

Association Between Roadways and Cactus Ferruginous Pygmy-owls in Northern Sonora, Mexico

FINAL REPORT

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EXECUTIVE SUMMARY

Between 2002 and 2005, we studied the influence of roadways on the ecology and behavior of cactus ferruginous pygmy-owls (*Glaucidium brasilianum cactorum*) in northern Sonora, Mexico. Our study was motivated by biologists and transportation planners at the Arizona Department of Transportation working in cooperation with the U.S. Fish and Wildlife Service who sought to understand and mitigate adverse effects of roadways on pygmy-owls. Pygmy-owls are currently of profound conservation concern in southern Arizona where their populations have declined to near extinction and where pygmy-owls were listed as endangered between 1997 and 2006.

To identify management strategies to facilitate successful movements of pygmy-owls across roadways, we assessed (1) relationships between flight behavior and environmental conditions along flight corridors, (2) factors that influenced the rate of road crossing by pygmy-owls, (3) vegetation used by pygmy-owls within or adjacent to road corridors, and (4) habitat selected by pygmy-owls within their home ranges. The vast majority of flights by adults and dispersing juveniles were <40 m. Flight distances increased as the height an owl was perched before a flight increased. Pygmy-owls typically flew at heights <2 m above ground that placed them at risk of vehicle collision, although owls that flew longer distances tended to reach higher maximum heights above ground. Flights >80 m were rare; however, owls were capable of crossing larger roadway corridors and other openings in vegetation, such as agricultural fields, in single flights up to 335 m in length. These behaviors, combined with consistent selection of large trees as perches, suggest that maintaining or planting large trees and woodland vegetation along road corridors could reduce the risk of vehicle collision and make roadways more permeable to pygmy-owls.

For pygmy-owls with territories that were adjacent to roadways, the rate at which owls crossed roads decreased as traffic volume and the width of roadway corridors increased. We estimated that traffic volume of approximately 6 vehicles per minute or roadway corridors ≥ 167 m would completely prevent crossing by pygmy-owls that were nesting 200 m from a roadway. Approximately 21 vehicles per minute would prevent crossing by pygmy-owls nesting 100 m from a roadway. Pygmy-owls that crossed roadways tended to use tall trees adjacent to roads and these tall trees were often associated with riparian vegetation along drainage corridors. No adult ($n = 19$) or juvenile ($n = 54$) owls that we radio-marked were struck by vehicles.

Only 24 of the 54 juvenile pygmy-owls (44%) that we radio-marked after fledging survived to initiate natal dispersal; in contrast, none died during the 4 to 6 week period after onset of dispersal. Juveniles dispersed an average of 5.6 ± 0.8 km (\pm SE, range = 1.1-19.2 km) from nests. The number of roads crossed during dispersal increased as total distance moved during dispersal increased, suggesting that the small- to moderate-sized roads typical of northern Sonora did not pose a significant barrier to dispersing pygmy-owls. Only one radio-marked juvenile encountered Mexico Route 15, the largest road in northern Sonora, and crossed after first remaining near the road edge for approximately 24 hours. Movements of several other dispersing pygmy-owls were apparently slowed by the presence of agricultural fields or the trajectory of dispersal changed so as to avoid large fields. Consequently, large vegetation openings such as roadway corridors may present a significant obstacle for dispersing pygmy-owls.

Pygmy-owls sometimes nested within 100 m of roadway corridors where traffic volume exceeded 5 vehicles per minute. When compared to available nest sites, pygmy-owls typically placed nests closer to roadway corridors than expected by chance after adjusting for the influence of surrounding vegetation structure. This behavior likely reflects an attraction to vegetation edges, yet may augment risk of collisions with vehicles. Nest success and juvenile survival were lower at nest sites

closer to large roadways, suggesting that habitat quality for pygmy-owls may be reduced in these areas.

To mitigate potentially adverse impacts of roadways on pygmy-owls, we developed a series of general recommendations to improve roadway design. Although our findings offer both auspicious prospects for mitigating the influences of roadways on pygmy-owls, they also pose new challenges and new questions for transportation planners and conservation biologists.

INTRODUCTION

Designing roadways that are efficient yet minimize adverse effects on wildlife is a major challenge for transportation planners (Transportation Research Board 2002). Consequently, modern roadway design should include elements to minimize adverse effects on wildlife, including providing the opportunity for animals to cross safely and easily. Reliable information by which to accomplish this goal, however, is not available for most species (Forman and Alexander 1998) and would be especially valuable for wildlife species of concern.

Roadways influence wildlife populations in a variety of ways (Oxley et al. 1974, Rost and Bailey 1979, Swihart and Slade 1984), including increasing rates of vehicle-related mortality (Fahrig et al. 1995, Evink et al. 1996, Reijnen et al. 1996, Mumme et al. 2000). Roadways also affect the behavior of animals by changing the way they perceive and use the landscape (Feldhamer et al. 1986, Vermeulen 1994) which can interfere with critical life-history activities (Reijnen and Foppen 1994). These influences can be complex when roadways fragment habitat and create openings in vegetation that will benefit some species but be detrimental to others. Species that inhabit areas near vegetation edges for example may be attracted to roadway edges where individuals may be at higher risk of predation or collision with vehicles. For these species, mitigating the adverse influence of roadways is especially important.

Cactus ferruginous pygmy-owls (*Glaucidium brasilianum cactorum*, hereafter “pygmy-owls”) were listed as an endangered species in Arizona in 1997 (USFWS 1997). Despite conservation concerns driven by steady declines in abundance in Arizona and northern Sonora (Flesch and Steidl 2006, Flesch 2007), pygmy-owls were recently removed from the endangered species list for reasons unrelated to recovery (USFWS 2006). In Arizona, pygmy-owls are now rare, therefore gathering detailed information on movements and behavior of pygmy-owls near roadways is difficult to obtain. Because pygmy-owls are more common in neighboring northern Sonora, Mexico and occupy similar vegetation communities as owls in Arizona (Flesch 2003a), research there has direct application for management of pygmy-owls in Arizona.

