	249	289	460
TER5	6/11/04 – 8/07/04	89	349	347	529
TER7	3/20/04 – 7/06/04	63	423	431	653
TER14	3/15/04 - 7/07/04	63	349	364	523
Mean Size			**355**	**372**	**562**
Median Size			**349**	**364**	**529**
Standard Deviation			**68**	**60**	**84**

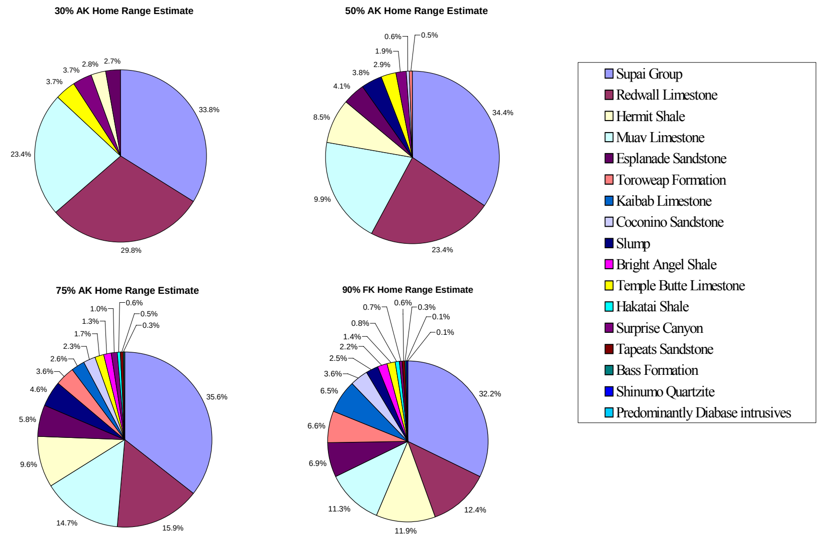
In terms of geologic surface cover, the 90% FK home range isopleths were dominated (mean cover = 32.2%, ±7.2% SD) by the Supai Group which is composed of sandstone-shale layers that form a 45° sloped terrace between the Redwall Limestone and the Hermit Shales (Steven 1983), (Fig 3.3, Appendix 3). Collectively, these three layers support sparse Pinyon-juniper woodlands (Warren et al. 1982) which was the primary vegetation cover type that occurred in spotted owls home ranges (Fig 3.3, Appendix 2).

Telemetry locations obtained at night outside of the core areas were assumed to represent foraging activities (Ganey et al. 2005, Willey and Van Riper 2007). Fifty-eight percent of these "foraging" locations occurred among Redwall Limestone, Supai and Hermit Shale layers. Pooling all tracking data, 80% of telemetry foraging locations occurred within piñyon-juniper woodlands with an understory of Mormon tea and greasewood. Desert scrub vegetation, including snakeweed, Mormon tea, and Utah agave was also present in home ranges.

Owl locations within home ranges appeared clumped in distribution, rather than spread evenly through the home range area (Appendix 1). This suggested that the owls may use "activity centers" (Ganey and Balda 1989b, USDI 1995, Ganey et al. 2005, Willey and Van Riper 2007) within their home ranges. The 30% isopleths showed the highest density with 30% of the locations occurring in an area that, on average, comprised 7.5 % (± 1.4% SD) of 90% FK home range estimates. The 30% isopleths appeared to coincide with the delineated 40-ha core area buffers centered on roost and nest sites (Fig 3.4, Table 3.3).

Figure 3.3. Geology and vegetation features occurring within five spotted owl territories from 2004-2006, Grand Canyon National Park.

Percent composition of geologic strata within home range estimates 2004-2006, Grand Canyon National Park.



Percent composition of vegetation communities within home range estimates 2004-2006, Grand Canyon National Park.

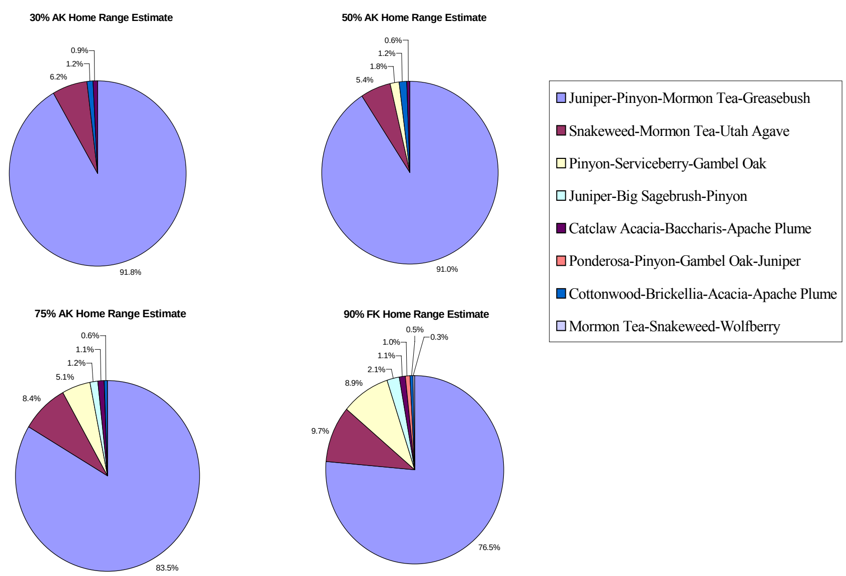


Figure 3.4. AK30% isopleths overlaid with core areas for 5 spotted owl territories in Grand Canyon, Arizona.

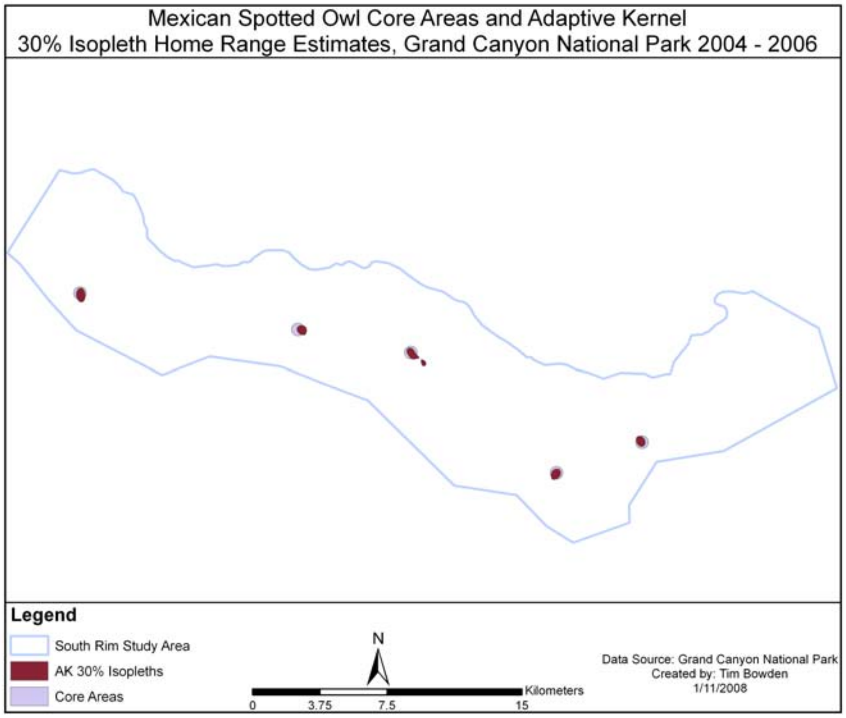


Table 3.3. Percent composition of land cover within AK 30% isopleths and Core Areas within 5 spotted owl territories 2004-2006, Grand Canyon National Park.

Land Cover	**AK 30%**	**Core Areas**
Vegetation Communities		
Pinyon/Serviceberry/Gambel Oak	0	0.78
Catclaw Acacia/Baccharis/Apache Plume	0.91	0.95
Cottonwood/Brickellia/Acacia/Apache Plume	1.17	2.20
Snakeweed/Mormon Tea/Utah Agave	6.17	5.87
Juniper/Pinyon/Mormon Tea/Greasebush	91.75	90.19
Geologic Strata		
Esplanade Sandstone	2.73	0.37
Hermit Shale	2.85	0.01
Bright Angel Shale	0	0.49
Temple Butte Limestone	3.69	2.86
Surprise Canyon	3.65	3.04
Muav Limestone	23.42	25.50
Redwall Limestone	29.83	26.18
Supai Group	33.83	41.56

Habitat Analysis

For the individually based third order habitat selection analysis my sample size ranged from 61 – 89 (mean = 69) owl locations per home range for five home ranges. The AIC values for the individually based analysis did not distinguish among the logistic, log-log, or probit regression models; however, the AIC values for the pooled third order habitat selection analysis identified logistic regression as the best fit model (Table 3.4). The selections made by individual owls within home ranges did not significantly differ among home ranges (Fig 3.5), so I report the results of the pooled third order habitat selection (n = 345 owl locations) (Fig 3.6). Along the South Rim of the Grand Canyon owls selected for Redwall and Muav geologic layers (p-value = 0.0470 and 0.0032 respectively) disproportionately to their availability within home ranges (Table 3.5).

The second order habitat selection analysis compared the pooled spotted owl locations (n = 345 locations for 5 male owls) to the South Rim study area (Fig 3.7) and was conducted to investigate the placement of home ranges within the study area. Given the assumption that owls could select any location within the South Rim study area, owls selected Redwall and Muav geologic layers and piñyon-juniper vegetation (p-value = 0.0005, 0.0049, and 0.0538 respectively). Owls selected against the "desert scrub" and "other vegetation" habitat covariates (p-value = 0.0002 and 0.0000 respectively) (Table 3.6).

Table 3.4. Akaike's information criterion (AIC) values for five individual and one pooled third order habitat selection analyses for Mexican spotted owls in the Grand Canyon National Park, 2004 – 2006. A value of "NC" means the coefficient estimation procedure failed to converge.

	TER3	TER4	TER5	TER7	TER14	Pooled
Logistic	16.7	39.2	50.9	61.1	45.7	626.6
Log-Log	17.5	NC	49.4	NC	43.3	631.3
Probit	17.6	41.7	50.1	NC	44.9	630.3

