Ecology of Common Ravens at the Marine Corps Air Ground Combat Center, Twentynine Palms, California

Final Project Report Covering Research Conducted Between December 9, 2002 and December 18, 2004

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U.S. Geological Survey
Western Ecological Research Center

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Introduction

This report presents the results of a two-year study on Common Ravens (*Corvus corax*) to the Natural Resources and Environmental Affairs (NREA) Division of the Marine Corps Air Ground Combat Center (MCAGCC) and the Natural and Cultural Resources Office, Southwest Division Naval Facilities Engineering Services Command. The research was conducted by the U.S. Geological Survey/Biological Resources Discipline, San Diego Field Station from December 9, 2002-December 18, 2004.

Natural resource managers at MCAGCC contracted the USGS to conduct this study based on concerns regarding raven overpopulation. Common Ravens have experienced a tremendous population explosion in the California desert, with regional increases of up to tenfold over a recent 25-year period (Boarman 1993, Boarman and Berry 1995). As human communities have grown, Common Ravens, a subsidized predator (Soulé 1990), have followed, taking advantage of resources that human developments inadvertently provide. Raven population growth is a concern to natural resource managers at MCAGCC because ravens prey on juvenile desert tortoises (*Gopherus agassizii*) and are a factor in tortoise decline and listing as a Federally "Threatened" species (U.S. Fish and Wildlife Service 1990, Boarman 1993).

Predation by subsidized predators can drive rare native prey populations to endangerment and extinction because anthropogenic resources insulate the predator from the effects of fluctuations in prey populations, allowing predator populations to remain high even as prey become more rare. The subsequent depletion of rare prey occurs by two mechanisms: hyperpredation (Courchamp et al. 2000) and spillover predation (Schneider 2001). Hyperpredation occurs in areas where abundant subsidized predators and rare prey co-occur, while spillover predation describes the situation in which predators spread out from subsidy sites into areas lacking such resources and then capture rare prey. Raven predation on desert tortoises occurs under both of these scenarios. Breeding ravens, which have reached elevated levels due to human subsidies but are spread out across the landscape, generally prey on tortoises through hyperpredation (Kristan and Boarman 2003). Non-breeding ravens, which often form large aggregations around attractions, exhibit patterns consistent with spillover predation when they prey on tortoises in areas adjacent to attractions. Active management of ravens and control of the subsidies on which they thrive may be necessary to prevent further decrease in tortoise populations. Furthermore, managers should be aware of the differences between hyperpredation and spillover predation so that strategies can be developed specific to the two types of subsidized predation (Kristan and Boarman 2003).

In addition to causing increased predation pressure on desert tortoises, ravens are a concern at MCAGCC because they have formed a large nocturnal roost on power lines near the Exercise Support Base at Camp Wilson. This roost represents a potential Bird Air Strike Hazard (BASH) because it is less than 3 km from the Expeditionary Air Field used for Marine training exercises. Ravens and other members of the Corvid family (crows and jays) often form large communal roosts (Goodwin 1976, Stiehl 1981, Steenhof 1983, Caccamise et al. 1997) in trees (Hurrell 1956, Stiehl 1981), abandoned buildings (Temple 1974), cliffs (Coombes 1948), power lines (Steenhof 1983, Engel et al. 1992), and even on the ground amidst dense vegetation (Stiehl 1981). Communal roosting behavior is thought to be an adaptation either for predator avoidance (Lack 1968) or to increase the chances of finding food (Ward and Zahavi 1973, Loman and Tamm 1980, Marzluff et al. 1996, Caccamise et al. 1997). Roost site selection by ravens is not well understood, although it has been suggested that shelter from the elements, especially wind (Stiehl 1981), and proximity to anthropogenic resources (Steenhof 1983, Engel and Young 1992) may be important factors.

Because of the large numbers of ravens and their potential threat to both desert tortoise recovery and air traffic safety, it is important to increase our understanding of raven habitat use and roosting behavior at MCAGCC. Information gleaned from studies such as ours should aid management efforts to reduce raven populations on the base. The research presented in this report will attempt to assess temporal and spatial patterns of raven activity, to analyze use of anthropogenic subsidies at MCAGCC and to observe the behavior of ravens at the nocturnal roost. Specifically, we are attempting to answer five questions: (1) are anthropogenic resource sites used by ravens more frequently than randomly selected features and remote desert areas?; (2) is the operational and residential part of the base (i.e, the cantonment) an attraction compared to the open desert?; (3) is there a seasonal difference in raven abundance?; (4) is roosting phenology (evening arrival and morning departure) best explained by sunset, light level, or human activity?; and, (5) does raven attendance at the nocturnal roost vary seasonally or is it more closely related to Marine Corps activities on the base?

Methods

Study Location

MCAGCC lies in south-central San Bernardino County, 8 km north of the city of Twentynine Palms, and covers 2524 km^2 of the western Mojave Desert. Topography consists of mountain ranges and bajadas, interspersed with basins. Climate is seasonal, with highs >37 °C in the summer and lows <2 °C in winter and an annual mean temperature of 19.7 °C (Rowlands 1995a). Mean annual precipitation is 103.4 mm, 36.1% of which falls during the summer months. Plant species represented in the region include galleta grass (*Pleuraphis rigida*), creosote bush (*Larrea tridentata*), burrobush (*Ambrosia dumosa*), an annual grass (*Schismus barbatus*), and other low-growing plant species (e.g., *Baileya multiradiata* and *Erodium texanum*) (Stewart and Baxter 1987, Baxter and Stewart 1990), all of which are typical of Creosote Bush Scrub and Allscale-Alkali Scrub habitats (Rowlands 1995b).

MCAGCC is divided into 24 training areas (TAs) and Mainside, the cantonment area which consists of operational offices and facilities, as well as amenities and housing for approximately 18,000 people. Additional infrastructure exists at Camp Wilson, a facility for housing Marines during desert training exercises located in West TA about 10 km northwest of Mainside. This camp consists of sleeping quarters (K-span huts), dining facilities (a Chow Hall and a fast food restaurant), operational facilities, garbage dumpsters, and a sewage treatment facility. The number of Marines staying at Camp Wilson is variable as training is conducted on a rotational basis; an average of about 2000 Marines arrives approximately monthly and stays for a period of 2 to 3 weeks.

Habitat Use

Research visits were made to MCAGCC at approximately one-month intervals from December 2002-December 2004. Timing of visits was chosen based on pre-established Marine Corps training schedules so that surveys were conducted in the middle of training periods and not on the days when Marines were arriving or departing from the base. However, many training sessions were canceled in 2003 and 2004 due to deployments, so several visits were conducted while no active training was taking place. A modified stratified random sampling scheme was used (Ratti and Garton 1994) with 18 sites divided into 3 strata (6 in each): attraction sites (anthropogenic subsidies in Mainside, Camp Wilson, and Range TA), cantonment sites (residential and operational areas in Mainside with no specific subsidy), and desert reference sites (away from human activities, infrastructures and subsidies in East, West, Sand Hill, Acorn, and Gypsum Ridge TAs; all of these TAs are located in the southwestern portion of the base) (Table 1, Figs. 1a and 1b). Attraction sites were selected based on the presence of either a food or water subsidy, while cantonment and desert sites were chosen at random. Visits were categorized seasonally as winter (December 22-March 20), spring (March 21-June 20), summer (June 21-September 22), or fall (September 23-December 21). Each visit consisted of point counts on 3 consecutive days, using methods modified from Ralph et al. (1995). Point count surveys were conducted after 1200 hours Pacific Standard Time when ravens were most likely to be active (Boarman et al. In review) and surveys were alternately started in Cantonment and in the more remote desert TAs to reduce confounding effects of time on abundance patterns. All ravens within 100 m of the point center (visually estimated) were counted for a 5-minute period. Beginning in December 2003, additional sites were surveyed each month outside the base boundary in vicinity of the towns of Yucca Valley and Joshua Tree (Table 2, Fig. 2). As with the surveys on the Base, a total of 18 sites were selected, with 6 at human subsidies, 6 randomly selected in residential or commercial sections of town, and 6 randomly selected in the desert, removed from cities or towns and presumably removed from subsidies.

Prior to analyses, count data were log transformed ($X' = \log(X+1)$) because residual plots suggested the data had a Poisson distribution (Zar 1999). We used a mixed linear model (SAS PROC MIXED; SAS Institute Inc. 2004) in which the mean number of ravens counted at each site per day over each 3-day visit was the response variable; stratum, season, year, Marine presence or absence, whether the site was on or off base, and season × stratum were fixed effects; and site nested within season × stratum was a random effect. When effects were significant at $\alpha=0.05$, a Tukey test was used to determine which means differed from one another.

Roosting Behavior

We monitored a nocturnal roost site located about 1 km southeast of Camp Wilson. Ravens at this site roost on a single-strand electrical distribution wire about 7 m above the ground. We observed raven activity at the roost from approximately 30 minutes before sunset to 60 minutes after sunset (or until roost became quiet and all birds seemed to have selected a position to roost for the night) on the first and third evening of each visit to determine the timing and direction of raven arrival and to estimate roost attendance. In addition, we observed the roost from approximately 60 minutes before sunrise to 15 minutes after sunrise (or until all birds had departed from the roost) on one morning per visit to record the timing and direction of raven departure from the roost. During both morning and evening visits to the roost, ravens were observed from a point approximately 200 m from the power lines. Pentax 10 × 43 binoculars were used while light levels were sufficient, and ITT Night Vision binoculars (G3 Night Enforcer F5000 Series) were used to aid counts in lower light levels. The number of roosting ravens was counted at 5-minute intervals and the general direction from which birds arrived was noted (qualitatively). When raven numbers became too high to count, we counted ravens on one section of power line and multiplied by the number of sections occupied. We also recorded light levels using an Extech Instruments (Model 401036) data-logging light meter that measured light levels in Lux (± 2%) at 10-second intervals. Data were later downloaded to a computer for analysis.