From 2002 through 2005, we studied relationships between pygmy-owls and roadways in northern Sonora to gain information for management in Arizona. We addressed the following objectives:

1. Assess the effects of roads and other large vegetation openings on movements of adult pygmy-owls within their home ranges.
2. Assess the effects of roads on juvenile pygmy-owls during dispersal.
3. Determine the effects of roadways on nest-site selection of pygmy-owls.
4. Document intensity and variation in noise levels at pygmy-owl nests adjacent to roads.

GENERAL DESIGN APPROACH

We classified roadways into four classes: low-use dirt, moderate-use dirt, low-use paved, or high-use paved highways. Throughout northern Sonora, we located nests near roads of different size classes as well as nests in areas with no roads. To assess whether owls avoided roadways when selecting nest sites, we compared characteristics surrounding each nest with those of a potential nest located nearby that was available to owls. To assess the influence of roadways and other large vegetation openings on movements and behavior of adult pygmy-owls, we selected a sample of nests located near roads of varying size and monitored radio-marked males, characterized conditions of roadways and vegetation, and assessed habitat selection during the breeding season. To assess the influence of roadways on movements and behavior of juvenile owls before, during, and after natal dispersal, we monitored radio-marked juvenile pygmy-owls immediately after they fledged from nests located near larger roadways. We describe methods and results of these efforts with respect to each objective and discuss our findings and how they apply to management.

Objective 1: Assess Effects of Roadways on Movements of Adult Male Pygmy-Owls during the Breeding Season**METHODS**

Field Monitoring: During the breeding seasons of 2003 and 2004, we radio marked 19 territorial adult male pygmy-owls near roadways in northern Sonora. Because we located only two nests near high-use paved highways, we marked both of these males and selected a random sample of owls from nests located near the other three classes of roadways (small paved, large improved dirt, and small dirt). Because the number of potential sites near dirt roadways was large, we selected pairs of sites within approximately 10 km of one another to reduce travel time and increase efficiency.

We trapped owls during dawn, dusk, or bright moonlight by placing mist-net arrays around a decoy owl and speaker that broadcasted recorded territorial calls. Once trapped, we fitted owls with a harness-mounted radio transmitter (Holohil Systems Ltd. Ontario Canada) up to 2.2 g in mass that averaged $3.8 \pm 0.05\%$ (\pm SE) of body mass. We monitored movements and behavior continuously during mornings (from before dawn to 5 hrs after dawn) and evenings (from 3 hrs before dusk to dark) at least once per week from early incubation in early May until young dispersed in early to mid-August for the 12- to 15-week lifespan of each transmitter. Observations were not made at other times of day because owls were often sedentary and perched within 30 m of nests throughout midday. We attempted to space visits evenly throughout the monitoring period by alternating morning and evening visits whenever it was logistically feasible. We tracked owls with a two- or three-element hand-held antenna and a hand-held receiver (Telonics Inc. Mesa, Arizona TR-4 or Communications Specialist Inc. Orange, California, R-1000).

During each visit, we confirmed owl locations visually whenever possible (84% of locations). When this was not possible due to low light, vegetation obstruction, frequent movement, or our desire not to disturb owls, we located owls by triangulation (15% of locations) and occasionally by biangulation (1% of locations) and monitored signals at close range until owls could be observed visually. To minimize error associated with telemetry, we triangulated or biangulated owl locations from within 100 m. At all visual locations, we recorded behaviors performed by owls (perching, vocalizing, striking at prey, preening, and interacting with another pygmy-owl), the initial perch height, and UTM coordinates of all perch substrates.

To minimize our influence on owl behavior, a single observer monitored owls from distances often >25 m in woodland and >50 m in open savannah and desert scrub. For each location, we noted whether owls appeared to notice our presence and whether owls likely flushed in response to our presence. When owls apparently flushed from two successive perches in response to our presence, we discontinued visual monitoring for the next 60 min. Typically, however, owls could be approached to within 15 m without flushing, and slept, captured prey, fed young, and otherwise seemed to behave normally during observations.

Habitat Selection: Patterns of habitat selection are important for two reasons. First, data on habitat attributes selected or avoided by pygmy-owls will aid development of management prescriptions for vegetation along roadway corridors to facilitate crossing and improve landscape permeability for pygmy-owls. Second, as part of our investigation of factors that explained the rate of road crossing by pygmy-owls, we expected that vegetation conditions on the side of roads opposite nests would influence crossing frequency independently of other factors. Therefore, we used models of habitat selection as the foundation from which to estimate the probability of use in these areas.

To determine vegetation attributes selected by pygmy-owls, we compared attributes at and around perch substrates used by pygmy-owls to those available within each home range. To quantify use, we selected a random sample of perch locations obtained for each male owl. To obtain a representative sample of locations throughout each home range and to minimize bias potential due to disturbance by observers, we considered the initial location from each visit and subsequent locations recorded at hourly intervals during which owls (1) had not been flushed by observers and (2) were ≥ 50 m from previous locations. To quantify availability within home ranges, we considered the closest potential substrate (woody plant > 2 m tall and > 1.5 cm diameter ≥ 1 m above ground) from coordinates located at random within 95% minimum convex polygons (MCP) that we used to delineate each home range. We obtained a minimum of 30 samples to quantify use and availability within each home range except in one case where the male was depredated after only six visits ($n = 17$ locations).

To quantify vegetation attributes in areas on the side of the road opposite nests, we calculated the geometric center of each home-range polygon with use of the X-tools extension to ArcView 3.2 (available at <http://www.xtoolspro.com>). To establish an area that we considered potentially available to owls, we established a circular buffer around the center point of each home range with radius equal to one half of the maximum linear breadth of 100% MCP and considered the area on the side of the road opposite the nest and within the buffer available to owls. We then selected locations within this area using the procedure described above. For owls that crossed roads ($n = 18$) this area was at least partially within their actual, measured home ranges as defined by 100% MCP.

Roadway Conditions: To quantify traffic volume along roads within or adjacent to home ranges, we counted the number of vehicles that used roadways during 20-min bouts, 9 to 39 times per site (mean \pm SE = 16 ± 2) at times distributed randomly throughout the morning and evening observation periods during which we monitored owls. We classified vehicles into two groups: (1) cars and small trucks and (2) large trucks and buses. To quantify the width of roadway corridors, we measured the width of pavement and the adjacent maintained or cleared area perpendicular to roadway corridors every 50 m within the circular buffer as defined above. We measured distances between nests and the largest road in or adjacent to home ranges with a GPS: at one site, distance was measured to the likely nest site based on sign (pellets, prey remains, scat).