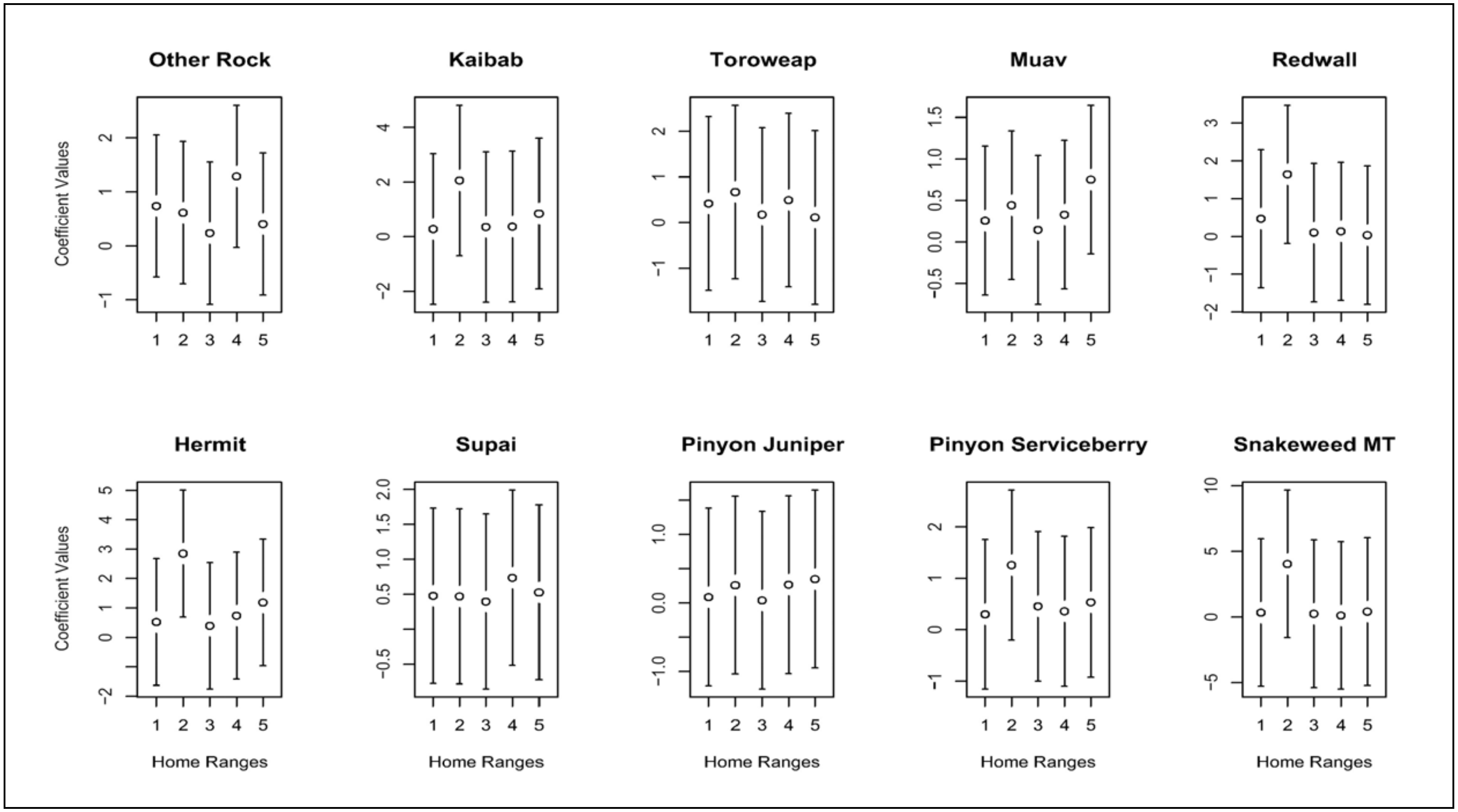


Figure 3.5. Tukey's test for multiple comparisons (alpha = 0.05) to compare coefficients among home ranges along the South Rim Grand Canyon National Park, 2004 – 2006. Home range values are: 1) TER3, 2) TER4, 3) TER5, 4) TER7, and 5) TER14

Figure 3.6. Percent composition of habitat covariates that occurred within the average 8-ha buffer around Mexican spotted owl locations and random locations within home ranges (FK 90% estimate). The "All Use" bins represent the pooled telemetry locations for 5 male owls (n = 345) while "Available" represents pooled random locations (n = 60,000) within home ranges located below the South Rim of the Grand Canyon National Park 2004 – 2006. Standard error bars are displayed.

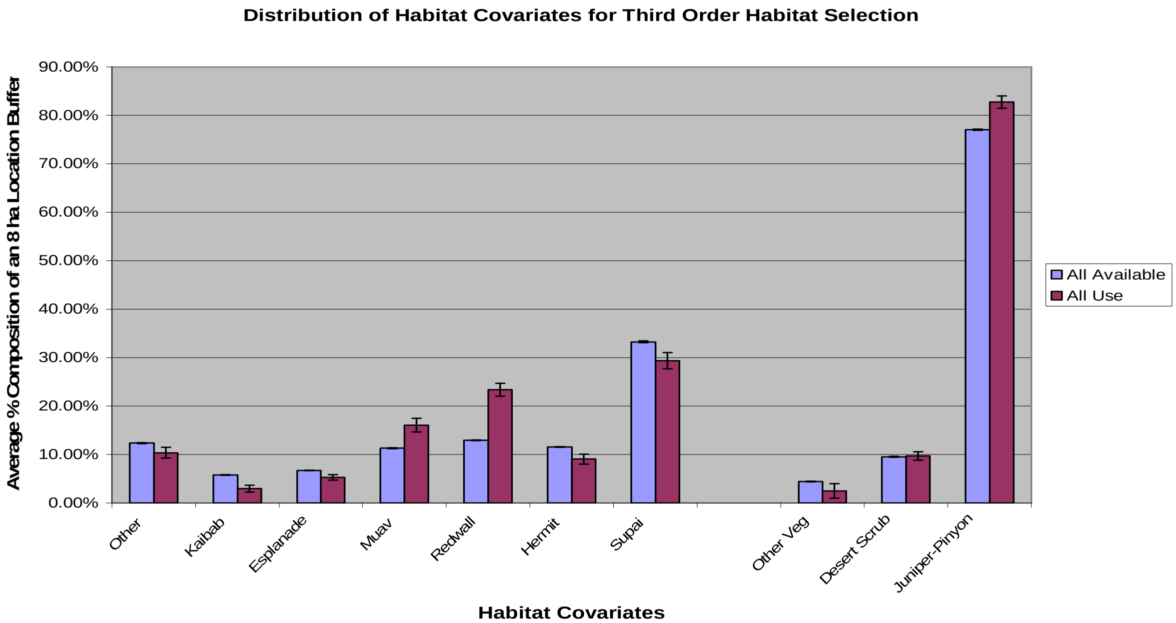


Table 3.5. Significance tests for habitat covariate coefficients in the third order habitat selection analysis, using logistic regression.

Parameter	Name	Coefficient	SE	Lower CL	Upper CL	P-Value
Significant:						
B_0	Intercept	-3.2797	1.2668	-5.7626	-0.7967	0.0100
B_5	Redwall	0.2067	0.1037	0.0035	0.4099	0.0470
B_6	Muav	0.4440	0.1494	0.1512	0.7368	0.0031
Non-significant						
B_1	Kaibab	0.2635	0.1601	-0.0502	0.5773	0.1006
B_2	Hermit	0.1553	0.1312	-0.1018	0.4124	0.2372
B_3	Esplanade	0.2078	0.1339	-0.0547	0.4703	0.1217
B_4	Supai	0.0779	0.0991	-0.1163	0.2722	0.4323
B_7	Other Rock	0.1147	0.1115	-0.1038	0.3332	0.3043
B_8	Desert Scrub	-0.0035	0.0750	-0.1505	0.1435	0.9626
B_9	P-J	0.0537	0.0600	-0.0638	0.1713	0.3708
B_{10}	Other Veg	-0.2310	0.1286	-0.4830	0.0210	0.0732

Figure 3.7. Percent composition of habitat covariates that occurred within the average 8-ha buffer around Mexican spotted owl locations and random locations within the South Rim study area (Fig 3.1). The "All Use" bins represent the pooled telemetry locations for 5 male owls (n = 345) while "SR Available" represents random locations (n = 25,000) within home ranges located below the South Rim of the Grand Canyon National Park, 2004 – 2006. Standard error bars are displayed.

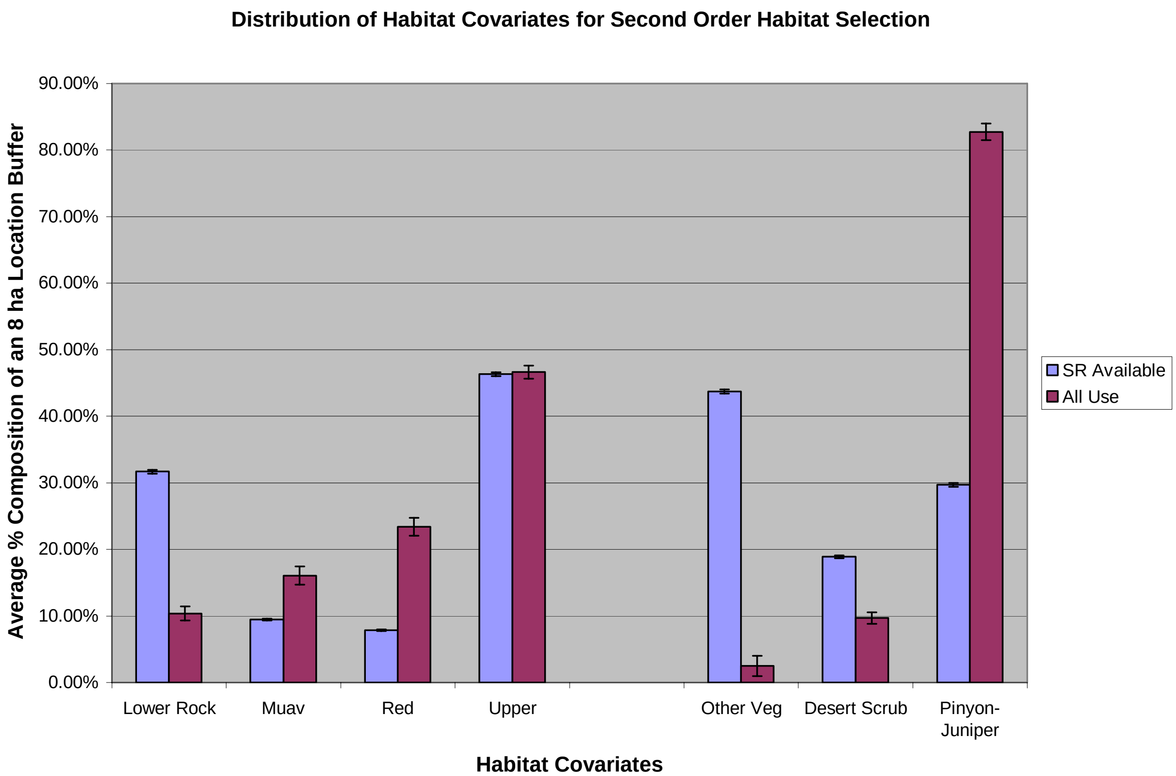


Table 3.6. Significance tests for habitat covariate coefficients in the second order habitat selection analysis, using logistic regression.

Parameter	Name	Coefficient	SE	Lower CL	Upper CL	P-Value
Significant:						
B_0	Intercept	-2.8428	0.7062	-4.2270	-1.4586	0.0001
B_2	Redwall	0.4850	0.1384	0.2137	0.7563	0.0005
B_3	Muav	0.2932	0.1037	0.0900	0.4964	0.0049
B_5	Desert Scrub	-0.3370	0.0901	-0.5135	-0.1604	0.0002
B_6	P-J	0.1143	0.0591	-0.0015	0.2301	0.0538
B_7	Other Veg	-0.4960	0.0931	-0.6784	-0.3136	0.0000
Non-significant						
B_2	Lower Rock	0.1635	0.1053	-0.0430	0.3700	0.1215
B_4	Upper Rock	0.1364	0.0879	-0.0359	0.3087	0.1217

Discussion

In northern Arizona, Mexican spotted owl habitat use studies have been conducted in mixed conifer forests (Ganey and Balda 1989a), pine-oak forests (Ganey et al. 1999), and arid rocky canyons (this study). Owls within the Grand Canyon National Park were primarily located towards the heads of canyon where topographic relief is extreme and canyon width narrows. At a landscape level, spotted owl telemetry locations were positively correlated with piñyon-juniper vegetation that occurred within canyons as well as with the Redwall and Muav geologic layers (Table 3.5). Owls appeared to avoid some vegetation communities that occurred within the landscape surrounding spotted owl use areas. However, on occasion, owls made trips onto plateaus above the canyon rim, possibly to forage or defend their territory.

Mexican spotted owls occupying habitats such as mixed-conifer and pine – oak forests, pinyon-juniper woodlands, and rocky canyons show variation in home range size (Ganey et al. 1999, Ganey et al. 2005, Willey and Van Riper 2007). In the Grand Canyon, breeding season home range size (AK95% mean = 561.9 ha, ±83.8 SD) was similar to that reported for Utah in comparable landscapes (Willey and Van Riper 2007; mean = 506 ha, ±516 SD). The breeding season home ranges in the Grand Canyon were less variable in size than observed in Utah, which may reflect sampling processes, habitat homogeneity, or something distinct about the Grand Canyon study area. Breeding season home range sizes in the Grand Canyon were also similar in size to those found in xeric habitats of New Mexico (Ganey et al. 2005), but were larger than those reported from relatively more mesic coniferous forests in northern Arizona (Ganey et al. 1999) and New Mexico (Ganey et al. 2005); however, comparisons among regions are confounded by differences in methods and tracking periods. Home range size for spotted owls appears to be associated with various factors, including elevation and region (Ganey et al. 2005), habitat configuration (Willey 1998), and distribution of mature forest and prey abundance (Carey et al. 1992).