We used ANOVA to determine whether season, year, the presence or absence of training Marines, or any 2^{nd} order interaction term affected the number of roosting ravens. When the ANOVA model detected significant differences, a Tukey test was used to determine which means were different from one another. For each 5-minute count of roosting ravens on a given night, the cumulative proportion of the eventual total for that night was calculated. This proportion was arcsine-square root transformed to improve normality (Zar 1999) and used as the response variable in a mixed linear model (SAS PROC MIXED) to determine whether light levels (log transformed), clock time, or time-relative-to-sunset was the driving factor affecting raven arrival at the roost. The model was run separately for each of the 3 explanatory variables of interest (light, clock time, time-relative-to-sunset). In addition, a global model was run in which all 3 of the variables were included and a null model was run in which none of the 3 explanatory variables was included. Because the roosting data vs. time-relative-to-sunset curve had an S-shape (Fig. 3), second and third order polynomial terms were inserted into the mixed model for this variable. These higher order terms allowed for a better approximation of the non-linear response. For each variable, the model also included season, interaction term between season and the explanatory variable of interest, and presence or absence of Marines. In addition, site nested within stratum × season was included as a random factor. Corrected Akaike's Information Criteria values (AIC_c) were generated for each model (SAS PROC MIXED) and the ΔAIC_c was calculated as the difference between the lowest AIC_c value and a given model's AIC_c. These values were converted to AIC_c weights having a value between 0 and 1 for each model. The weight for each model represents an estimate of the relative likelihood of that model providing the best predictive fit to the data (Burnham and Anderson 1998).

Nest Searching

Nest searching was conducted in 2003 from May 12-15 in the following TAs: Acorn, Range, Gypsum Ridge, Emerson Lake, Maumee Mine, Gays Pass, Quackenbush, Lavic Lake, Black Top, and Lead Mountain. In addition, land adjacent to the base south of Sand Hill and West TAs, west of Maumee Mine TA, and north of America Mine TA was searched. In 2004, searches for raven nests took place from 26-29 April 2004 in Black Top, Bullion, Delta, Emerson Lake, Lava, Lavic Lake, Lead Mountain, Maumee Mine, Noble Pass, and Prospect; and on 11 May in American Mine, Cleghorn Pass, Gypsum Ridge, and Rainbow Canyon. In addition, land adjacent to the base near the towns of Landers, Ludlow, and Pisgah was searched, as was the line of power towers running along the northwest corner of the base (along the border of Sunshine Peak TA). An effort was made in 2004 to cover areas not searched in 2003, both on and off base.

Nest surveys were conducted with two observers by driving through the areas of interest and making frequent stops to scan suitable substrate such as Joshua trees (*Yucca brevifolia*), rock cliffs, power poles, water towers, and observation towers. A Kowa 85 mm spotting scope (20-60 power zoom) was used to scan distant substrate, while 10-power binoculars were used to examine nesting habitat that was within approximately 200 m of observers. The locations of all large stick nests were recorded, as well as the presence of ravens or other bird species at the nests, the number of juveniles observed, and the type of substrate. If ravens or other raptor species were not seen at the nests, they were recorded as belonging to an "unknown species." All nest locations were mapped using ArcGIS. In addition to the nests found during searches, we mapped raven and other raptor nests known from previous searches that took place in the region between 1993-1996 (Boarman unpubl. data).

BASH Risk

We obtained data on the frequency of civilian and military airplane collisions with ravens and crows to help assess the relative likelihood of future collisions. Civilian Bird Air Strike Hazard (BASH) data collected by the Animal and Plant Health Inspection Service (APHIS) covered the period from May 1990-October 2003, while the military data collected by the US Air Force covered the period from January 1985-January 2004.

On 10 February 2004, observations were made in the evening south of the Expeditionary Airfield at MCAGCC to determine the extent of raven traffic near the landing strip as they approached the roost location. Special attention was paid to ravens flying above the approach and take-off zones at either end of the landing strip. The number of ravens was recorded as well as the size of raven groups and the approximate height at which they were flying. During other nights of roost observation, qualitative observations were recorded of ravens flying in the vicinity of the airfield.

West Nile Virus

Because West Nile Virus (WNV) has been confirmed in southern California, we looked for diseased or dead ravens while conducting surveys, with the intention of collecting any such individuals to be tested for WNV. In addition, we looked for decreases in the numbers of ravens (roosting or counted during point count surveys) that could not be explained by seasonal changes or changes in the amounts of human subsidies.

Additional Efforts

On one evening during most visits to MCAGCC, searches were conducted for roosting or staging behavior of ravens in other areas. Evening searches also provided opportunities to follow up on observations of groups of ravens that were occasionally reported to NREA personnel in the vicinity of the base. In addition, while traveling on the base, we recorded incidental observations of ravens using anthropogenic subsidies.

Results

Habitat Use

Point count surveys were conducted on base during 23 3-day visits between January 2003-December 2004 (Table 3) and off-base during 13 3-day visits from December 2003-December 2004 (Table 4; Fig. 4). Point count results (number of birds observed per 5-minute count) averaged by season and strata are shown in Table 5 (On base) and Table 6 (Off base). Significantly more ravens were counted at attraction sites than at cantonment sites and at cantonment sites than at desert sites (Fig. 4). No significant differences in point counts were detected among the seasons or between sites on and off base, and there was no significant stratum × season interaction (Table 7). In addition, based only on the on-base counts, we did not find differences in counts when Marines were present or absent (df = 1,340; $F = 0.39$; $P = 0.5309$).

Roosting Behavior

Attendance at the nocturnal roost ranged from 23-2100 ravens in 47 nights of observations over 24 visits to MCAGCC between December 2002-December 2004 (Fig. 5). Significant Differences in the number of roosting ravens were found among seasons, between periods of Marines training and non-training, and between years (Table 8; Fig. 6). Fall and winter had more roosting ravens than spring and summer; counts in 2003 were greater than in 2004; and, more ravens were present at the roost during periods of Marine training than during periods when training did not take place. Qualitative observations on roosting behavior were also recorded at the roost. Loose raven flocks arrived and began staging in the general area of the roost starting 30-60 minutes before sunset and ending about 10 minutes after sunset. Staging areas were located on the ground under the power lines, in Deadman Lake dry lake bed about 0.5 km southeast from the center of the roost, as well as in the Sand Hill TA approximately 6-8 km to the southwest of the roost. Ravens generally staged on the ground until about 10-15 minutes past sunset, then began settling on the power lines for the night (roosting) in increasing numbers from that point until about 30-35 minutes past sunset, when the numbers began to level off. The majority of birds arrived at the roost or the staging areas on the ground near the roost from the west and southwest (Landers and Yucca Valley), while many also arrived from the south and southeast (Mainside and Twentynine Palms). These patterns were observed in reverse during morning visits. Ravens began vocalizing at about 60 minutes before dawn. At 35-50 minutes before dawn, they would begin flying from the roost and gathering on the ground beside the power lines in a staging display similar to the evening behavior. The majority of birds had departed by 20 minutes before dawn, with the staging area also clearing at this time as ravens flew to the west (in the general direction of Landers) and to the south (in the general direction of Mainside and Twentynine Palms). By sunrise, all ravens had usually departed from both the roost and the staging area.

The proportion of roosting ravens in the evening was significantly related to each of the three explanatory variables (clock time, time relative to sunset, and the level of ambient light) that we tested using the mixed model analysis (Table 9). A comparison of AIC_c values among the models suggested that time relative to sunset ($\Delta AIC_c = 0$) was a better predictor of raven roosting than light level ($\Delta AIC_c = 52.9$) and clock time ($\Delta AIC_c = 232.9$). When these values were converted to AIC_c weights, the time relative to sunset model had a relative likelihood of 100%, while the other two variables had likelihoods of 0%. A visual analysis of the data used in the mixed model (Fig. 3) also suggests that time relative to sunset is the variable that best predicts raven arrival at the roost as the vertical spread among the data points is less severe than for clock time or light level. The global model with all 3 of the variables had a slightly improved ΔAIC_c value over the models containing any single variable ($\Delta AIC_c = -7.6$), while the null model had the highest ΔAIC_c value (568.6) indicating that it had the lowest predictive value.

Nest Searching

Twenty-four nests were found in 2003 and 15 were found in 2004, for a total of 39 (Fig. 7). Of these, 23 were confirmed raven nests, 15 were unknown species, and one was a prairie falcon (*Falco mexicanus*) nest. Broken down by substrate, 21 nests were found on cliffs, 8 on power poles, 4 in Joshua trees, and 6 in other anthropogenic structures (small water towers, military observation towers, or remote maintenance buildings). In addition, there were 20 nests in the vicinity of MCAGCC that were found during past research efforts conducted from 1993-1996. Of these, six were confirmed raven nests (all on power poles), while the rest were of unknown origin (all but one on power poles).

BASH Risks

Both the military and civilian databases on BASH incidents showed that raven-related accidents do occur, although they are not common. The database maintained by the United States Air Force reports 8 BASH incidents involving ravens from 1985-2004 for a total of $135,000 in damages. Most incidents in the database did not result in damages, while one incident caused nearly $120,000 in damages The APHIS Civilian Air Strikes database shows 16 raven-related incidents from 1990-2003 with only minor damages reported (less than $30,000 total). By comparison, incidents involving crows occurred much more frequently, with approximately 100 military ($460,000 in damages) and 350 civilian ($1.25 million in damages) incidents reported.