Vegetation: To quantify vegetation conditions, we centered measurements at the base of each used and available perch substrate and recorded the species and measured the height and canopy diameter by averaging the widest canopy dimension with a perpendicular measurement across the canopy. We classified the general location around substrates as upland or riparian, and the vegetation formation as woodland, desertscrub, savannah, thornscrub, or opening (drainage channel, road corridor, or field). From each substrate, we measured the distance to and height of the closest woody plant (≥ 2 m tall) in four, 90° quarters delineated by the cardinal directions, and recorded the life form (tree or shrub) of each substrate (Cottam and Curtis 1956). Because pygmy-owls often use a "sit and wait" hunting strategy that necessitates some degree of visibility, we quantified mid-story vegetation volume by placing a 1-m^2 board, 6 m from the base of substrates and 0.5 m above ground every 60° around substrates and visually estimated the percent obstruction from 1 m in front of perch substrates. Estimates were recorded to nearest 10% if between 20 and 80% and to the nearest 5% otherwise. Because estimated obstruction was similar at substrates measured with 4 versus 6 samples in 2003, we made 4 measurements in 2004. Finally, to describe the position of substrates within larger vegetation patches, we measured the distance between the base of all substrates and the nearest vegetation edge that we defined by the vegetation formations listed above. We made all measurements with use of a tape, measuring pole, or rangefinder.

Flight Behavior: Because environmental conditions likely influence the frequency, distance, and height of owl flights, we assessed these relationships and their implications for roadway permeability and design. We characterized relationships between flight behavior of owls and the vegetation structure and composition along each flight path and within each individual's home range. We identified the species and measured distance and height of the nearest potential perch (any woody plant ≥ 2 m tall) within 20° of flight paths and estimated the height of perches in origin and destination trees. We estimated the lowest and highest point above ground of each flight to the nearest dm when heights were ≤ 1.5 m above ground and to the nearest 0.5 m when heights were > 1.5 m. When observers lost sight of owls before they perched, we recorded the minimum potential distance of each flight. Finally, we noted if owls crossed roadways or other major vegetation openings (washes or fields) during each visit and marked locations of all crossings. We reported all means ± 1 standard error.

ANALYSES

Spatial Use: To estimate the location of owls whose positions' were triangulated, we used the Andrews' estimator (Lenth 1981) and LOAS software (Ecological Solutions Software 2001); for locations that were biangulated, we used the intersection of both bearings. To quantify error associated with telemetry, we calculated the linear distance between known and estimated locations (Millsbaugh and Marzluff 2001) and the area of error polygons. Estimated linear error (mean \pm SE) for triangulations averaged 20.5 ± 1.4 m ($n = 124$), error polygons averaged 589 ± 146 m², and receiver stations averaged 48 ± 1.8 m from estimated locations. Estimated linear error for biangulations averaged 24.7 ± 6.9 m ($n = 11$) and receiver stations averaged 69.3 ± 7.9 m from estimated locations. Because telemetry error was small, we included locations obtained by angulation when estimating spatial use.

To quantify home-range size (hectares) of each radio-marked male, we used 95 and 100% MCP (Mohr 1947) as well as fixed-kernel utilization distributions (Worton 1989) with bandwidths calculated by least-squares cross validation at the 50, 75, and 95% probability contours. MCP provides an estimate of the overall area used by each animal whereas fixed kernel provides an estimate of the intensity of use. Because autocorrelation among locations (Swihart and Slade 1985) is of no consequence when individuals are treated as the sampling unit and locations are representative of use during a standardized time period (Otis and White 1999), we used all locations to calculate MCP for each animal (Marzluff et al. 1997). To determine if sample sizes were adequate, we inspected plots of the number of locations versus home-range area for each individual (Odum and Kuenzler 1955) and found that estimates became approximately asymptotic between 40 and 90 locations after which it did not increase by $> 5\%$. To calculate utilization distributions, we used initial locations and those obtained at hourly intervals provided owls were not flushed by observers during the interval. Because presence of duplicate locations produced degenerate bandwidths that often corresponded to single trees near nests that were used habitually by owls, we eliminated these locations before analyses so as to delineate more general areas of use (Kernohan et al. 2001). We considered 30 locations per individual adequate for fixed-kernel estimates although ≥ 50 is preferable (Seaman et al. 1999). We calculated all home-range estimates with BIOTAS software (Ecological Solutions Software 2004).

Habitat Selection: We assessed factors that explained habitat selection within each home range individually because resources at this scale are available only to territory holders and their mates and not the population at large (Thomas and Taylor 1990). To identify factors that explained habitat selection, we used logistic regression with a binary response variable (used vs. available) and

considered tree height, canopy diameter, location (upland or riparian), mean height and distance to nearest neighbor trees and shrubs, distance to nearest vegetation edge, and the mean and variance of vegetation volume in the mid-story (0.5 to 1.5 m above ground) as potential explanatory variables. Before analyses, we compared all possible pairs of explanatory variables and retained one variable from correlated pairs ($r > 0.7$) that had the greatest test statistic. We then fit models that included all covariates and quadratic terms, and sequentially eliminated variables that did not contribute appreciably to model fit ($P > 0.10$). To compare use and availability of woodland versus other vegetation formations within each home range, we used Fisher's Exact tests. Because we lacked sufficient samples to assess selection of perch species by each individual, we pooled data among sites and used a likelihood ratio test to identify plant species used in greater proportion than available. Species with <15 observations were grouped by life form (tree or shrub).

To describe the probability of pygmy-owls using areas on the side of the road opposite nests relative to using other areas within the estimated home range, we used habitat-selection models obtained with the logistic regression procedure described above as resource selection functions (RSF) for each individual (Manly et al. 2002). We evaluated each RSF with the values of resources measured within circular buffers on the side of the road opposite nests and the values of resources measured at available sites throughout home ranges, and generated values proportional to the probability of use within each area. To calculate the relative probability of use in areas on the side of the road opposite nests, we subtracted the mean probability of use of locations in this area from that available throughout the entire home range. Because probabilities were based on factors that explained selection of each male, the magnitude of this value increased as the probability of use on the side of roads opposite nests increased relative to overall resource availability.