Breeding season home ranges included vegetation types and rock strata associated with the steeply rising canyon walls surrounding activity centers in the Grand Canyon. Spotted owls appeared to select locations that contained the Muav and Redwall geologic layers while using the other habitat covariates in proportion to their availability within home ranges (Table 3.5). The Muav and Redwall geologic layers made up more than half of the area within 30% AK isopleths (Table 3.3) and nearly half of the area within all delineated core areas within the Park (Fig 2.4). This suggests that nest habitat within spotted owl home ranges is of central importance in the rocky tributaries of the Grand Canyon as it appears to be in other environments (USDI 1995).

Piñyon-juniper woodlands appear to be widely used by Mexican spotted owls in lower elevation xeric environments and were the primary overstory vegetation associated with home ranges in the Grand Canyon. In rocky canyon environments in Utah, piñyon-juniper woodland was also the most common vegetation community associated with owl use areas (Willey and Van Riper 2007). Pinyon-juniper woodlands were reported to be used in central and southern Arizona (Ganey et al. 1992, Ganey and Balda 1989a) and southern New Mexico (Zwank et al. 1994, Ganey et al. 2005). In southern New Mexico, piñyon-juniper woodlands were shown to represent lower quality habitat then mixed-conifer forests (Ganey et al. 2005) however, this may not be true in rocky canyon environments where piñyon-juniper woodlands are the dominate vegetation community and steep walls provide high perches, shelter from predators, and thermal relief for nesting and roosting owls.

Management Considerations

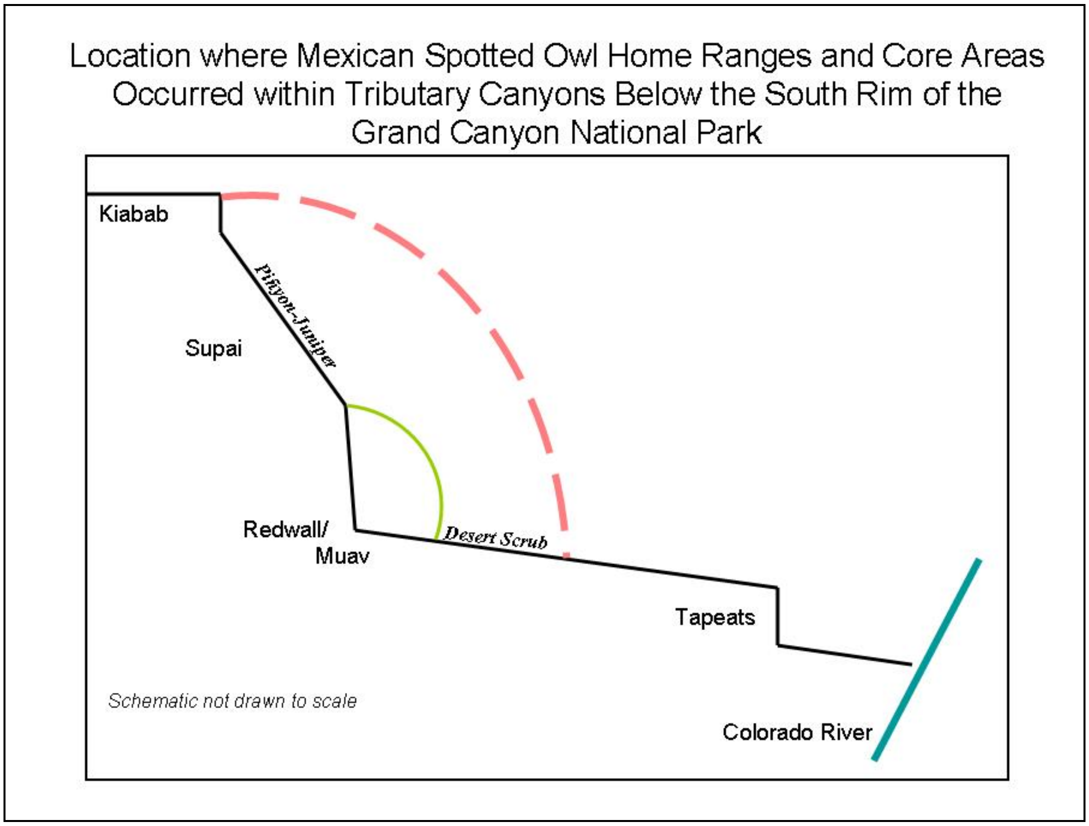
This research investigated spotted owl habitat selection at two scales and the results indicate that selection varied between these scales. Within home ranges owls appeared not to select any vegetation habitat covariates however, at the landscape level owls were selecting areas with piñyon-juniper woodlands. Overall, three habitat components seem important to spotted owls within the Grand Canyon; piñyon-juniper vegetation, Redwall limestone, and Muav limestone. Taken together, these three components identify an area of preference within tributary canyons that is located toward the heads of canyons and below the canyon rim. Within these areas, spotted owl telemetry locations were concentrated around nest and roost sites which were primarily located in Redwall limestone cliffs. The delineation of 40-ha core areas, as recommended in the Recovery Plan for the Mexican spotted owl (USDI 1995), proved to be an effective conservation strategy that correctly identified areas of concentrated use within home range estimates.

GENERAL CONCLUSIONS

Mexican spotted owl locations that occur within home ranges appear to follow patterns consistent with a model for central place foragers (Orians and Pearson 1979, USDI 1995, Ganey et al. 2005, Willey and Van riper 2007). This also seemed true in the Grand Canyon where telemetry locations that I estimated were clumped around nest and roost sites and radiated out from these cores into the outer isopleths of home ranges (Appendix 1). Further, male spotted owls were observed returning prey to the nest site. Frequent foraging bouts from the nest area appear to be the typical behavior for male spotted owls during the breeding season (Ganey 1988, Gutierrez et al. 1995, Willey and Van Riper 2000).

Previous research indicates that Mexican spotted owls are highly selective of nest and breeding season roost locations (Ganey et al. 2000, Ganey 2004). Mexican spotted owls that I observed in the Grand Canyon placed nests in caves and on overhung ledges in Redwall Limestone cliffs. Roosts were placed in similar locations but also occurred in surrounding vegetation. Within home ranges, owls selected the Redwall and Muav geologic layers disproportionately to their availability (Table 3.5). Redwall limestone may provide both shade and protection for spotted owls and appears to be an important habitat component within the Grand Canyon.

Figure 4.1. Cross-section of the location where Mexican spotted owls placed home ranges (dashed line) and core areas (solid green line) within the Grand Canyon National Park, 2004 – 2006.



While Mexican spotted owls are more frequently associated with forest habitats, within the Grand Canyon, where both classic forest and rocky canyon habitats were available, owls chose rocky canyons over forested areas. The location of spotted owl home ranges that I estimated in the Grand Canyon occurred within the heads of tributary canyons of the Colorado River (Fig 4.1). My results indicate that the locations of spotted owl home ranges are positively correlated with the presence of piñyon-juniper woodlands within the South Rim study area (Table 3.6). Within this area, piñyon-juniper woodlands coincide with the Redwall geologic layer where spotted owls placed nests and breeding season roosts (Fig 4.2). However, the Redwall forms a prominent geologic layer that occurs throughout the Grand Canyon and is associated with various vegetation cover types throughout the Park (e.g. Fig 4.3). If spotted owls are selecting nest sites in Redwall cliffs and are capable of utilizing a broad array of habitat types for foraging (e.g. Ganey et al. 2000), then my data may represent a narrow sample of the vegetation cover types that ultimately occur within home ranges in the Grand Canyon. A larger sample of territories is required to better distinguish the role that vegetation plays in the selection of nest and home range locations.

Figure 4.2. Location of two habitat covariates that were significantly correlated with spotted owl home range placement within the South Rim study area, Grand Canyon National Park 2004 – 2006.

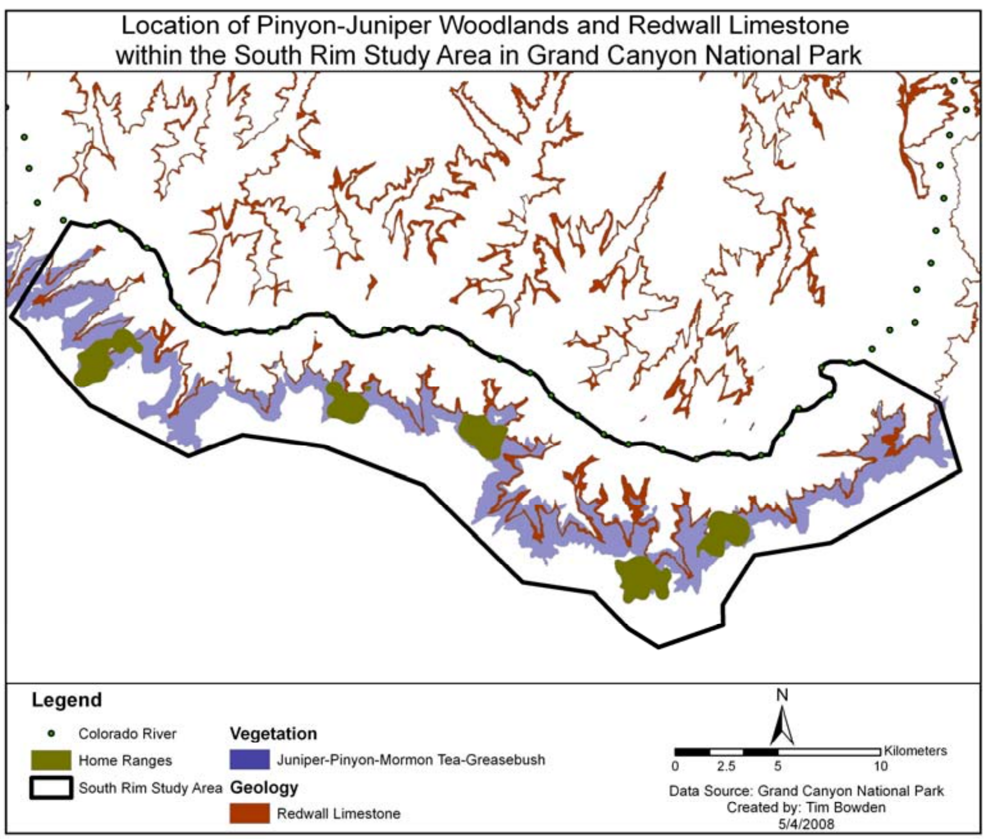
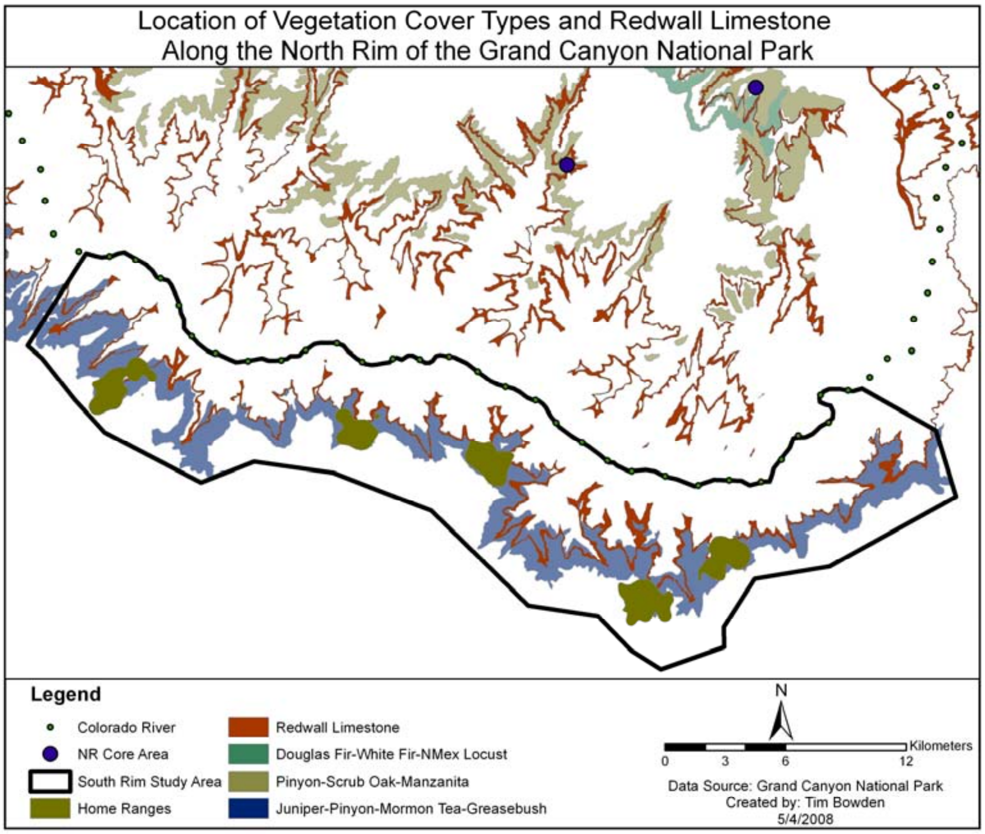