On the evening of 10 February 2004, we observed approximately 125 ravens fly over the airfield en route to the roost. The birds flew at a height of 20m or less, possibly presenting a hazard for jets landing or taking off. On other evenings of roost observation, numerous ravens were observed approaching the roost from the direction of the airfield, presumably having crossed over it or very close to it. Similarly, ravens were seen heading towards the airfield after departing the roost in the morning just before dawn.

West Nile Virus

We found one dead raven during approximately 540 hours conducting point count surveys at MCAGCC and in the surrounding communities, as well as 47 nights and 17 mornings observing ravens at the roost. The deceased bird was turned in to NREA for WNV testing. At this time, test results are not available, although the cause of death was not believed to be WNV.

We did observe fewer roosting ravens in the fall and winter 2004 than the same period in 2003 (Fig. 5). For example, in November 2003, approximately 1900 ravens attended the roost, while only 1000 were counted in November 2004. However, our relative abundance estimates based on point counts did not decrease significantly from 2003 to 2004, and we have no data to suggest that there was a change in raven populations.

Additional Efforts

Searches for additional roosting sites turned up one site where raven were found roosting, but it apparently was not used on a regular basis. The site was about 1 km to the west of Landers landfill, outside the MCAGCC border, and it consisted of an abandoned house and surrounding power lines, telephone lines, and Joshua trees. We discovered approximately 150 ravens roosting at the site on 11 September 2004, but did not find ravens present on subsequent visits.

No additional roosting sites were found on the Base. Searches focused on power lines in Sand Hill and Acorn TAs. Groups of approximately 25-30 ravens were seen in 2 areas, though they appeared to be gradually dispersing, with individuals leaving the group and flying in the direction of the Camp Wilson roost. In addition, searches were conducted in the vicinity of the Base's landfill, along Highway 62 from Twentynine Palms west to Copper Mountain College, in the mountains to the northeast of the cantonment in Mainside (in East TA), along power lines following Amboy Road to the east of Twentynine Palms, within the town of Twentynine Palms. Four ravens were seen at Luckie Park, but the search was otherwise unsuccessful. On 1 July 2003, the Sand Hill "Special Use" area was searched but no ravens were seen. Luckie Park was again checked, but no ravens were seen.

Supplemental visits were made to the MCAGCC landfill (in addition to regular point counts) on 15 mornings to see if ravens forage there before operations begin. On 8 of those mornings, no ravens were seen, while an average of 12 ravens was seen on the remaining 7 days. Similarly, extra visits to the garbage facility at Camp Wilson were conducted on 12 mornings. Ravens were seen there on 11 of those visits, with an average of about 11 ravens each morning.

Incidental observations did not locate any additional areas where ravens were concentrated around anthropogenic subsidies. Single, paired, and small groups of ravens were seen regularly in the city of Twentynine Palms and Mainside, but they were not observed in groups at anthropogenic resource sites.

Discussion

Raven Abundance and Use of Subsidies

Results of point counts indicate that ravens are present in higher numbers at attraction sites than at desert and cantonment sites. This was consistent with other studies on raven use of habitat altered by humans (Boarman et al. 1995, Boarman et al. In prep.). The difference was driven by relatively large numbers of ravens at a few of the attractions (i.e., MCAGCC Landfill and Camp Wilson garbage facility). Overall, counts were lower than expected at many of the attraction sites, with few birds seen at the Mainside recycling center, dumpsters behind the Non-Commissioned Officer's club, and irrigation ponds near the golf course. Ravens were also more abundant at cantonment sites than at desert sites, suggesting that the cantonment is a general attraction to ravens, even in locations lacking specific subsidies. This may reflect the fact that human provided food and water are spread throughout the cantonment areas. For example, water is widely available throughout the cantonment where people water their lawns or wash their vehicles (either personal or military). Food is also available throughout the cantonment at the many dumpsters and fast food restaurants, as well as around refuse containers and pet food bowls left out in the residential areas.

Roosting Behavior

In each year of our study, we observed that roosting raven numbers were greatest in the fall and winter, and then decreased significantly in the spring and stayed very low through the summer (Figs. 5 and 6). Other studies have also found more corvids attending communal roosts in the fall and winter months than in spring and summer (Stiehl 1981, Caccamise et al. 1997), and have observed the same precipitous decrease from winter to spring that we observed at MCAGCC. In the spring, ravens may disperse from the vicinity of roosts to find nesting territories, leaving only non-nesting sub-adults to continue attending the roost until the end of the breeding season. Alternatively, many ravens of all age classes may take advantage of mild spring conditions to explore their surroundings in search of usable habitat for foraging, nesting, and roosting. Or, perhaps, the decrease in ravens at the end of winter may be due to a die-off of first- and second-year ravens, and that the numbers at the roost only began to increase again with the maturation and dispersal of hatch-year birds in the fall. We could not, however, explain the decrease in roosting ravens between 2003 and 2004. There was no difference between years in point count data (Table 7), suggesting that raven populations were relatively stable.

The arrival of ravens at the roost in the evening was significantly related to time relative to sunset, clock time, and light levels. The model that included all three of these variables had the lowest AIC_c value of those tested, suggesting that each variable contributes independently to the predictive ability to the model. Of the three variables, time relative to sunset generated the lowest AIC_c value in the mixed model analysis, suggesting that it is the best single variable predictive of roosting. In terms of the behavior observed, this result manifested itself by the fact that ravens predictably landed on the roost during the period from 10-35 minutes after sunset. During this period, a rapid reduction in activity and vocalization at the roost was observed. In the morning, ravens predictably started vocalizing about one hour before sunrise and often departed from the roost while light levels were still unchanged by the pre-dawn glow of the sun. Although data collected in the morning was not included in the mixed model analysis, it supported the idea that roosting is driven more by timing than by light levels.

Staging behavior prior to roosting closely resembled that described by Engel et al. (1992) in southwestern Idaho. We observed ravens staging beneath power lines, in Dead Man Lake dry lake bed, and in desert areas 6-8 km away from the roost. In each case, ravens chose sparsely vegetated areas, possibly as a way of advertising their presence to other ravens (Stiehl 1981). After sunset, they would depart from staging areas and head towards the roost in pairs, small groups, or occasionally large groups of 100 or more birds. At this time, they were very vocal and gregarious, often chasing each other around or performing aerial displays consisting of steep, sometimes tumbling dives and barrel rolls. These behaviors suggest that communal roosting and staging—in addition to providing the previously mentioned benefits of predator avoidance and food finding—is an opportunity for the ravens to engage in social behaviors such as pair-bonding and perhaps displays that mock territorial defense.

Ravens and other corvids have been shown to have a high level of roost fidelity over time, with frequent observations reported in the literature of roosts being occupied for many years (Cushing 1941, Madson 1976, Stiehl 1981). Although we do not know how long the roost at MCAGCC has been occupied, the presence of a 15-20-cm high mound of decayed pellets beneath the power lines suggests that it also has a long history of use. We also do not know why the ravens chose this spot for roosting. Other research has suggested that roosts provide thermal or wind protection (Walsberg 1986, Watts et al. 1991). The roost site at MCAGCC may be somewhat protected from wind, lying in a low spot near Deadman Dry Lake with a high ridgeline running approximately 3-4 km east of the roost. In addition, it is located near Camp Wilson, where many ravens find forage and water, and a short flight from both the MCAGCC landfill and the Landers Regional Landfill.

Effect of Marine Training on Ravens

The presence or absence of Marines conducting desert training exercises at MCAGCC affects the amount of available food subsidies, and therefore it has the potential to affect the number of ravens present. We found that more ravens roosted on base during periods when training took place, but that training schedules did not affect the number of ravens counted during point count surveys. This pattern may suggest that the ravens that reacted to the presence of Marines by spending more time on the Base during training (and consequently more nights at the roost) did not necessarily spend more time foraging at the cantonment, the desert, and the subsidy sites. Instead, they may have foraged around locations where Marines were conducting training (which did not coincide with survey locations). It could also be true that since the roost presumably drew birds from a variety of attraction sites, that a small increase in ravens across a variety of sites led to a large cumulative increase at the roost.

Nest Searches

The density of raven nests on and around the base is apparently low based on our finding only 39 nests (23 confirmed raven nests) in a total of 8 days of searching (Fig. 7) during the 2003 and 2004 breeding seasons. This was an unexpectedly small number of nests considering that so many ravens (up to 2100) roost on the base in the winter, although our nest searching was not comprehensive. There may be pockets of habitat with high nest density, such as around the Landers landfill, which we did not cover during our searches. Or, as mentioned above, roosting ravens may largely be first- and second-year birds that either disperse to areas outside the range of our surveys or do not survive through the winter.

Roost Searches

The single example of roosting behavior that we observed at a site other than at Camp Wilson (west of Landers landfill) suggests that ravens may alternate among roost sites, a behavior that other studies on raven roosting have found (Engel and Young 1992, Cotterman and Heinrich 1993). The secondary roost observed late in the summer was a fairly small and ephemeral gathering, as raven roosts often are (Cotterman and Heinrich 1993). These birds may have eventually joined with similar groups of first- and second-year birds at the established Camp Wilson roost site.

Management Implications

Observations of raven behavior during this study suggest that human garbage is an important and controllable resource used by ravens. We observed three ways in which ravens have access to garbage. First, ravens commonly feed on refuse at the landfill. Although garbage is covered with dirt at the end of each day, ravens still apparently find ample forage. A thicker layer of dirt cover may help with this problem. We also recommend investigating the use and effectiveness of a tarp to temporarily cover the garbage. Second, open dumpsters—such as those found at the Camp Wilson garbage facility and throughout Mainside—provide a food bounty to ravens. We recommend implementing a policy requiring that dumpsters be self-closing to reduce raven access to this subsidy. The third source of garbage for ravens is litter. On several occasions, we observed ravens feeding on discarded packages of Meals Ready to Eat (MREs) dropped by Marines along main and secondary supply routes. An increase in the current clean up and education efforts may help reduce this diffuse but potentially significant food source for ravens.