Owl Interactions with Roadways: To determine factors that explained the rate that pygmy-owls crossed roads, we assessed the influence of home-range size, distance between nests and roads, traffic volume, road corridor width, and the relative probability of use of resources on the side of roads opposite nests. To estimate rate of road crossings for each male, we calculated the number of visits where we found that owls had crossed the main road adjacent to nests divided by the total number of visits and used this value as a response variable in multiple linear regression with stepwise selection ($P \leq 0.25$ to enter, $P \leq 0.10$ to stay). Because traffic volume and width of road corridors were highly correlated ($r = 0.97$, $P < 0.0001$), we fit two models so that the influence of each factor on road crossing frequency could be addressed. We used these models separately to predict levels of traffic volume and width of road corridors that would preclude pygmy-owls from crossing roads. To estimate traffic volume and width of the road corridor at each site, we calculated the mean number of vehicles per 20 min and the mean width of all corridor measurements obtained within circular buffers around each home range.

Flight Behavior: We described the relationship between flight distance and minimum and maximum flight height, with Pearson correlations. To determine factors that explained variation in distances and heights of individual flight events, we considered the species, height, and distance to the nearest potential perch along each flight path and the perch height from which flights began because availability was defined for each flight event. To determine factors that explained mean flight distance and mean flight height of each individual owl, we averaged observations for each individual for which we recorded ≥ 15 flight events and assessed the influence of mean vegetation volume, tree height, tree density, and distance to nearest vegetation edge at available locations within each home range using multiple linear regression. Because flights to or from nest cavities or toward prey or other pygmy-owls could bias our descriptions, we eliminated these observations before analyses. To compare patterns of flight behavior among individuals we used ANOVA. We transformed variables when necessary to better meet assumptions of statistical tests.

RESULTS

Effort: We trapped 18 breeding adult males in early May and 1 in mid-May (median date of capture = 6 May) during the breeding seasons of 2003 and 2004. Sixteen males survived the lifespan of transmitter batteries that averaged 12.6 ± 0.2 weeks (88 days). Two of three males that did not survive were killed by raptors between two and four weeks after marking and one male died from unknown causes at 12 weeks. We monitored the 15 males that nested successfully and survived ≥ 12 weeks an average of 25.6 ± 2.0 times (range = 15-39) for a total of 86.0 ± 7.9 hrs (range = 37-129 hrs) per male. We maintained visual contact during $37.6 \pm 2.2\%$ of sampling effort. We monitored the four males that died early in the season or that did not nest successfully an average of 15.5 ± 8.0 times (range = 5-39) for a total of 47.0 ± 22.2 hrs (range = 16-112 hrs).

Owl Interactions with Roadways: Four males (21%) inhabited areas near low-use dirt roadways, 11 (58%) near moderate-use dirt or low-use paved, two (11%) near moderate-use paved, and two near high-use paved roadways. Distances between nests and roads averaged 192 ± 35 m (range = 31-555 m).

Traffic volume and width of roadway corridors varied markedly among the four categories of roadways ($F_{3, 15} \geq 106.01$, $P < 0.001$, ANOVA). Traffic volume (vehicles/hr) averaged 3.0 ± 1.2 along low-use dirt, 19.5 ± 1.5 along moderate-use dirt and low-use paved, 40.2 ± 3.3 along moderate-use paved, and 166.2 ± 3.3 along high-use paved roadways. Width of roadway corridors averaged 3.8 ± 2.5 m along low-use dirt, 8.5 ± 1.4 along moderate-use dirt and low-use paved, 20.5 ± 3.3 along moderate-use paved, and 70.0 ± 3.3 along high-use paved roadways.

We observed all but one male (95% of 19) cross the largest road within or adjacent to their home range at least once. Males crossed roadways during an average of $18.1 \pm 3.1\%$ of visits with the rate of crossing being highest (43-45%) at two sites where roads were located between nests in uplands and adjacent riparian vegetation where males often hunted. Males crossed roadways during $29.5 \pm 6.6\%$ of visits along low-use dirt roadways, $16.0 \pm 4.0\%$ of visits along moderate-use dirt and low-use paved roadways, $14.5 \pm 9.4\%$ of visits along moderate-use paved roadways, and $10.2 \pm 9.4\%$ of visits along high-use paved roadways. Overall, however, rate of road crossing did not vary among roadway categories ($F_{3, 15} = 1.36$, $P = 0.29$, ANOVA).

Table 1: Factors that explained rate of road crossing by 19 radio-marked male pygmy-owls that nested along a gradient of roadway sizes in northern Sonora, Mexico 2003 and 2004. Rate of roadway crossing was defined as the number of observation periods that an owl crossed the main roadway within or adjacent to its home range divided by the total number of 3 to 5 hour periods in which the owl was monitored. Most owls were monitored between incubation in early May through early August. Parameter estimates and *P*-values are based on multiple linear regression. Estimates equal the average change in rate of road crossing with each one-unit increase in the factor.