Figure 4.3. Location of vegetation cover types and Redwall Limestone in relation to Mexican spotted owl core areas located below the North Rim of the Grand Canyon, 2004 – 2006.



This research has identified a productive population of breeding owls within the Grand Canyon. Continued monitoring of breeding might highlight the Grand Canyon as an important reserve for spotted owl reproduction. The delineation of 40-ha core areas seems to be an effective conservation strategy and the Park's commitment to this strategy will facilitate further research on owl nest site selection. Additional habitat variables such as canyon temperature and the availability of water within the upper portions of canyons may also help to distinguish canyons selected by spotted owls. Woodrats (primarily *Neotoma albigula* or *N. cinereus* based on dentary bone structure) were the most common prey type found in the diet of spotted owls in the Grand Canyon. Future research on demography and ecological requirements of prey may provide insight into the variation in fledgling production among territories (Carey et al. 1992, Willey 2006). Research using telemetry within the Grand Canyon is challenging due to radio signal bounce off of canyon walls, however signal bounce varied among canyons and tracking locations, creating “good” and “bad” positions to receive radio signals. Researchers using this method in the Grand Canyon would benefit from conducting error analysis to identify good tracking positions prior to collecting wildlife movement data. Finally, the Grand Canyon may be host to one of the larger populations of Mexican spotted owls in the region (Willey and Ward 2003) and continued effort to monitor this population will provide information valuable to the conservation of spotted owls across the Colorado Plateau (USDI 1995).

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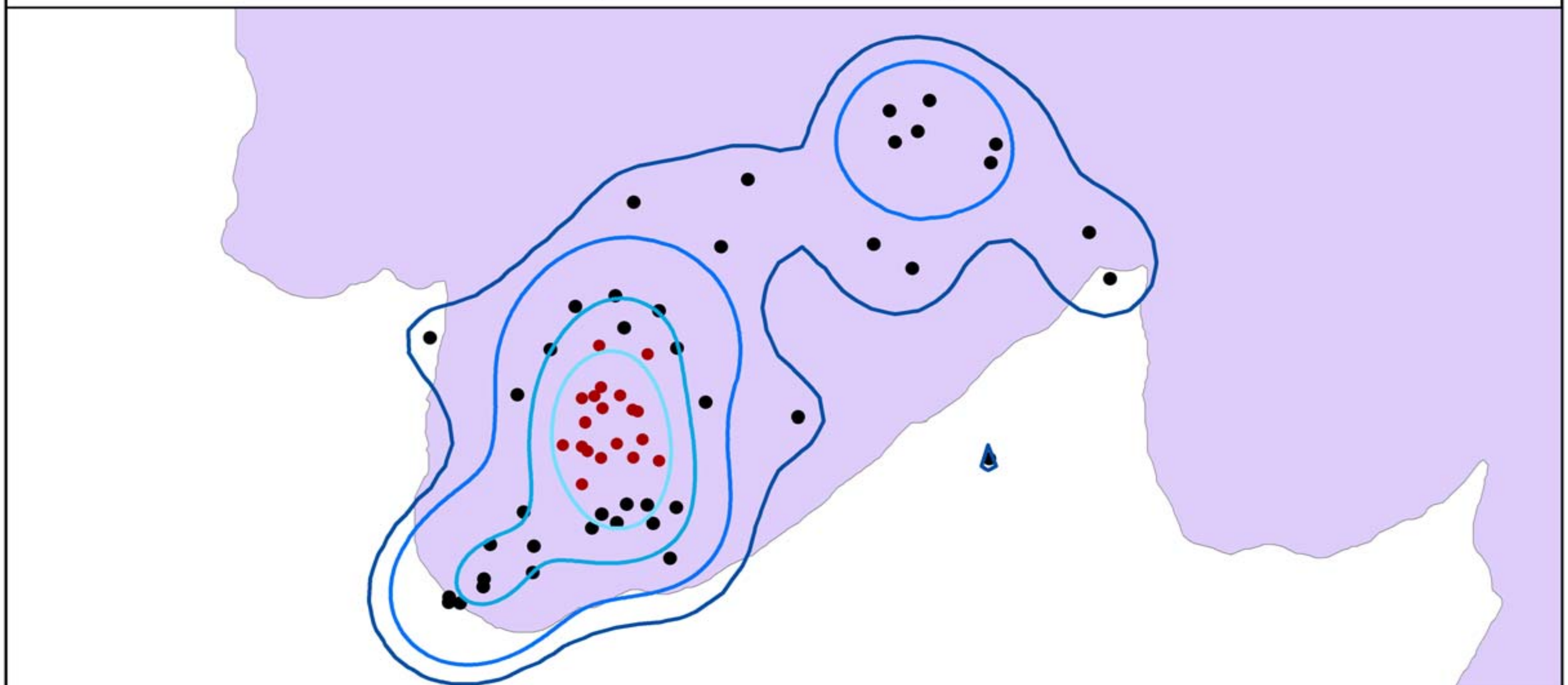
APPENDICES