Each of the first two management suggestions listed above addresses the problem of ravens gathering and successfully foraging at artificial food bounties, and as such, may be effective at directly reducing spillover predation by ravens on desert tortoises. By definition, spillover predation occurs when predators take advantage of anthropogenic resources to then move into adjacent areas where they find rare prey. Predation risk by ravens on tortoises has been shown to be high in the vicinity of landfills and other sources of garbage (Kristan and Boarman 2003). Following these suggestions should also reduce the regional raven population, and, therefore indirectly address the problem of hyperpredation by ravens on tortoises. The third suggestion above, to reduce the level of diffuse food resources that humans provide ravens, will have more of a direct effect on reducing hyperpredation, the situation in which a predator population level is inflated because of anthropogenic resources, and therefore its predation on rare prey is increased on a regional level.

Despite observations of ravens feeding on human refuse on the Base, the number of ravens observed during point counts was small compared to the masses attending the night roost. This suggests that anthropogenic resources at MCAGCC are not solely responsible for the large numbers of ravens at the roost. Also, the arrival of ravens to the roost from several directions indicates that raven abundance is a regional issue, likely caused by subsidies that are present in nearby towns as well as on the Base. Management efforts to reduce raven populations, therefore, will need to be employed regionally, guided by observations from studies such as this one. An effective approach may be for resource managers at MCAGCC to coordinate with adjacent municipalities and other land management agencies to develop and implement a plan to reduce raven populations. This plan should include improved control of resources as well as outreach to local businesses (e.g. restaurants and grocery stores) and to the public to increase awareness of the raven problem and to stress the need to keep garbage in secure containers. In addition, MCAGCC should continue to cooperate with the broad raven management program being developed by the Desert Managers Group.

An additional management concern is the proximity of the Camp Wilson roost to the Expeditionary Airfield (EAF), located in Sand Hill and West TAs. This proximity creates a potential BASH problem. BASH incidents involving ravens are relatively rare, but the result of such an incident could be catastrophic. For this reason, we feel that pilots should be aware that raven traffic may be high near the airfield in the fall and winter from 15 minutes before to 45 minutes after sunset, and from 45 minutes before sunrise until sunrise. One mitigating factor that may decrease the risk of collisions between Marine jets and ravens at MCAGCC is that the ravens fly fairly close to the ground (approx. 5-20 m) when approaching the roost in the evening or departing from the roost in the morning.

West Nile Virus

We saw no demonstrable effects from WNV on ravens. Although we observed a decrease in the number of roosting ravens in the fall in winter from the first to the second year of our study, we did not find large numbers of sick or dead birds or any other indication that the decrease was due to disease. There have been two confirmed cases of WNV in ravens in the Mojave (K. Padgett, California Department of Health Services, personal communication); however, we feel that the likelihood is low for WNV to become a significant problem for ravens in the MCAGCC area because mosquitoes, the WNV vector, appear to be quite rare.

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Table 1. Locations and descriptions of 18 point count stations used for Common Raven surveys conducted at MCAGCC from January 2003-December 2004. These points are shown in Figures 1a and 1b.

Site	Stratum	Easting[a]	Northing	Elevation (m)	Site Description
A1	Attraction	586826	3792885	557	Landfill
A2	Attraction	585989	3788404	529	Mainside sewage ponds
A3	Attraction	587735	3785777	557	Mainside recycling center
A4	Attraction	577712	3795130	452	Camp Wilson garbage facility
A5	Attraction	584575	3789998	541	Irrigation ponds near golf course
A6	Attraction	586675	3788588	555	Dumpsters behind NCO Club
C1	Cantonment	586281	3789636	567	Tenth and Griffin
C2	Cantonment	585898	3789026	544	Ninth and Bourke
C3	Cantonment	584018	3799651	524	Ludwig St. in Ocotillo Heights (residential)
C4	Cantonment	584412	3787690	486	First St. between Brown and Sturgis
C5	Cantonment	586963	3788649	526	Fourth and Sturgis
C6	Cantonment	588178	3786410	698	Gatehill and Jasmine (residential)
D1	Desert	569692	3790998	826	Sandhill TA
D2	Desert	565034	3798328	733	Acorn TA
D3	Desert	569100	3700462	685	Acorn TA
D4	Desert	571073	3701849	672	Gypsum Ridge TA
D5	Desert	564529	3793461	798	Sandhill TA
D6	Desert	590142	3791353	610	East TA

[a] Coordinates given in UTMs (Datum = WGS84).

Table 2. Locations and descriptions of 18 off-base point count stations used for Common Raven surveys conducted in the Yucca Valley and Joshua Tree area from December 2003-December 2004. These points are shown in Figure 3.

Site	Stratum	Easting	Northing	Elevation (m)	Description
AO1	Attraction	553891	3775995	989	Food-4-Less Plaza
AO2	Attraction	553661	3776294	989	Sewage pond
AO3	Attraction	553192	3774763	1039	Yucca Valley High School
AO4	Attraction	558077	3789236	973	Landers landfill
AO5	Attraction	554806	3776356	976	Walmart Plaza
AO6	Attraction	566794	3777043	810	High-Desert Medical Center
CO3	City/Town	556294	3776896	982	Prescott Street and Palisade Drive
CO6	City/Town	552762	3774183	1043	Zuni Trail and Amador Trail (Residential)
CO1	City/Town	551401	3775499	1003	Bannock Trail and Santa Fe Trail
CO2	City/Town	552843	3775712	993	Grand Ave. and Highway 62
CO4	City/Town	551646	3776069	1008	Buena Vista Trail and Mohawk Trail
CO5	City/Town	554849	3775154	1015	Warren Vista and Pueblo Trail (Residential)
DO1	Desert	555443	3790183	970	Balsa St. and Napa St.
DO2	Desert	551052	3779875	1216	Skyline Ranch Road
DO3	Desert	571023	3780248	735	Coyote Dry Lake
DO4	Desert	550530	3783215	1106	Pipes Canyon Road
DO5	Desert	559329	3771381	1240	Covington Flats (BLM land)
DO6	Desert	569838	3771426	1062	Quail Springs Rd. near JTNP border

[a] Coordinates given in UTMs (Datum = WGS84).

Table 3. Mean, standard error, and sample size of raven point counts by stratum and site visit during each of 24 monthly visits to MCAGCC.

	Attraction Sites			Cantonment Sites			Desert Sites			Overall		
Visit number and dates	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
1 (9-11 Dec. 2002)[a]	-	-	-	-	-	-	-	-	-	-	-	-
2 (20-22 Jan. 2003)	5.17	2.86	6	0.56	0.33	6	0.11	0.11	6	1.94	1.06	18
3 (17-19 Feb. 2003)	1.17	0.71	6	0.67	0.43	6	0.06	0.06	6	0.63	0.28	18
4 (10-12 Mar. 2003)	1.28	0.43	6	1.11	0.57	6	0.17	0.17	6	0.85	0.26	18
5 (31 Mar.-2 Apr. 2003)	1.39	0.73	6	0.61	0.25	6	0.06	0.06	6	0.69	0.28	18
6 (28-30 Apr. 2003)	0.39	0.13	6	0.28	0.13	6	0.00	0.00	6	0.22	0.07	18
7 (9-11 June 2003)	1.33	0.92	6	0.28	0.13	6	0.00	0.00	6	0.54	0.32	18
8 (30 June-2 July 2003)	6.22	3.90	6	1.06	0.65	6	0.00	0.00	6	2.43	1.40	18
9 (4-6 Aug. 2003)	1.11	0.40	6	0.56	0.39	6	0.00	0.00	6	0.56	0.21	18
10 (26-28 Aug. 2003)	0.89	0.45	6	0.44	0.44	6	0.00	0.00	6	0.44	0.22	18
11 (6-8 Oct. 2003)	0.94	0.30	6	0.06	0.06	6	0.00	0.00	6	0.33	0.14	18
12 (3-5 Nov. 2003)	2.42	1.48	6	0.39	0.28	6	0.00	0.00	6	0.94	0.54	18
13 (8-10 Dec. 2003)	3.44	1.51	6	0.56	0.19	6	0.00	0.00	6	1.33	0.60	18
14 (15-17 Jan. 2004)	1.89	1.02	6	0.61	0.30	6	0.00	0.00	6	0.83	0.38	18
15 (9-11 Feb. 2004)	1.50	0.64	6	0.11	0.11	6	0.08	0.08	6	0.56	0.26	18
16 (23-25 Mar. 2004)	0.22	0.11	6	0.00	0.00	6	0.08	0.08	6	0.10	0.05	18
17 (20-22 Apr. 2004)	0.17	0.11	6	0.06	0.06	6	0.11	0.07	6	0.11	0.05	18
18 (1-3 June 2004)	1.11	0.61	6	0.17	0.17	6	0.00	0.00	6	0.43	0.23	18
19 (28-30 June 2004)	3.39	1.21	6	0.44	0.38	6	0.00	0.00	6	1.28	0.54	18
20 (4-6 Aug. 2004)	2.53	1.35	6	0.69	0.33	6	0.00	0.00	6	1.07	0.51	18
21 (7-9 Sept. 2004)	5.03	3.19	6	0.75	0.75	6	0.00	0.00	6	1.93	1.16	18
22 (18-20 Oct. 2004)	0.50	0.19	6	0.44	0.22	6	0.17	0.11	6	0.37	0.10	18
23 (15-17 Nov. 2004)	2.03	0.74	6	0.39	0.22	6	0.06	0.06	6	0.82	0.32	18
24 (13-15 Dec. 2004)	1.78	0.93	6	0.22	0.11	6	0.00	0.00	6	0.67	0.3	18
Overall	1.92	0.29	138	0.44	0.07	138	0.04	0.01	138	0.80	0.11	414

[a] Data not presented for December 2002 visit because it was conducted prior to the implementation of a standard point count methodology.