Factor	Estimate	SE	<i>t</i>	<i>P</i>
Intercept	0.77	0.14	5.60	0.0001
Distance between nest and road edge (log m)	-0.10	0.026	3.71	0.0019
Traffic volume (log plus 1 no. vehicles/20 min)	-0.053	0.023	2.30	0.035

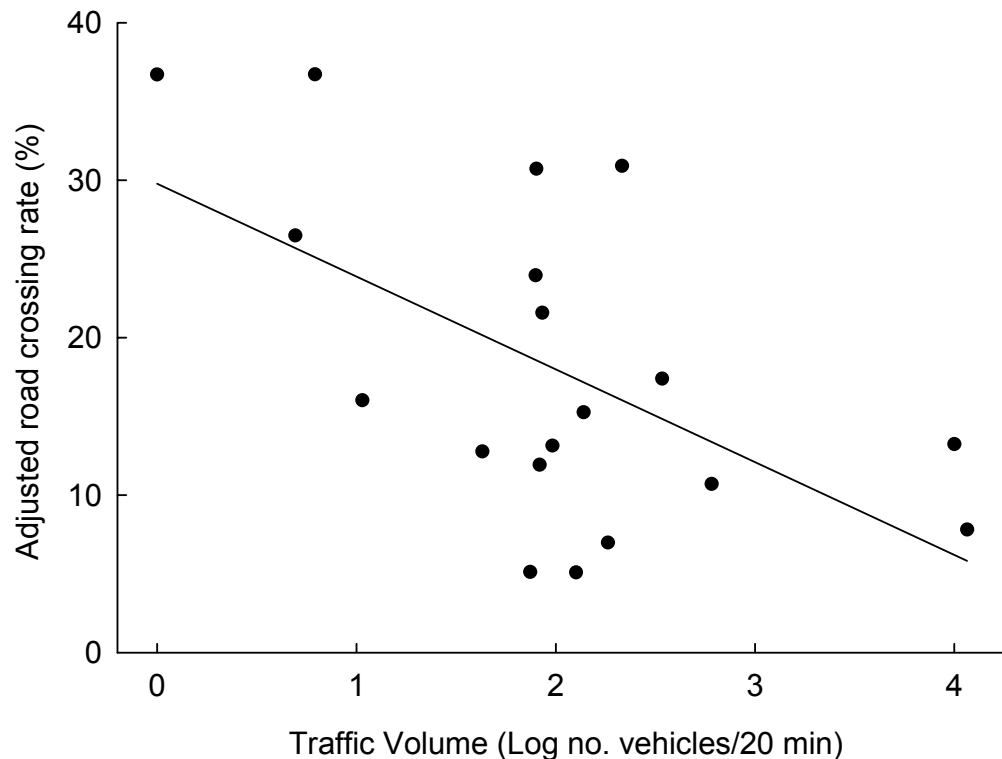


Figure 1: Rate of road crossing by 19 radio-marked pygmy-owls that nested along a gradient of roadway sizes declined as traffic volume (log plus 1 no. vehicles/20 min) along these roads increased ($P = 0.0035$) in northern Sonora, Mexico, 2003 and 2004. The inverse natural log of traffic volume transforms values to the original scale. Effect of traffic volume is adjusted for distance between nests and roads ($P = 0.0019$).

Rate of road crossing by pygmy-owls decreased by $5.8 \pm 2.5\%$ with each doubling of traffic volume ($t_{16} = 2.30$, $P = 0.035$, Fig. 1), after adjusting for distance between nests and roads (Table 1). We estimate that an average of 6 vehicles per minute would prevent crossing by a male pygmy-owl nesting 200 m from any type of roadway and that an average of 21 vehicles per minute would prevent crossing by a male pygmy-owl nesting 100 m from a roadway.

Rate of road crossing by owls decreased by $5.5 \pm 2.7\%$ with each doubling of width of roadway corridors ($t_{16} = 1.95$, $P = 0.069$, Fig. 2), after adjusting for the influence of distance between nests and roads (Table 2). We estimate that a road corridor 167 m wide would prevent crossing by a pygmy-owl nesting 200 m from the roadway. After adjusting for traffic volume or width of roadway corridors, rate of road crossing decreased by $7 \pm 2\%$ with each doubling of distance between nests and roadways ($t_{16} \geq 3.71$, $P \leq 0.0019$).

Rate of road crossing did not vary with any index of home-range size ($t_{15} \leq 0.69$, $P \geq 0.50$) or with relative probability of use in areas on the side of the road opposite nests ($t_{15} \leq 0.80$, $P \geq 0.44$), after we considered variation attributable to distance between nests and roads and either traffic volume or width of road corridors.

Table 2: Additional factors that explained frequency of road crossing by 19 radio-marked male pygmy-owls that nested along a gradient of roadway sizes in northern Sonora, Mexico 2003 and 2004. Because traffic volume and road corridor width were highly correlated, we fit two separate models, one with each factor to provide an estimate of each effect while holding distance between nests and roads constant. Methods and analyses are the same as for Table 1.

Factor	Estimate	SE	<i>t</i>	<i>P</i>
Intercept	0.80	0.15	5.34	<0.0001
Distance between nest and road edge (log m)	-0.103	0.027	3.74	0.0018
With of roadway corridor (log m)	-0.050	0.025	1.95	0.069