APPENDIX A

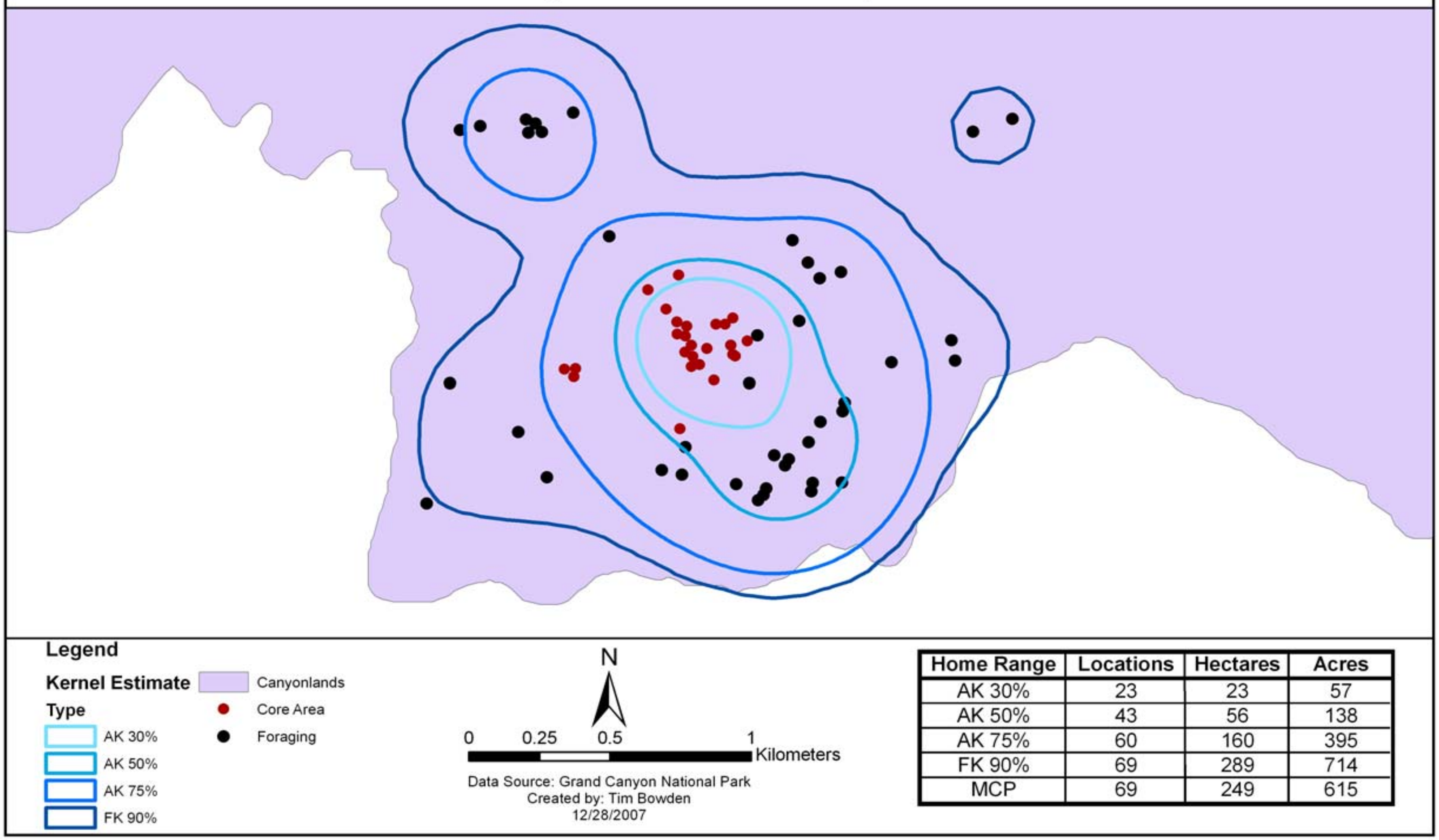
HOME RANGE MAPS FOR FIVE MALE SPOTTED OWLS IN GRAND CANYON NATIONAL PARK

TER3 Home Range
Grand Canyon National Park, 2004 - 2006



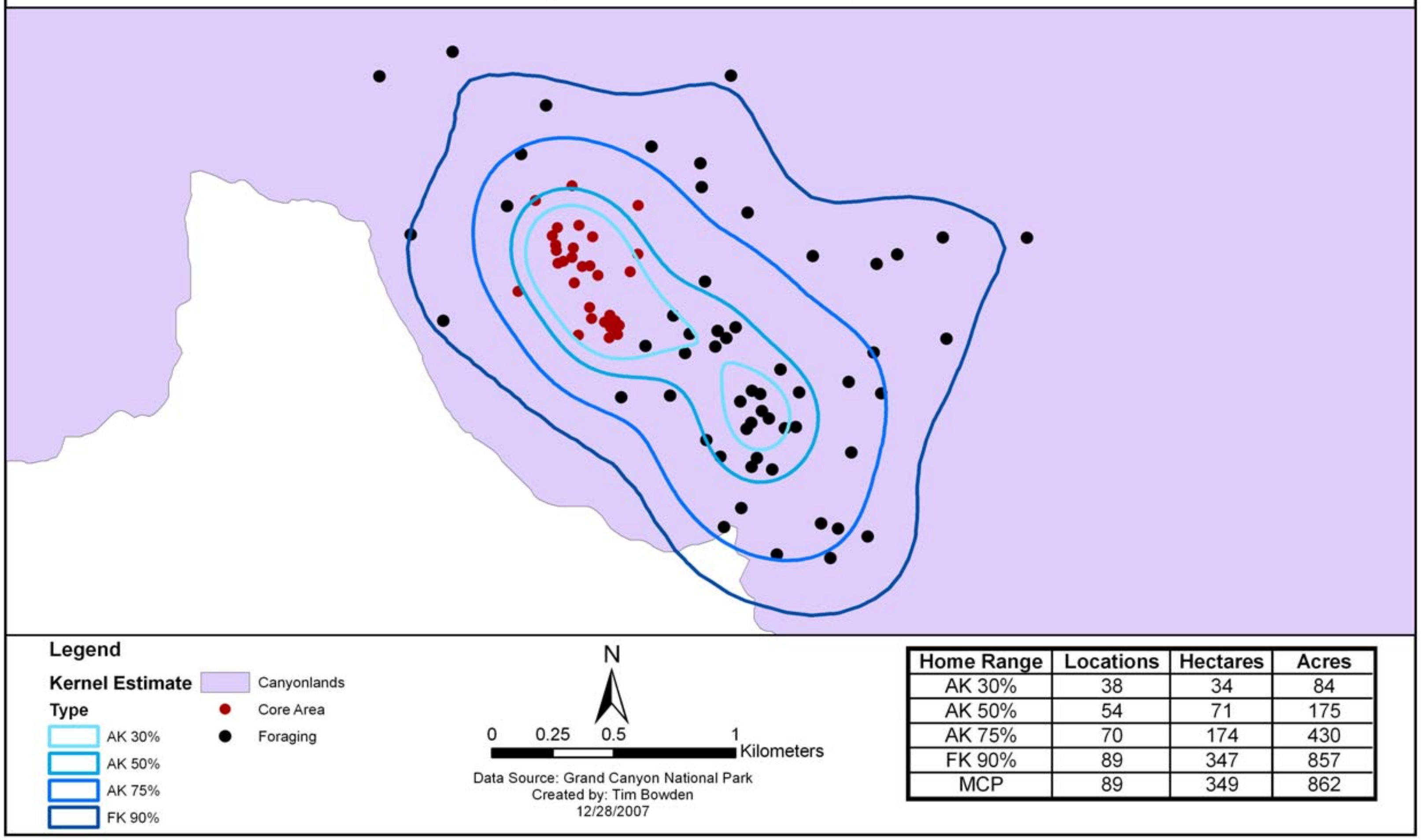
Home Range	Locations	Hectares	Acres
AK 30%	22	31	77
AK 50%	33	79	195
AK 75%	51	225	556
FK 90%	61	429	1060
MCP	61	407	1006

TER4 Home Range
Grand Canyon National Park, 2004 - 2006



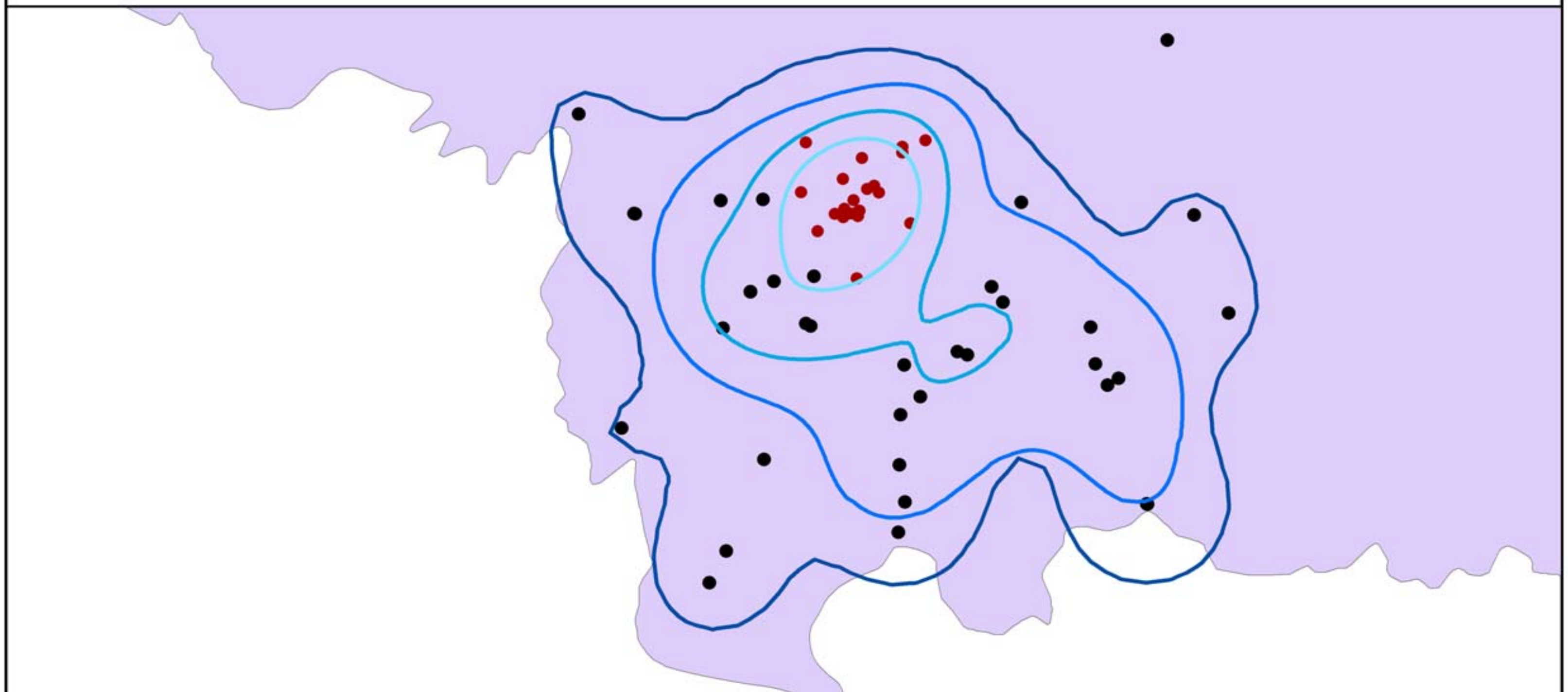
Home Range	Locations	Hectares	Acres
AK 30%	23	23	57
AK 50%	43	56	138
AK 75%	60	160	395
FK 90%	69	289	714
MCP	69	249	615

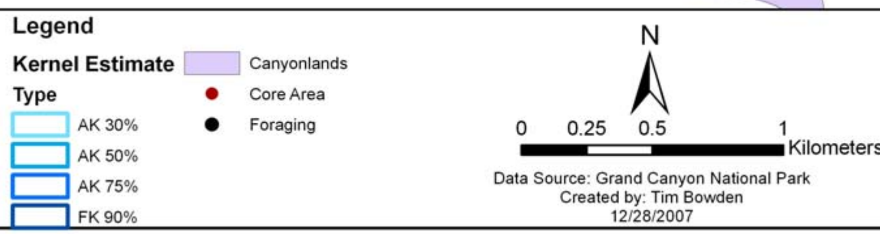
TER5 Home Range
Grand Canyon National Park, 2004 - 2006



Home Range	Locations	Hectares	Acres
AK 30%	38	34	84
AK 50%	54	71	175
AK 75%	70	174	430
FK 90%	89	347	857
MCP	89	349	862

TER7 Home Range
Grand Canyon National Park, 2004 - 2006

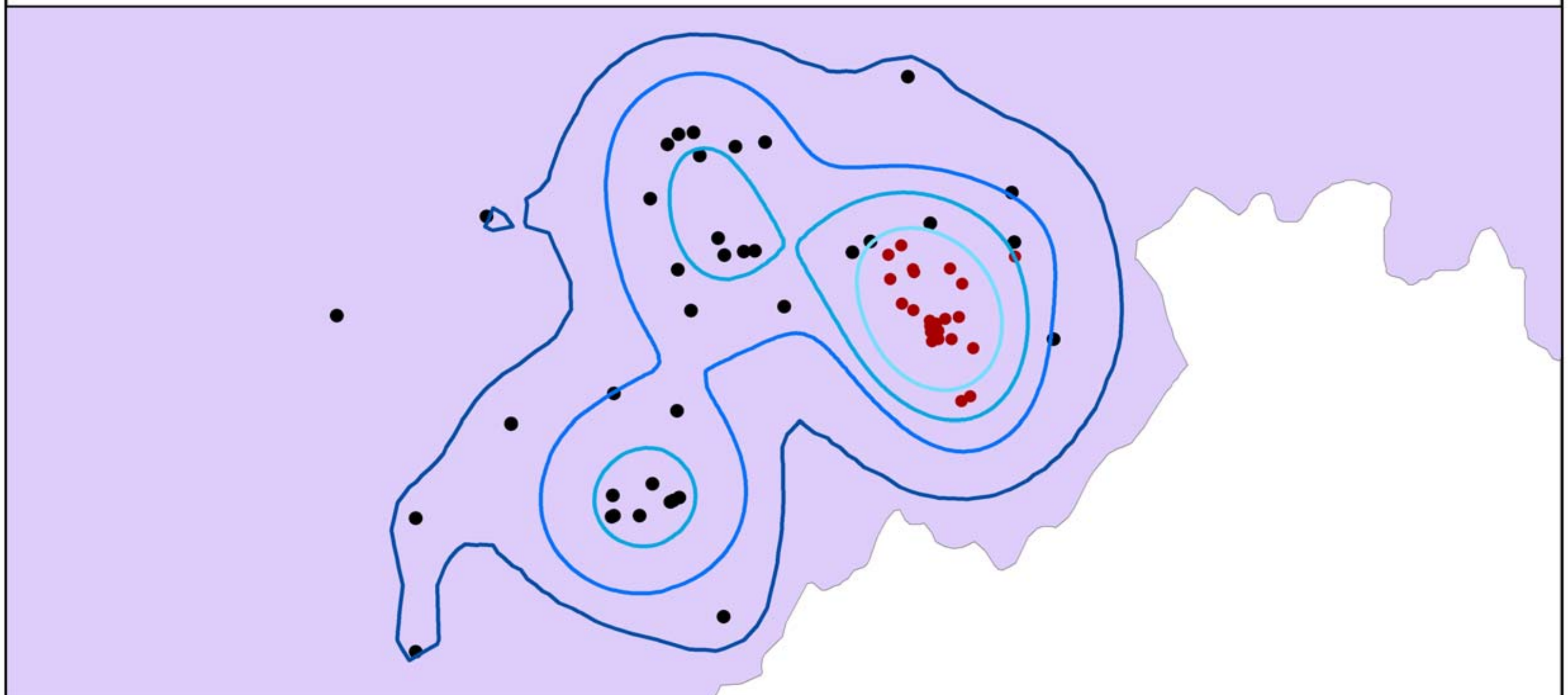




Data Source: Grand Canyon National Park
Created by: Tim Bowden
12/28/2007

Home Range	Locations	Hectares	Acres
AK 30%	22	26	64
AK 50%	35	81	200
AK 75%	48	232	573
FK 90%	63	431	1065
MCP	63	423	1045