Table 4. Mean, standard error, and sample size of off-base raven point counts by stratum and site visit from December 2003-December 2004.

	Attraction Sites			Cantonment Sites			Desert Sites			Overall		
Visit number and dates	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
13 (8-10 Dec. 2003)	3.61	1.55	6	0.28	0.18	6	0.28	0.22	6	1.39	0.62	18
14 (15-17 Jan. 2004)	0.78	0.36	6	0.22	0.07	6	0.00	0.00	6	0.33	0.14	18
15 (13-15 Feb. 2004)	1.61	0.64	6	0.39	0.25	6	0.11	0.11	6	0.70	0.27	18
16 (26-28 Mar. 2004)	2.94	2.55	6	0.06	0.06	6	0.39	0.39	6	1.13	0.87	18
17 (17-19 Apr. 2004)	3.22	2.83	6	0.17	0.11	6	0.17	0.11	6	1.19	0.95	18
18 (4-6 June 2004)	1.69	1.40	6	0.06	0.06	6	0.11	0.11	6	0.62	0.48	18
19 (1-3 July 2004)	1.89	1.33	6	0.00	0.00	6	0.17	0.17	6	0.69	0.47	18
20 (7-9 Aug. 2004)	2.89	2.08	6	0.22	0.14	6	0.00	0.00	6	1.04	0.73	18
21 (10-12 Sept. 2004)	14.78	13.92	6	0.22	0.11	6	0.28	0.28	6	5.09	4.66	18
22 (21-23 Oct. 2004)	4.83	3.21	6	0.33	0.12	6	0.00	0.00	6	1.72	1.14	18
23 (18-20 Nov. 2004)	5.53	3.67	6	0.89	0.53	6	0.11	0.11	6	2.18	1.30	18
24 (16-18 Dec. 2004)	3.28	1.03	6	0.17	0.11	6	0.11	0.11	6	1.19	0.48	18
Overall	3.78	1.18	78	0.26	0.06	78	0.15	0.05	78	1.40	0.41	234

Table 5. The seasonal mean, standard error, and sample size of raven point counts conducted at MCAGCC during 23 visits from January 2003-December 2004.

	Attraction Sites			Cantonment Sites			Desert Sites			Overall		
Season	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Winter	2.20	0.66	30	0.61	0.17	30	0.08	0.04	30	0.96	0.24	90
Spring	0.77	0.23	36	0.23	0.06	36	0.04	0.02	36	0.35	0.08	108
Summer	2.89	0.80	36	0.61	0.18	36	0.00	0.00	36	1.17	0.30	108
Fall	1.85	0.41	36	0.34	0.08	36	0.04	0.02	36	0.74	0.16	108
Overall	1.92	0.29	138	0.44	0.07	138	0.04	0.01	138	0.80	0.11	414

Table 6. The seasonal mean, standard error, and sample size of raven point counts conducted off-base during 13 visits from December 2003-December 2004.

	Attraction Sites			Cantonment Sites			Desert Sites			Overall		
Season	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n
Winter	1.19	0.37	12	0.31	0.13	12	0.06	0.06	12	0.52	0.15	36
Spring	2.62	1.28	18	0.09	0.05	18	0.22	0.13	18	0.98	0.45	54
Summer	6.52	4.65	18	0.15	0.06	18	0.15	0.11	18	2.27	1.58	54
Fall	3.87	1.04	30	0.40	0.13	30	0.15	0.07	30	1.47	0.39	90
Overall	3.78	1.18	78	0.26	0.06	78	0.15	0.05	78	1.40	0.41	234

Table 7. Results of mixed linear model analysis for raven point count surveys conducted monthly at MCAGCC from January 2003-December 2004 and in adjacent communities from December 2003-December 2004.

Source	Numerator DF	Denominator DF	*F*	*P*
Stratum	2	129	33.71	<0.0001
Season	3	129	0.96	0.4125
Year	1	509	0.62	0.4305
Season × Stratum	6	128	0.68	0.6683
Sites on or off base	1	139	0.18	0.6761

Table 8. Results of ANOVA comparing roost attendance among seasons, between periods of Marines training and non-training, and between years; in addition, 2nd order interaction terms are included. The raven roost is located on power lines approximately 1 km southeast of Camp Wilson and was observed for 2 nights per month from December 2002-December 2004.

Source	Numerator DF	Denominator DF	*F*	*P*
Season	3	40	194.26	<0.0001
Training	1	40	4.90	0.0333
Year	2	40	8.51	0.0009
Season × Training	2	40	1.18	0.3175
Training × Year	1	40	14.38	0.0006
Season × Year	1	40	22.64	<0.0001

Table 9. Results of mixed-model analyses comparing effects of time, relative time, and light level on the proportion of ravens at the roost.

	Numerator df	Denominator df	*F*	*P*	AIC_c[a]	ΔAIC_c[b]	Model likelihood[c]
Local time model					-259.8	232.9	**0.0%**
local time	1	356	668.17	< 0.0001			
season	3	41	8.61	0.0002			
local time × season	3	356	5.70	0.0008			
Marine presence or absence	1	40	19.31	< 0.0001			
Relative time model					-492.7	0.0	**100.0%**
relative time	1	348	84.51	< 0.0001			
season	3	41	3.07	0.0384			
relative time × season	3	348	5.50	0.0011			
(relative time)^2	1	348	78.57	< 0.0001			
(relative time)^2 × season	3	348	1.96	0.1194			
(relative time)^3	1	348	40.68	< 0.0001			
(relative time)^3 × season	3	348	2.11	0.0987			
Marine presence or absence	1	40	4.85	0.0335			
Log light level model					-439.8	52.9	**0.0%**
log light	1	356	1147.32	< 0.0001			
season	3	41	3.77	0.0178			
log light × season	3	356	7.31	< 0.0001			
Marine presence or absence	1	40	14.05	0.0006			

[a] Lower Corrected Akaike's Information Criterion (ΔAIC_c) values indicate a better fit of the data to the model.
[b] ΔAICc = difference between lowest AIC_c value and model AIC_c.
[c] Model likelihood is calculated from AICc, using the lowest value as a standard to scale the others against and then adjusting the resultant values so that they produce a sum of 100% (Burnham and Anderson 1998). This value represents the relative likelihood that the variable in question explains the timing of roost attendance.

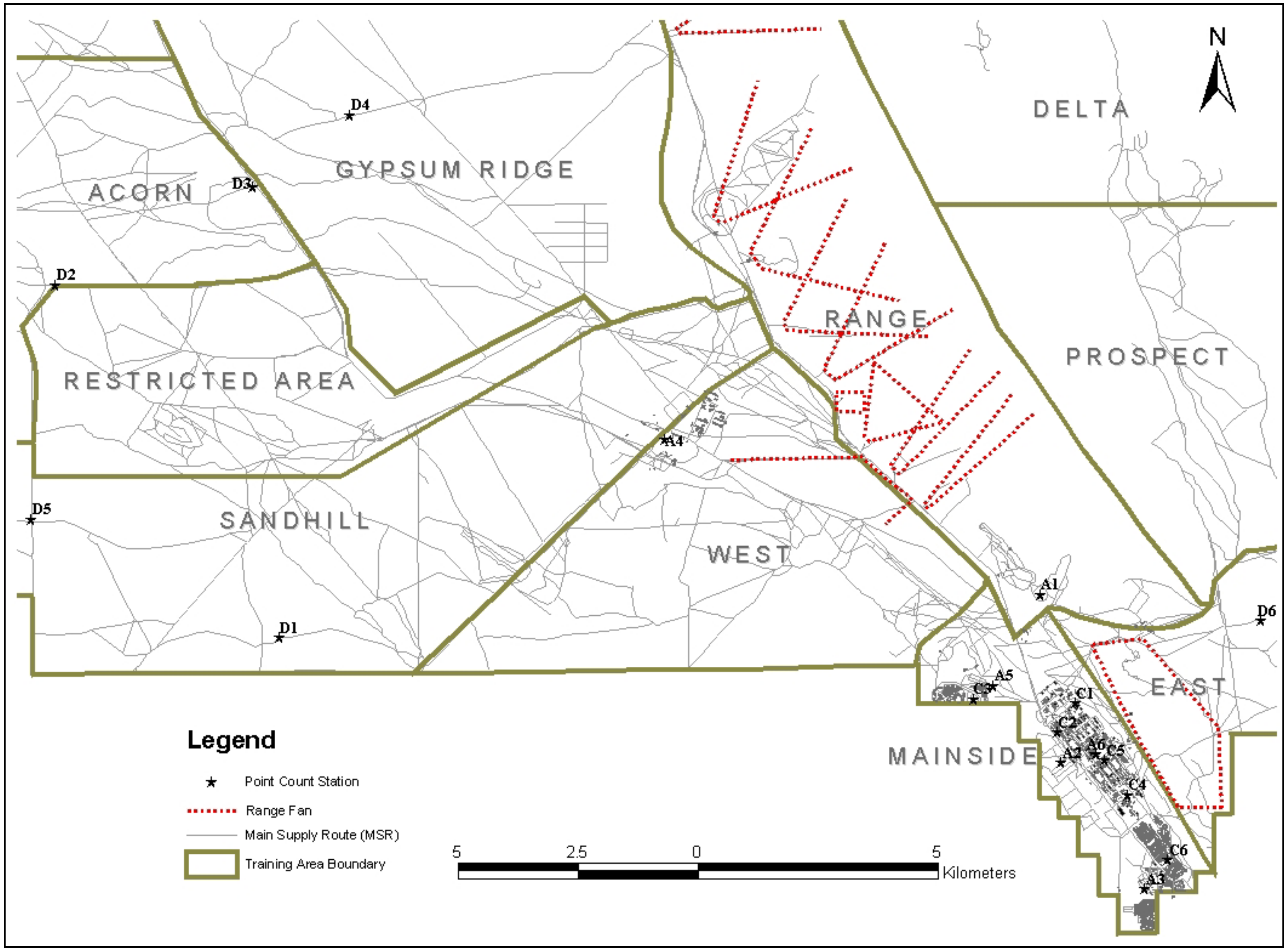

Figure 1a. Map showing locations of point counts used for Common Raven surveys conducted monthly at MCAGCC from January 2003-December 2004.