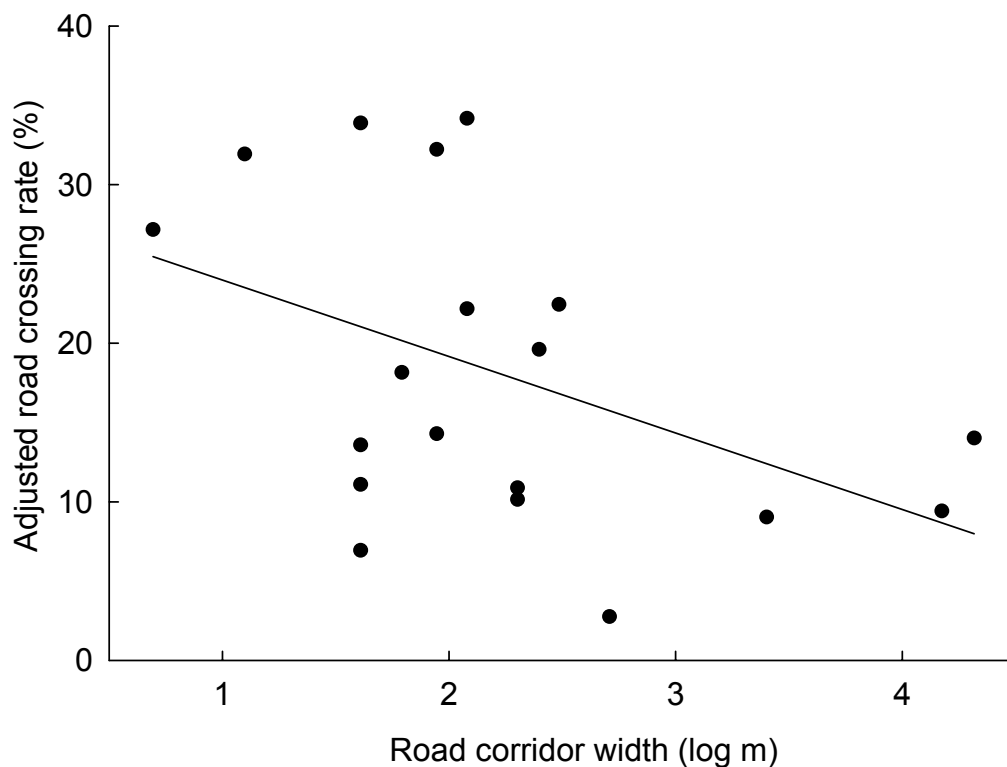


Figure 2: Frequency of road crossing by 19 radio-marked pygmy-owls that nested along a gradient of roadway sizes declined as the width of roadway corridors (log m) increased ($P = 0.069$) in northern Sonora, Mexico, 2003 and 2004. The inverse natural log of road corridor width transforms values to the original scale. Effect of road corridor width is based on linear regression adjusted for distance between nests and roads ($P = 0.0018$).

Flight Behavior: Flight behavior by pygmy-owls has important implications for arrangement of vegetation along roadways. Overall, 97% of flights were <80 m in length (Fig. 3). Flight distances of each individual averaged 28 ± 2 m and did not vary among individuals (range of means = 22-39 m, $F_{11, 244} = 1.22$, $P = 0.27$); maximum flight distances per individual averaged 80 ± 10 m. The three longest flights by adult males were 120, 123, and 210 m and occurred in open savannah, across a large agricultural field, and from a ridge top to valley bottom, respectively. Minimum height above the ground of owls in flight averaged 1.5 ± 0.2 m, ranged from 0.9 to 2.7 m, and varied among individuals ($F_{11, 227} = 6.45$, $P < 0.001$); maximum flight heights averaged 3.3 ± 0.2 m, ranged from 2.5 to 5.0 m, and also varied among individuals ($F_{11, 227} = 3.94$, $P < 0.001$) (Fig. 4). Overall the lowest and highest flight event by an adult male was 0.1 and 12 m, respectively ($n = 288$).

Flight behavior of pygmy-owls typically involved dropping rapidly from perches and flying just above or through understory vegetation until ascending rapidly just before perching. Owls that flew longer distances tended to reach higher maximum heights above the ground ($r = 0.23$, $P < 0.001$, $n = 280$) and somewhat lower minimum heights ($r = -0.11$, $P = 0.07$). Owls that obtained higher maximum flight heights also tended to reach higher minimum heights ($r = 0.62$, $P < 0.001$). Flight distance increased as the height an owl was perched before flight increased, as distance to the nearest potential perch increased, and as height of these potential perches decreased (Table 3). The closest available potential perch along flight paths averaged 10 ± 0.6 m away, yet males flew an average of 2.8 times further than these potential perches. Mean flight distance of individuals increased as density of trees within their home ranges increased ($t_{10} = 3.02$, $P = 0.013$).

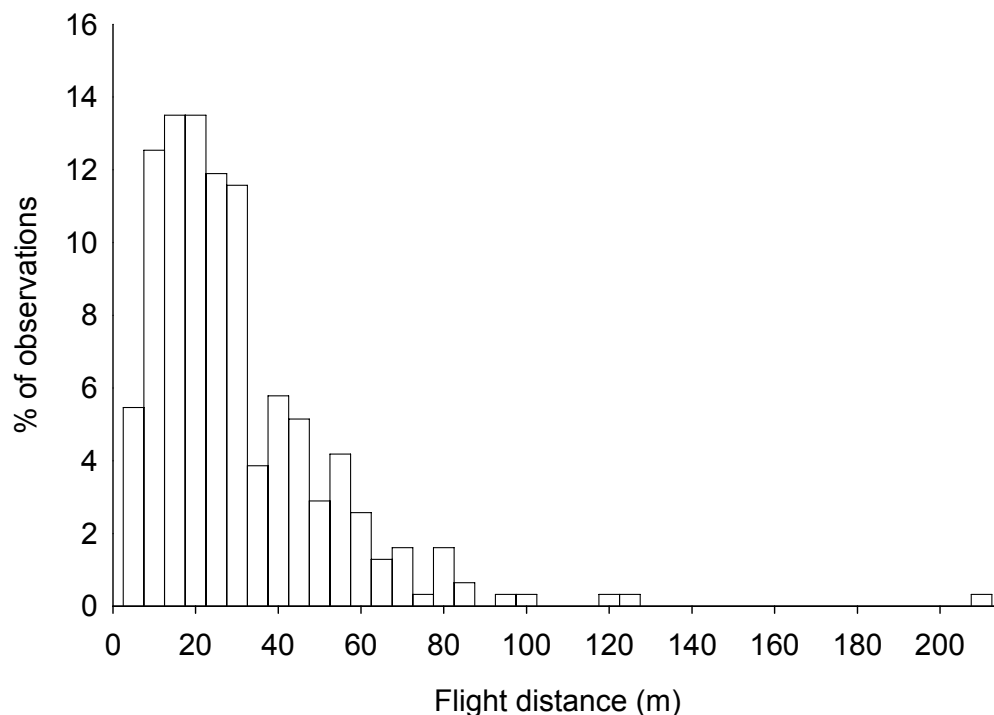


Figure 3: Distribution of 311 flight distances by 19 radio-marked pygmy-owls that nested along a gradient of roadway sizes in northern Sonora, Mexico, 2003 and 2004.

Both minimum and maximum flight height increased as the height an owl was perched before flight increased and as height of the nearest potential perch increased; minimum flight height decreased and maximum flight height increased as distance to the nearest potential perch increased (Table 4). Both mean minimum and mean maximum flight height of each individual increased as tree height ($t_9 \geq 2.41$, $P \leq 0.093$) and mid-story vegetation volume ($t_9 \geq 2.03$, $P \leq 0.073$) available within their home ranges increased.