TER14 Home Range
Grand Canyon National Park, 2004 - 2006

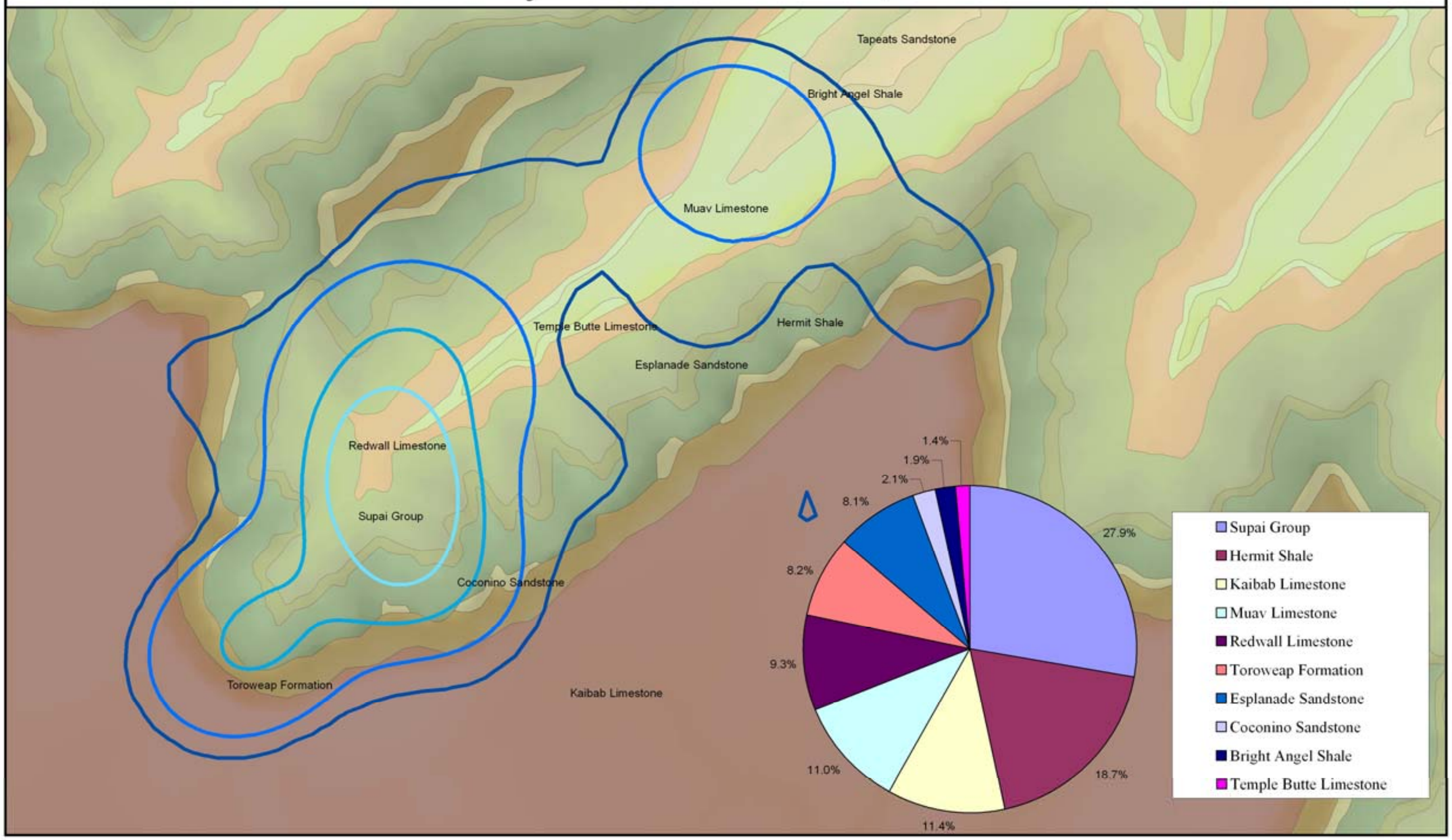


Home Range	Locations	Hectares	Acres
AK 30%	22	23	57
AK 50%	41	72	178
AK 75%	54	183	452
FK 90%	63	364	899
MCP	63	349	862

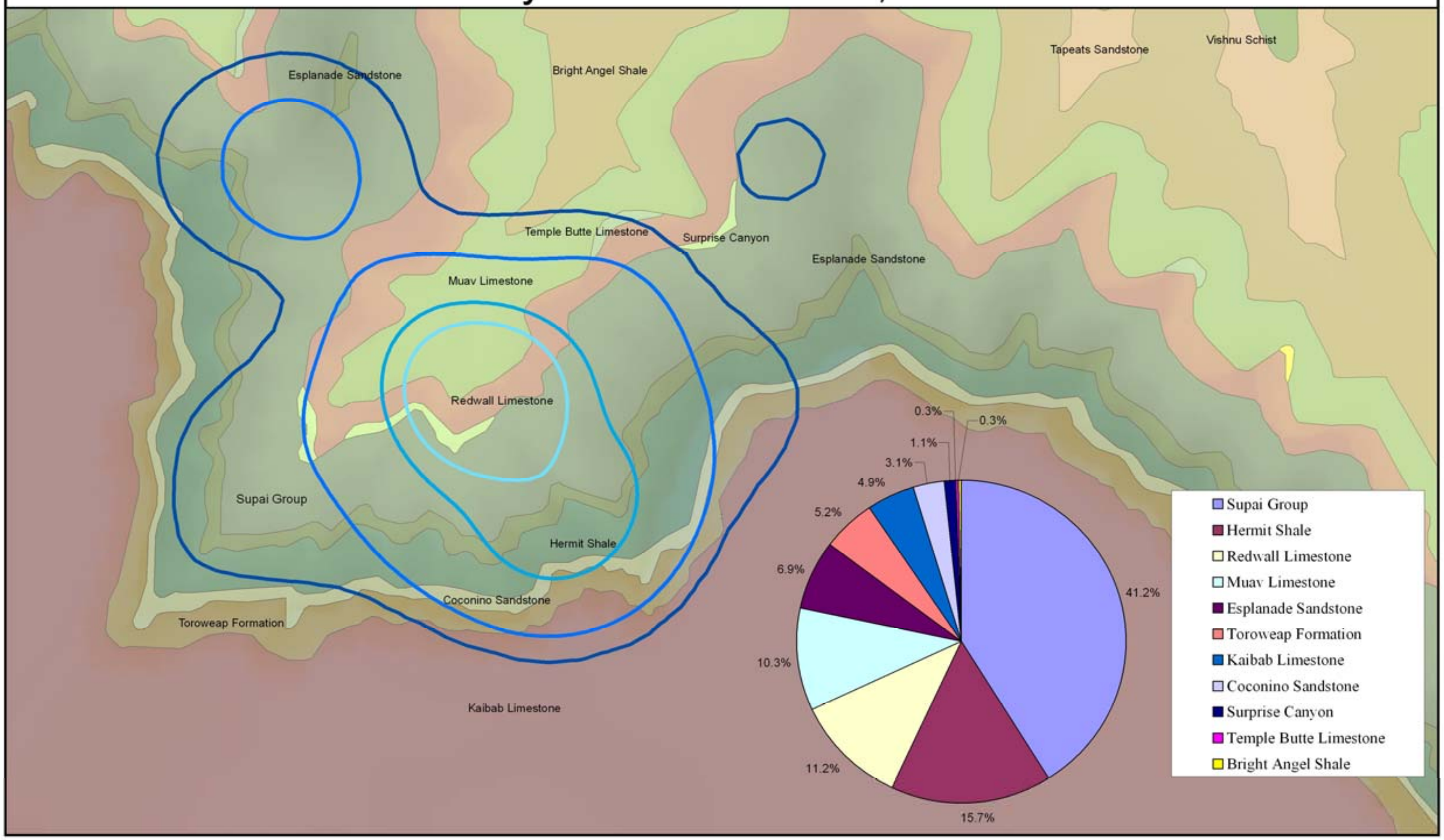
APPENDIX B

MAPS SHOWING GEOLOGIC STRATA PRESENT IN HOME RANGES FOR FIVE MALE SPOTTED OWLS IN GRAND CANYON NATIONAL PARK

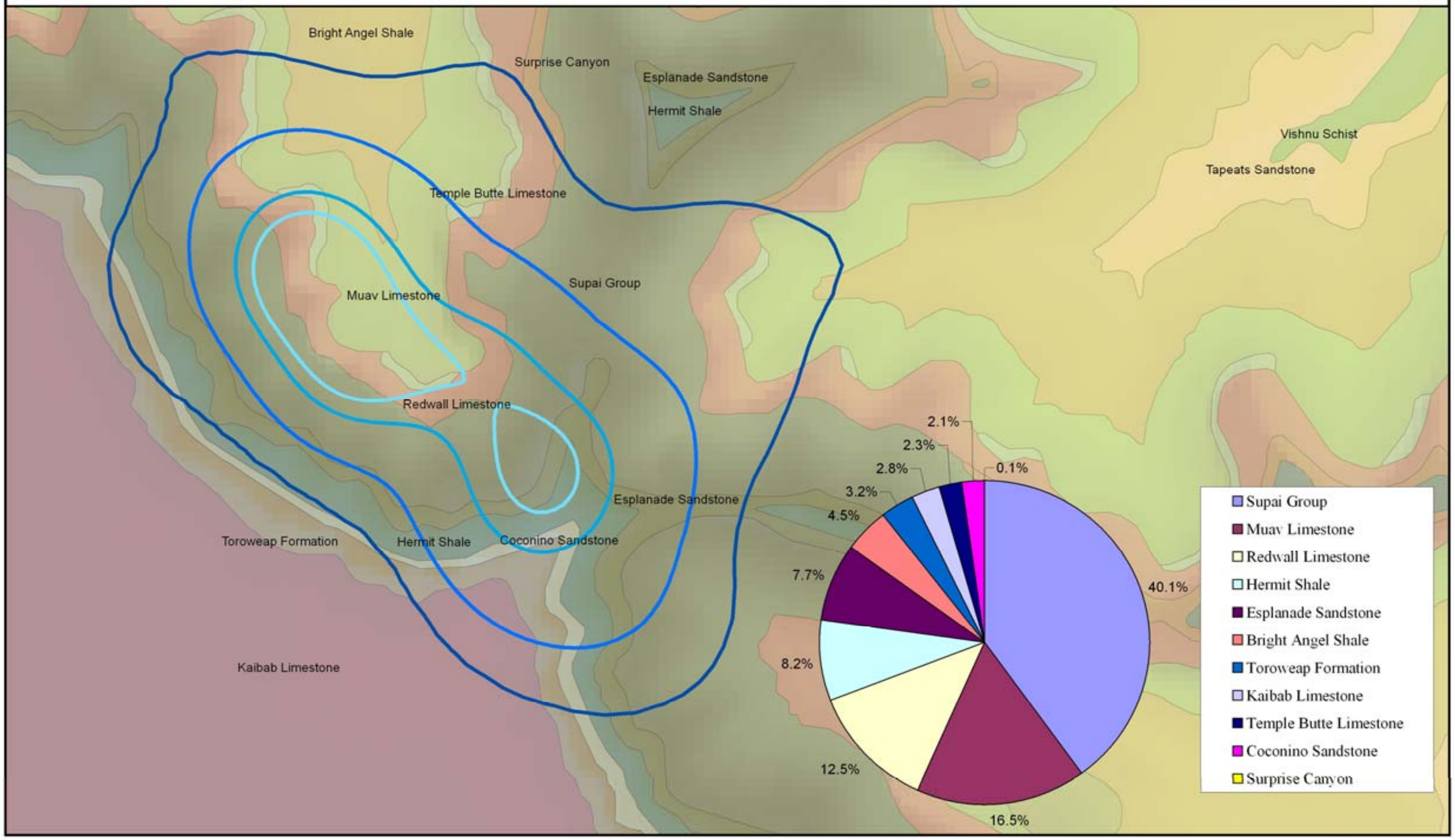
Geologic Strata within the TER3 Home Range
Grand Canyon National Park, 2004 - 2006