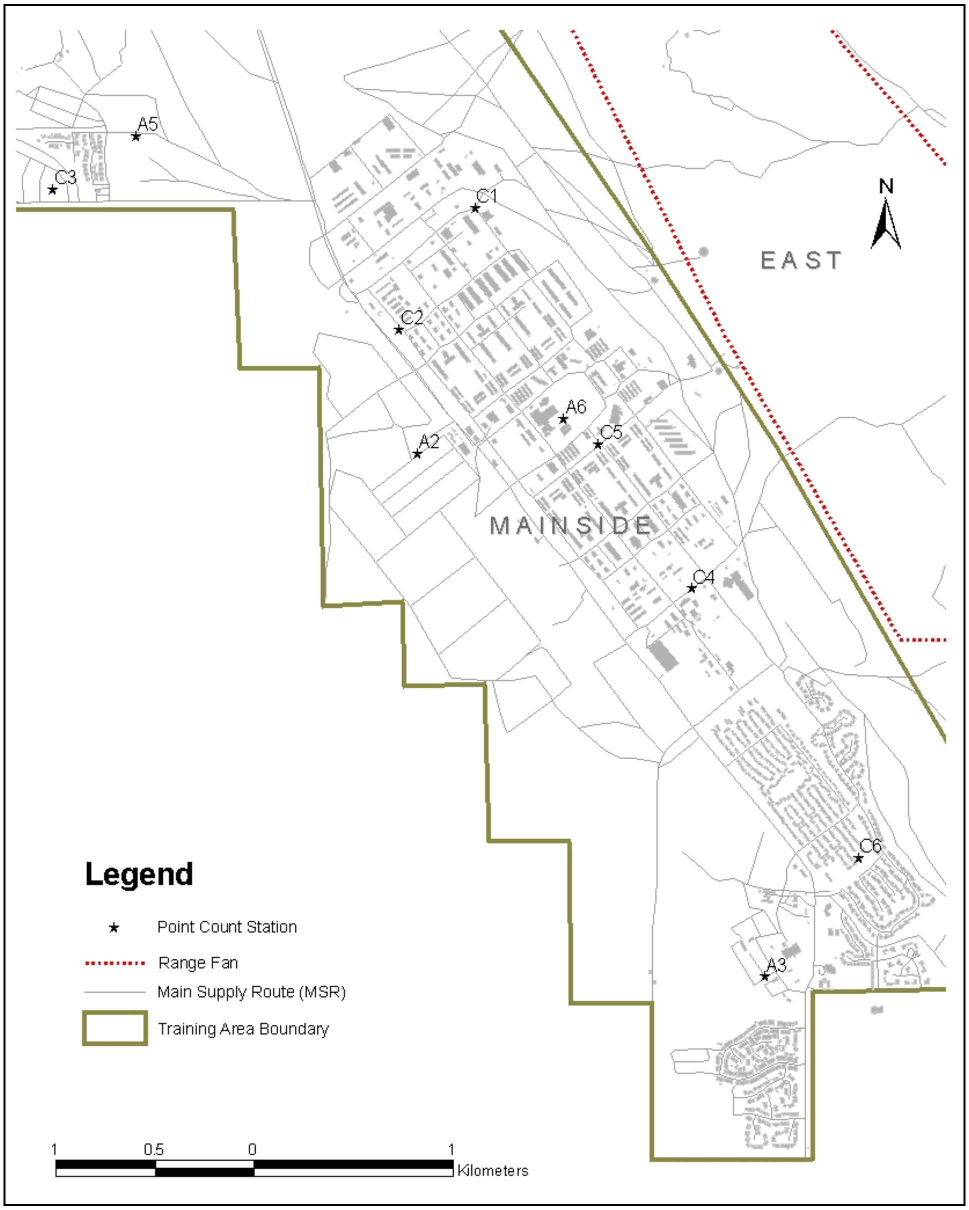

Figure 1b. Map showing detail of Mainside point counts used for Common Raven surveys conducted monthly at MCAGCC from January 2003-December 2004.

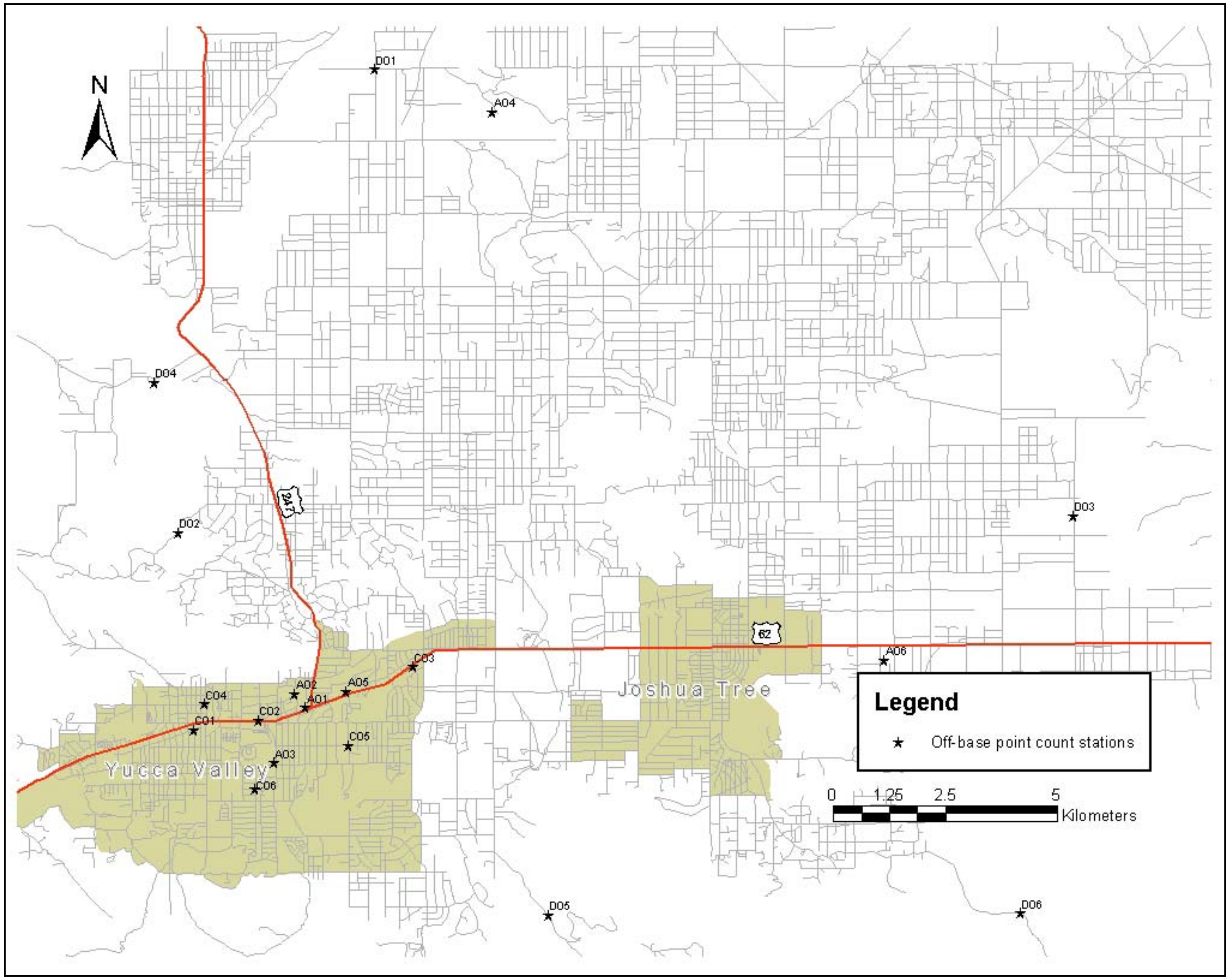

Figure 2. Map showing locations of off-base point counts used for Common Raven surveys conducted from December 2003-December 2004.