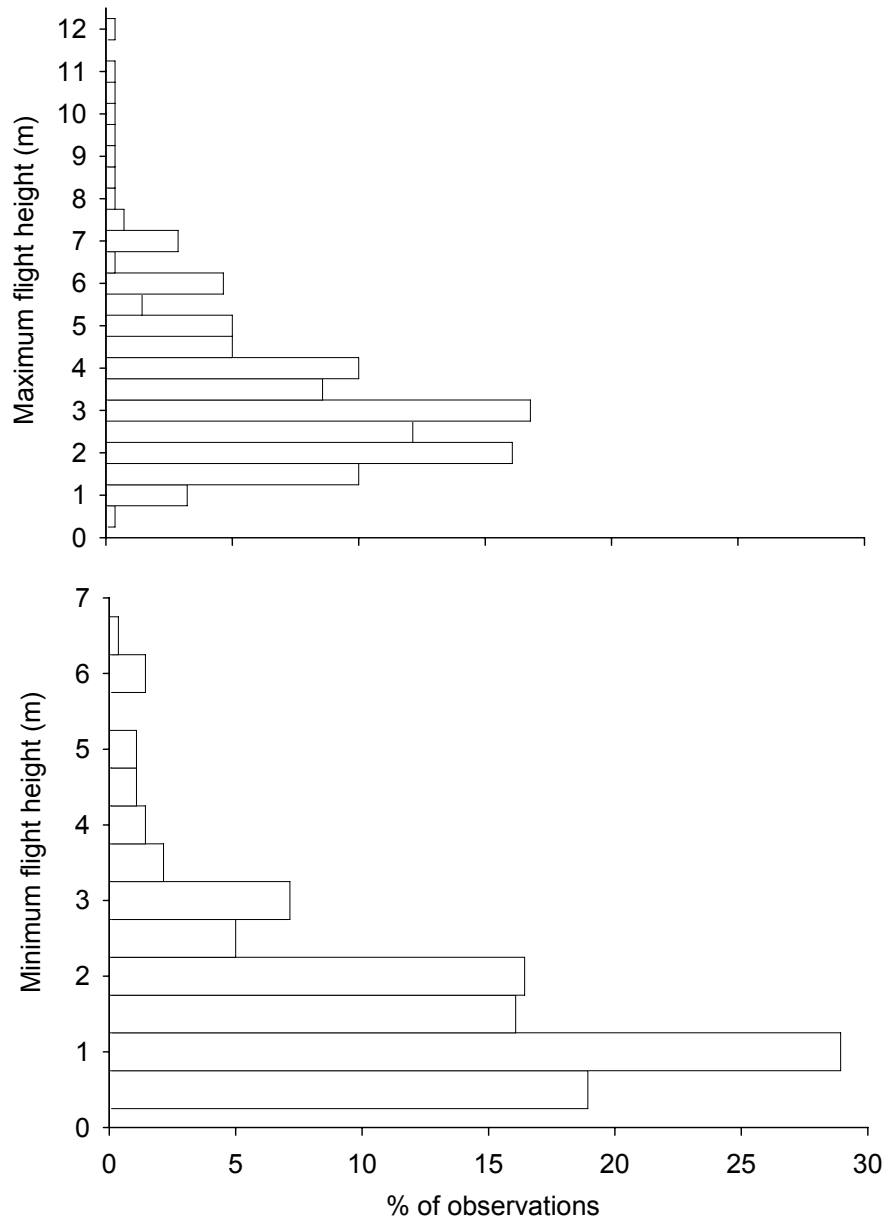


Figure 4: Distribution of 280 minimum and maximum flight heights by 19 radio-marked pygmy-owls that nested along a gradient of roadway sizes in northern Sonora, Mexico, 2003 and 2004.

Table 3: Factors that explained flight distance (m) during 267 flight events by 17 radio-marked male pygmy-owls in northern Sonora, Mexico 2003 and 2004. For each flight event we measured the distance and height of the nearest potential perch that we defined as any woody plant >2 m tall within 20° of flight paths and estimated the height of perches in origin and destination trees. Parameter estimates and *P*-values are based on multiple linear regression. Estimates equal the average change in flight distance with each one-unit increase in the factor.

Factor	Estimate	SE	<i>t</i>	<i>P</i>
Intercept	2.76	0.12	23.68	<0.0001
Height of perch before flight (m)	0.089	0.026	3.49	0.0006
Height of closest available perch substrate (m)	-0.049	0.026	1.90	0.059
Distance to closest available perch substrate (m)	0.025	0.0040	6.20	<0.0001

Perch height averaged 2.7 ± 0.1 m and ranged from 1.9 to 3.5 m among individuals ($F_{17, 1427} = 7.69$, $P < 0.001$); the lowest perch was on the ground and the highest was 17 m above ground (Fig. 5). Over 72% of perch substrates were between 2 and 6 m tall (Fig. 5). Mean perch height of each male increased as available tree height within home ranges increased ($t_{15} = 2.68$, $P = 0.017$).

Males flew an average of 43 ± 4 m (max = 66 m) when crossing roads ($n = 11$), with minimum flight height across roads averaging 1.1 ± 0.3 m (min = 0.2 m) and maximum flight height averaging 2.6 ± 0.6 m. Immediately before crossing roads, owls perched an average of 3.3 ± 0.5 m above ground in mesquite ($n = 10$) or catclaw (*Acacia greggii*, $n = 1$) trees adjacent to road corridors. We obtained only one visual observation of a pygmy-owl crossing a high-use paved roadway where the total

Table 4: Factors that explained minimum and maximum flight height (m) during 243 flight events by 16 radio-marked male pygmy-owls in northern Sonora, Mexico 2003 and 2004. For each flight event we measured the distance and height of the nearest potential perch that we defined as any woody plant >2 m tall within 20° of flight paths and estimated the height of perches in origin and destination trees. Parameter estimates and *P*-values are based on multiple linear regression. Estimates equal the average change in flight height with each one-unit change in the factor.