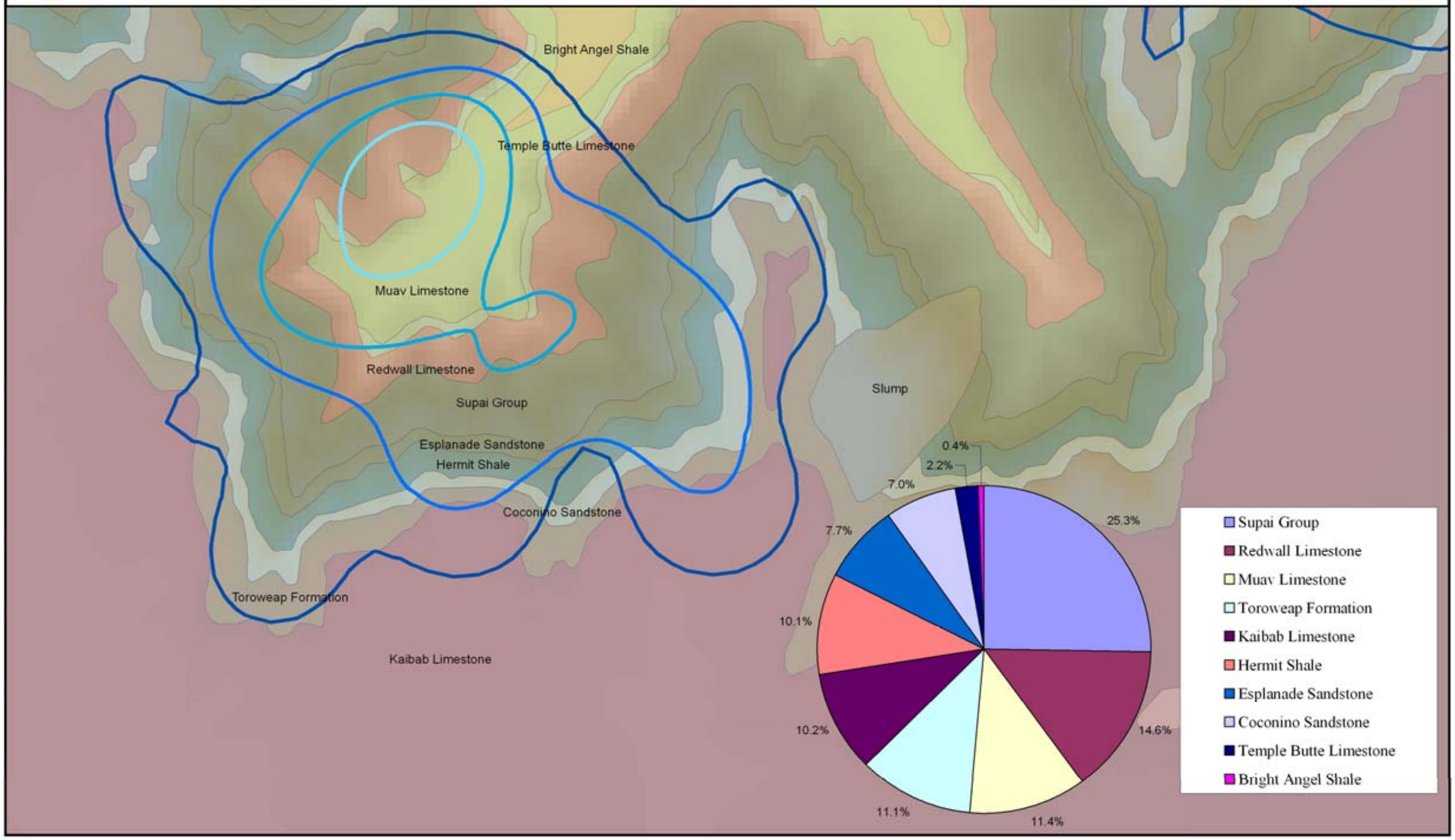
Geologic Strata within the TER4 Home Range
Grand Canyon National Park, 2004 - 2006



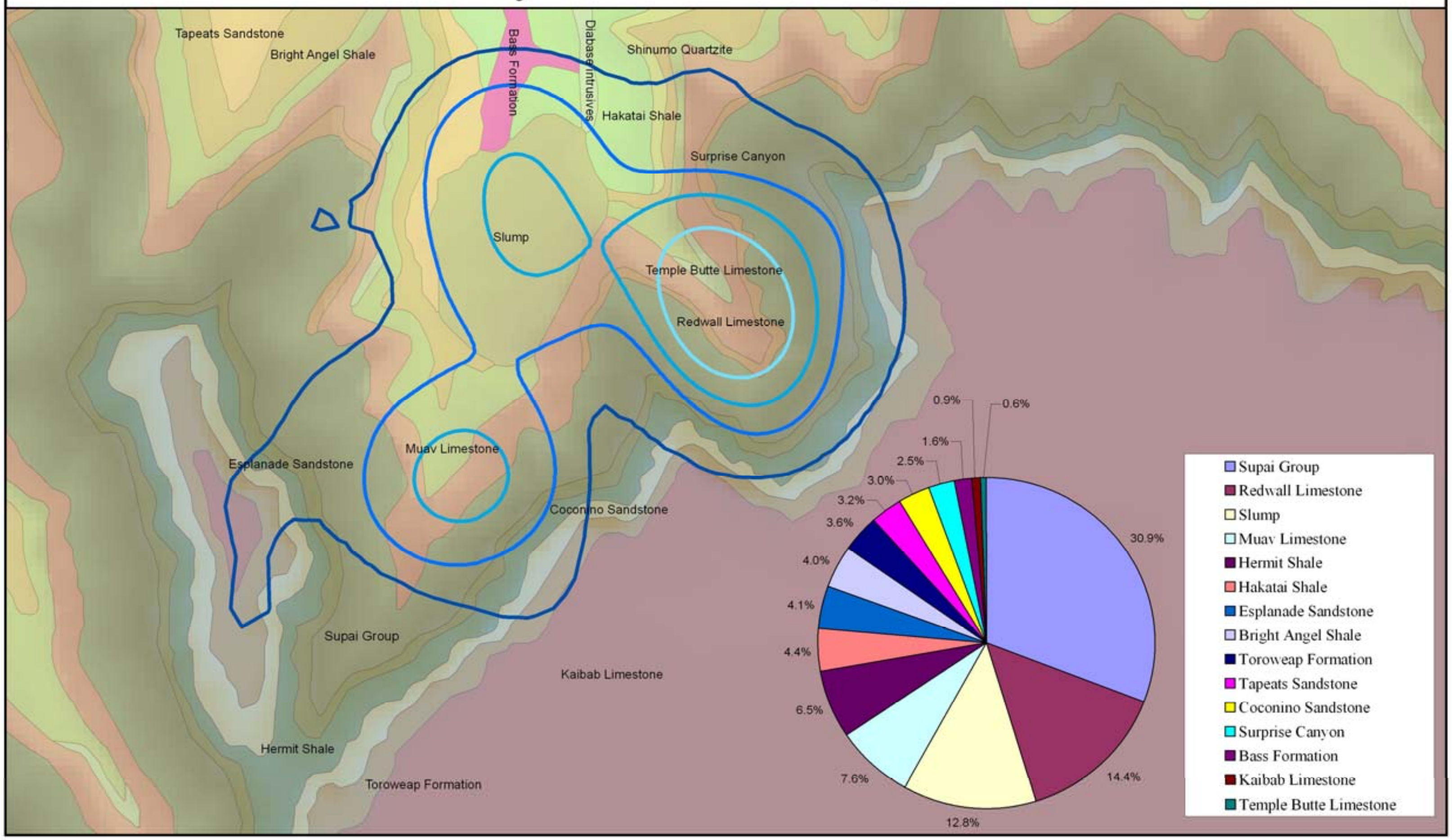
Geologic Strata within the TER5 Home Range
Grand Canyon National Park, 2004 - 2006



Geologic Strata within the TER7 Home Range
Grand Canyon National Park, 2004 - 2006



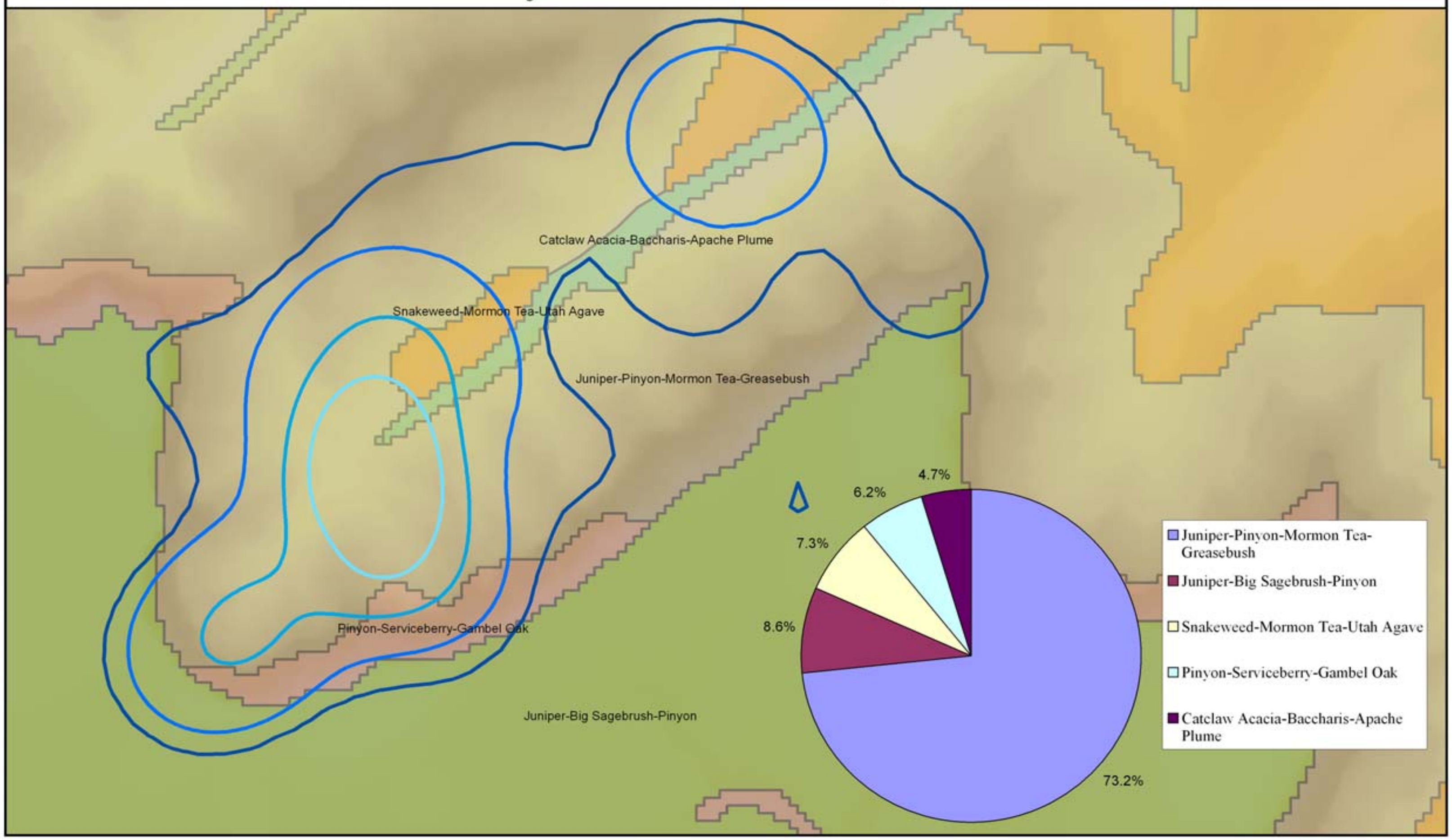
Geologic Strata within the TER14 Home Range
Grand Canyon National Park, 2004 - 2006