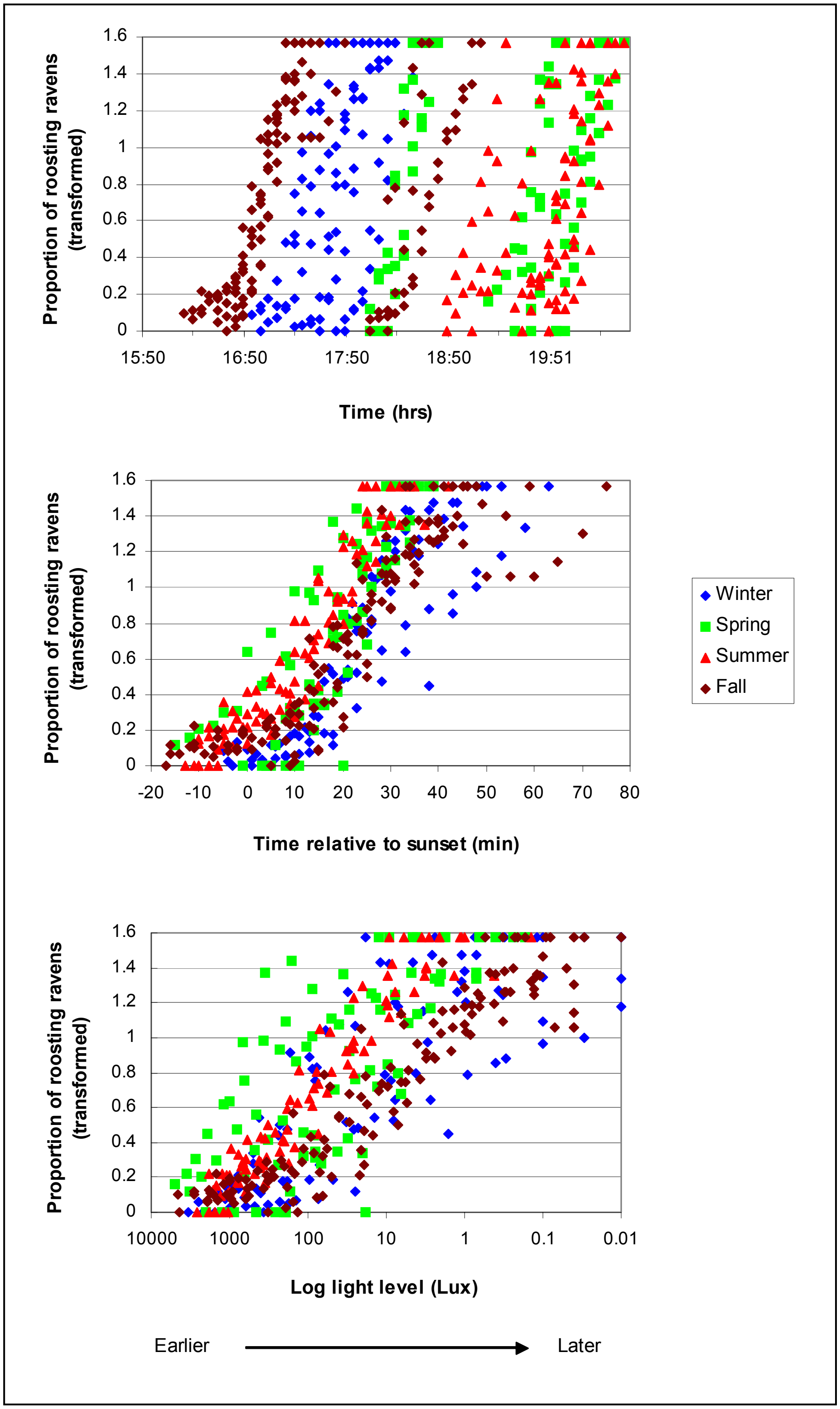

Figure 3. Time, time relative to sunset, and light level vs. the proportion of roosting ravens (arcsin square-root transformed) during each season at the nocturnal roost near Camp Wilson from December 2002-December 2004

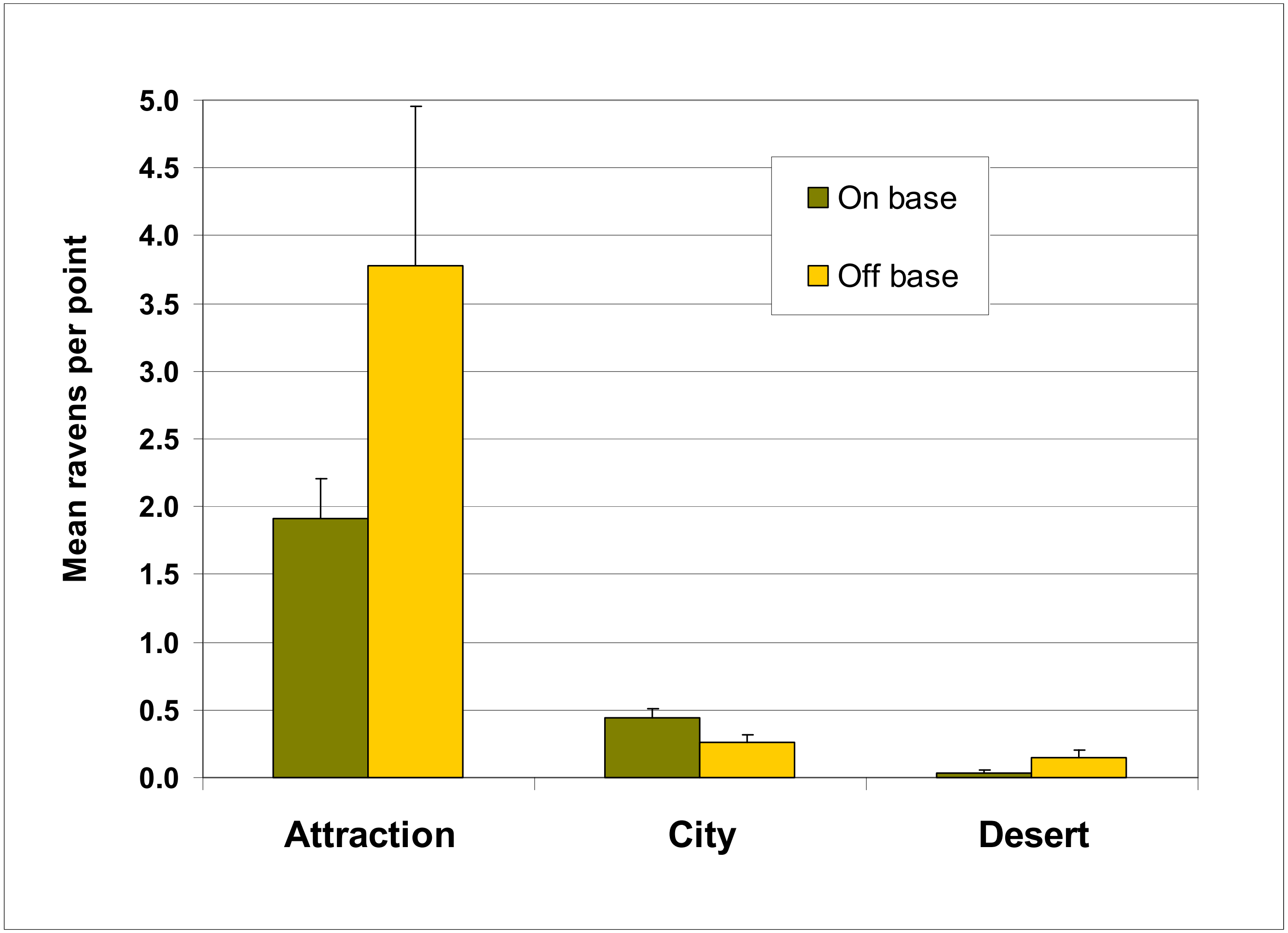

Figure 4. Means and standard error bars for ravens counts on and off of the MCAGCC Base at Attraction sites (n=6), Cantonment (n=6) sites, and Desert sites (n=6). Mean count numbers are based on 23 3-day visits to on-base sites conducted from January 2003-December 2004 and 13 visits to off-base sites conducted from December 2003-December 2004.

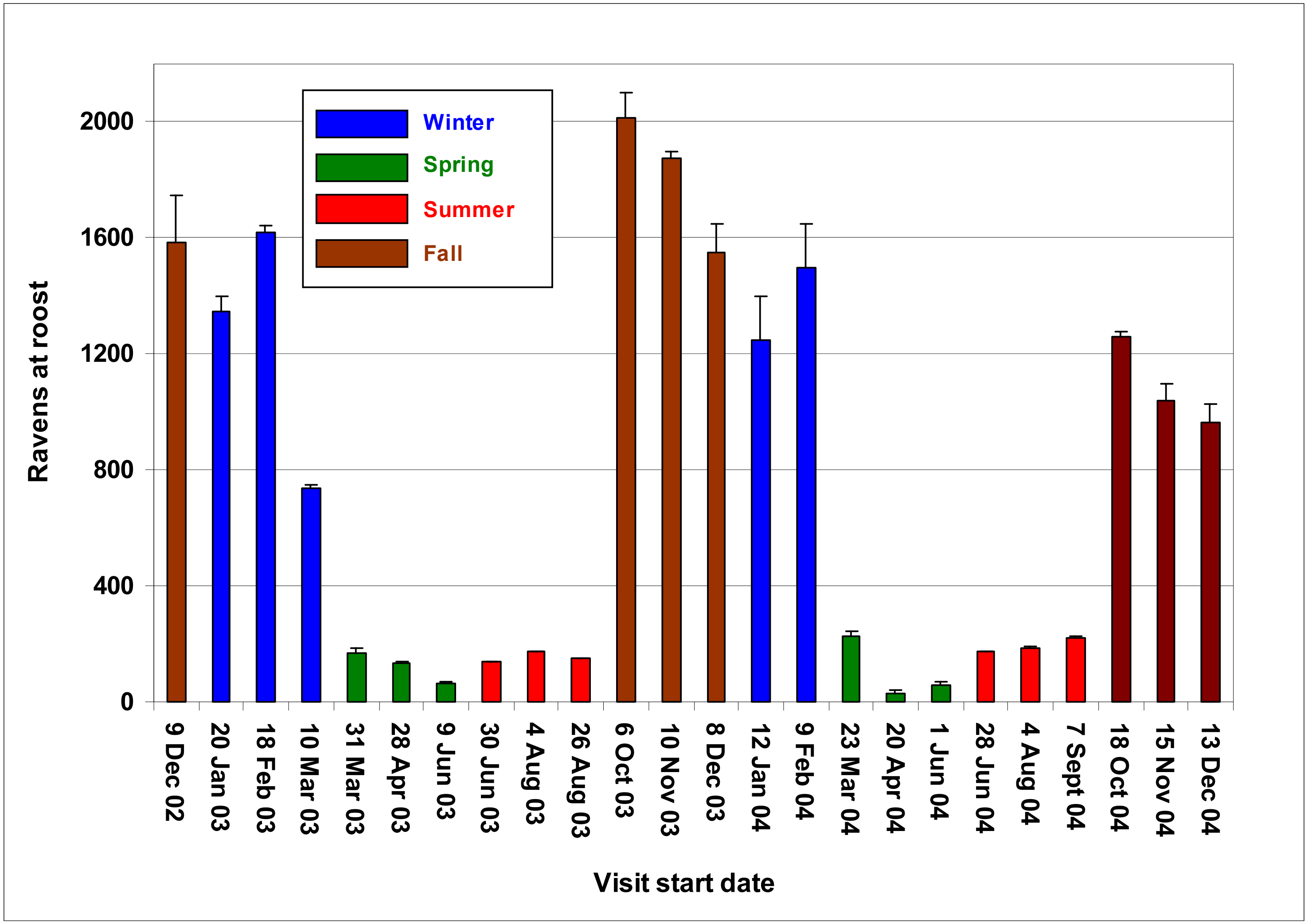

Figure 5. Mean maximum number of Common Ravens attending nocturnal roost near Camp Wilson for each of 24 visits from December 2002-December 2004.

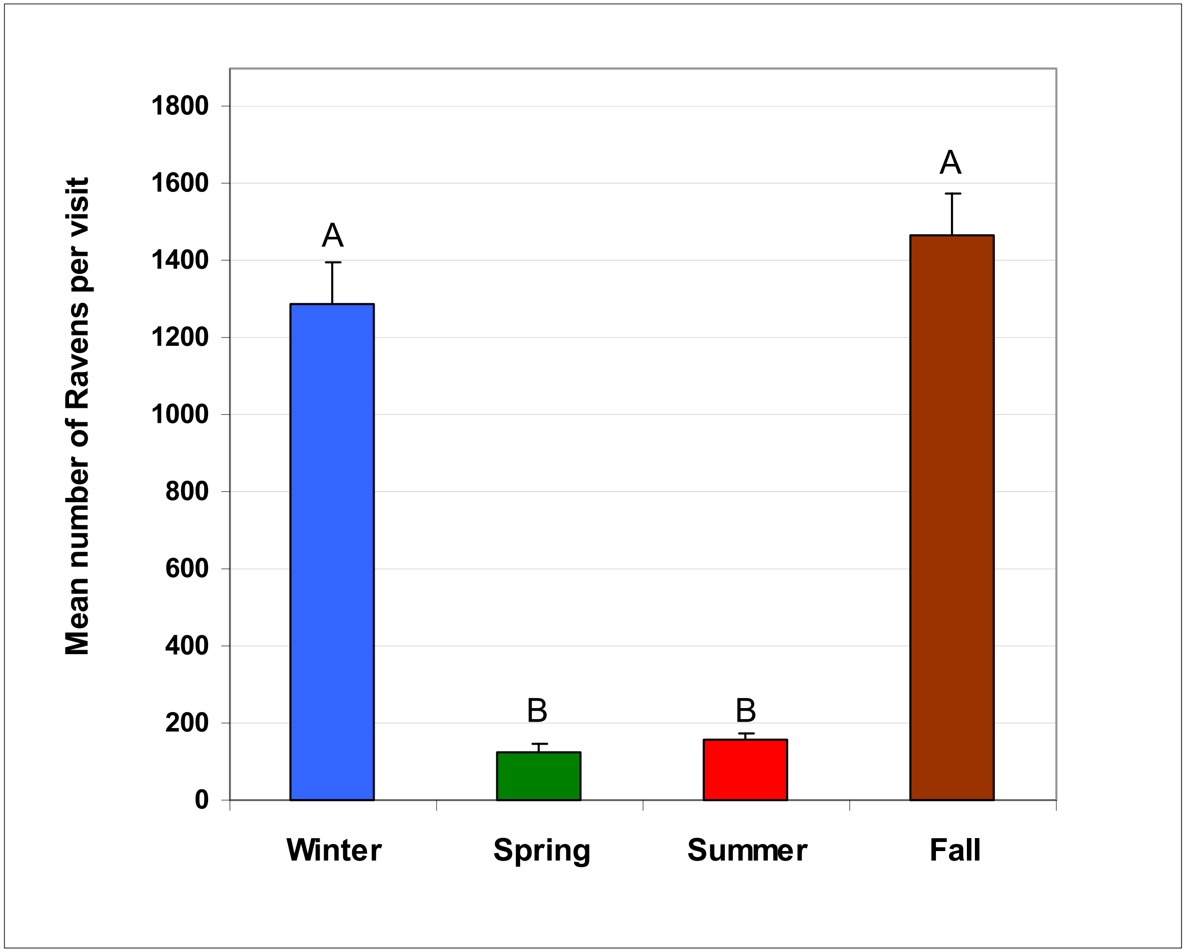

Figure 6. Mean maximum number of Common Ravens attending nocturnal roost near Camp Wilson during each season for 24 visits conducted from December 2002-December 2004. Different letters above colored bars indicate that means were significantly different from one another according to Tukey test.

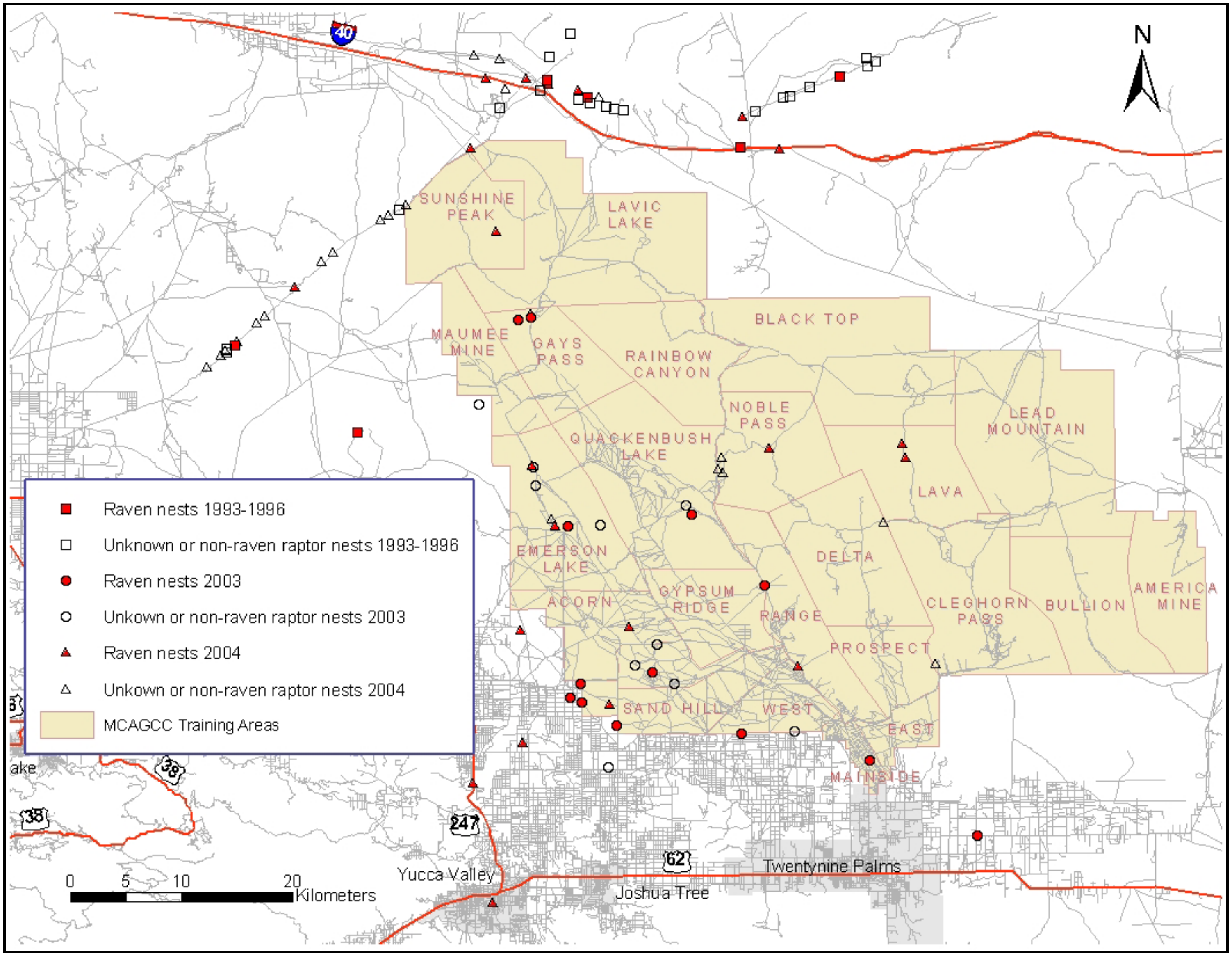

Figure 7. Map showing locations of Common Raven and other raptor nests found on MCAGCC and adjacent lands during nest searches conducted in 2003 and 2004, as well as those known from historic data collected from 1993-1996.