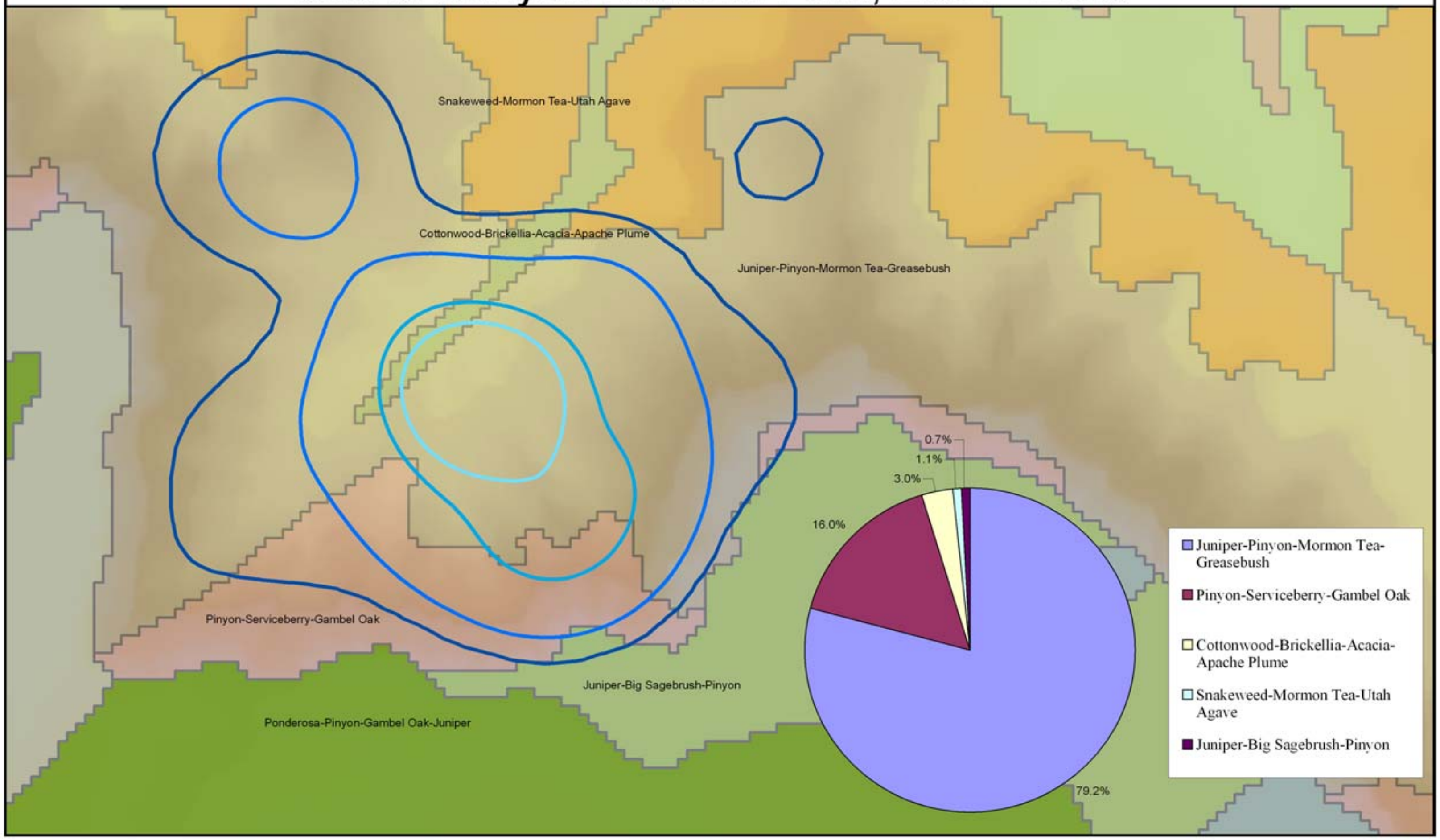
APPENDIX C

MAPS SHOWING VEGETATION COMMUNITIES PRESENT IN HOME RANGES FOR FIVE MALE SPOTTED OWLS IN GRAND CANYON NATIONAL PARK

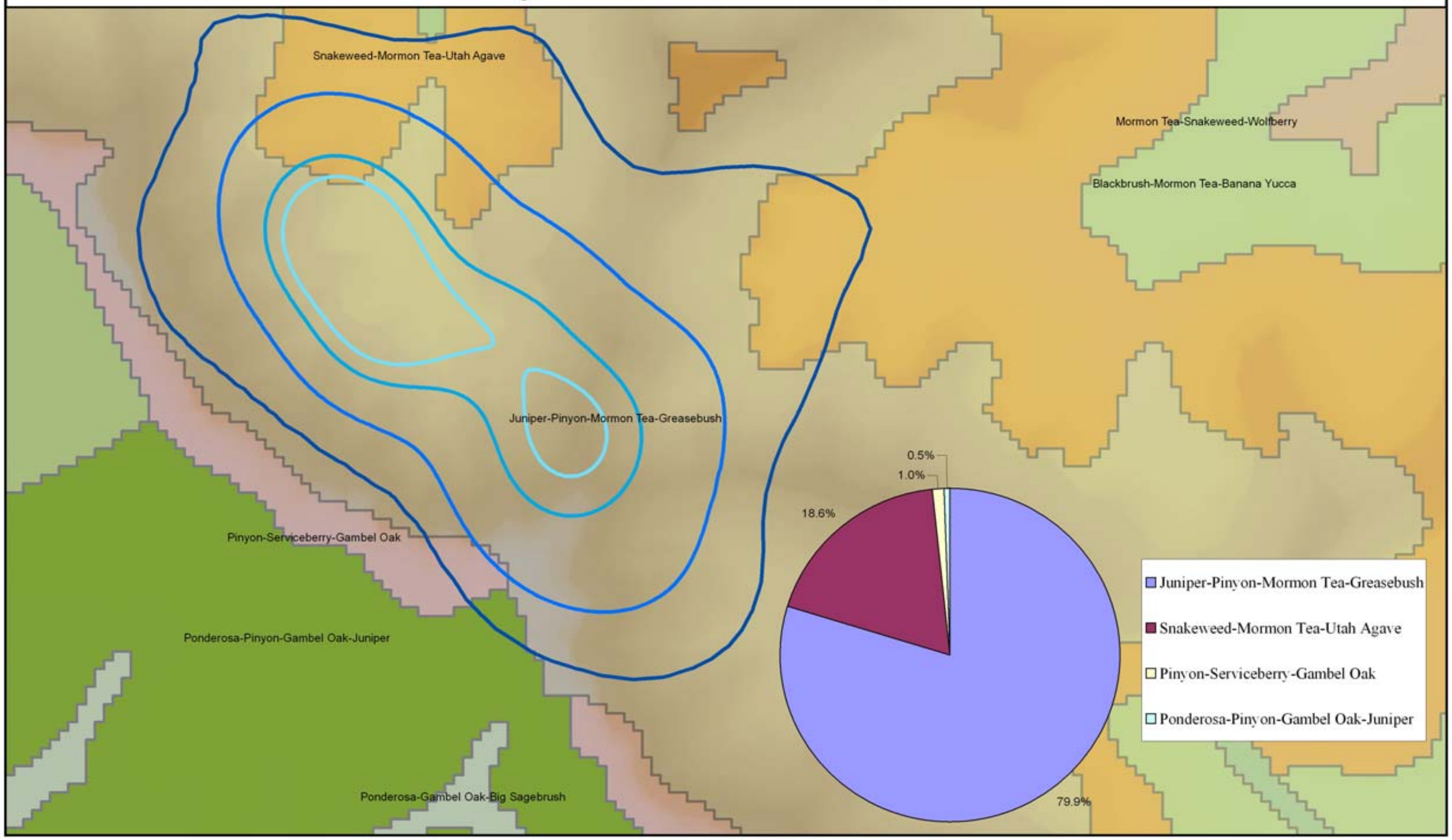
Vegetation Communities within the TER3 Home Range
Grand Canyon National Park, 2004 - 2006



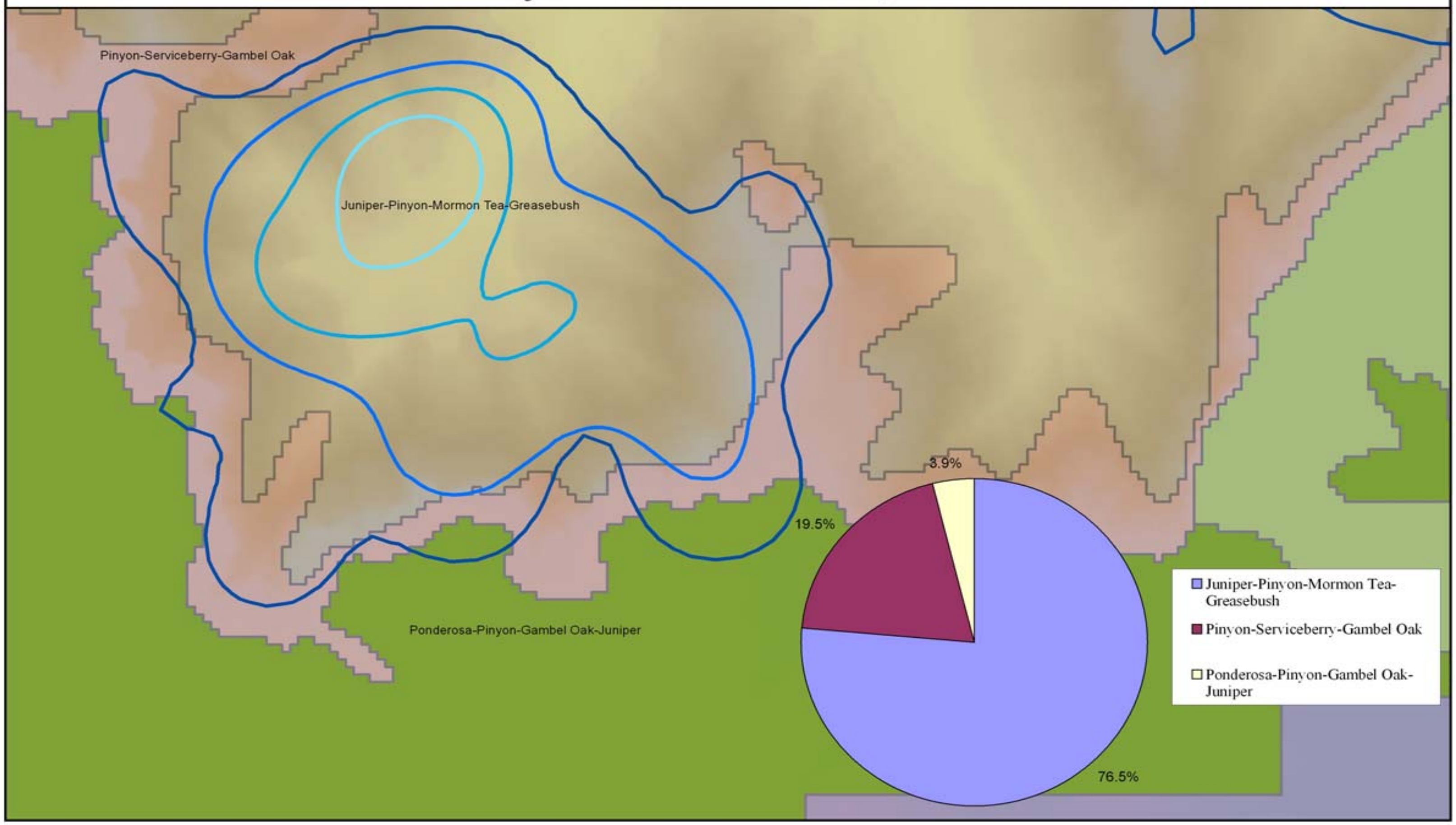
Vegetation Communities within the TER4 Home Range
Grand Canyon National Park, 2004 - 2006



Vegetation Communities within the TER5 Home Range
Grand Canyon National Park, 2004 - 2006



Vegetation Communities within the TER7 Home Range
Grand Canyon National Park, 2004 - 2006



Vegetation Communities within the TER14 Home Range
Grand Canyon National Park, 2004 - 2006