Response Factor	Estimate	SE	<i>t</i>	<i>P</i>
Maximum flight height (m)				
Intercept	0.50	0.23	2.19	0.029
Height of perch before flight (m)	0.74	0.051	14.54	<0.0001
Height of closest available perch substrate (m)	0.15	0.051	3.06	0.0024
Distance to closest available perch substrate (m)	0.016	0.008	2.14	0.033
Minimum flight height (m)				
Intercept	0.21	0.18	1.18	0.24
Height of perch before flight (m)	0.37	0.039	9.51	<0.0001
Height of closest available perch substrate (m)	0.13	0.039	3.34	<0.0001
Distance to closest available perch substrate (m)	-0.019	0.006	3.26	0.0013

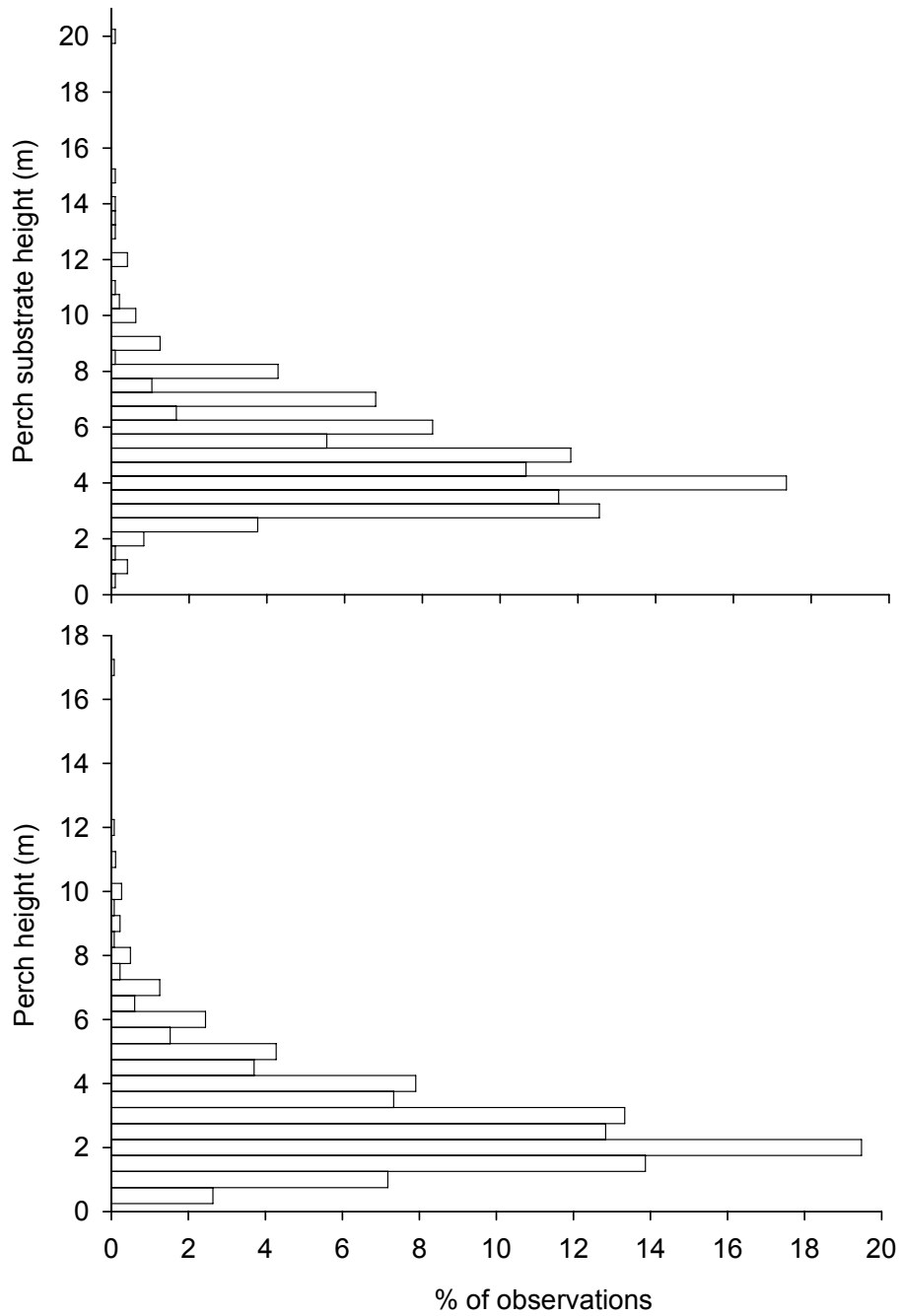


Figure 5: Distribution of 956 perch heights and 2,618 perch substrate heights used by 19 radio-marked pygmy-owls that nested along a gradient of roadway sizes in northern Sonora, Mexico, 2003 and 2004.

distance flown was 66 m and traffic volume along the road averaged 171 ± 6 vehicles per hr (Fig. 6). This same owl likely flew under two road overpasses when traveling back to the main portion of its home range (Fig. 7).

Owls seemed aware of roadways and vehicle traffic. One owl that crossed a moderate-use paved road while carrying a large spiny lizard (*Sceloporus* sp.), looked up then down the road corridor from a perch tree at the road's edge before flying just 0.2 m above the road surface. We also observed owls perched in woodland vegetation near roadways that seemed to be watching passing vehicles. No owls used box or pipe culverts when crossing roads despite their presence in some home ranges. Although we did not obtain enough observations to quantify vegetation conditions used by pygmy-owls when crossing roads, owls often used areas of woodland vegetation that were associated with drainage corridors before and after crossing (Figs. 8-10).



Figure 6: Road corridor crossed by a radio-marked pygmy-owl that flew 66 m across Mexico Route 2, a high-used paved roadway in northern Sonora, Mexico, 2003. The owl flew from the tree labeled perch that was along an approximately 20-m wide median of native woodland vegetation between the oncoming lanes and flew across the road to a patch of woodland vegetation along Rio Coyotillo east of Santa Ana. An overhead view of this event is illustrated in Figure 8.



Figure 7: Road overpasses and riparian vegetation along Mexico Route 2 that was traversed by a radio-marked ferruginous pygmy-owl in northern Sonora, Mexico, 2003. This owl flew from a patch of woodland vegetation along the Rio Coyotillo under both overpasses in a single flight as indicated by the direction, time, and strength of the radio signal. An overhead depiction of this flight event is illustrated in Figure 8.

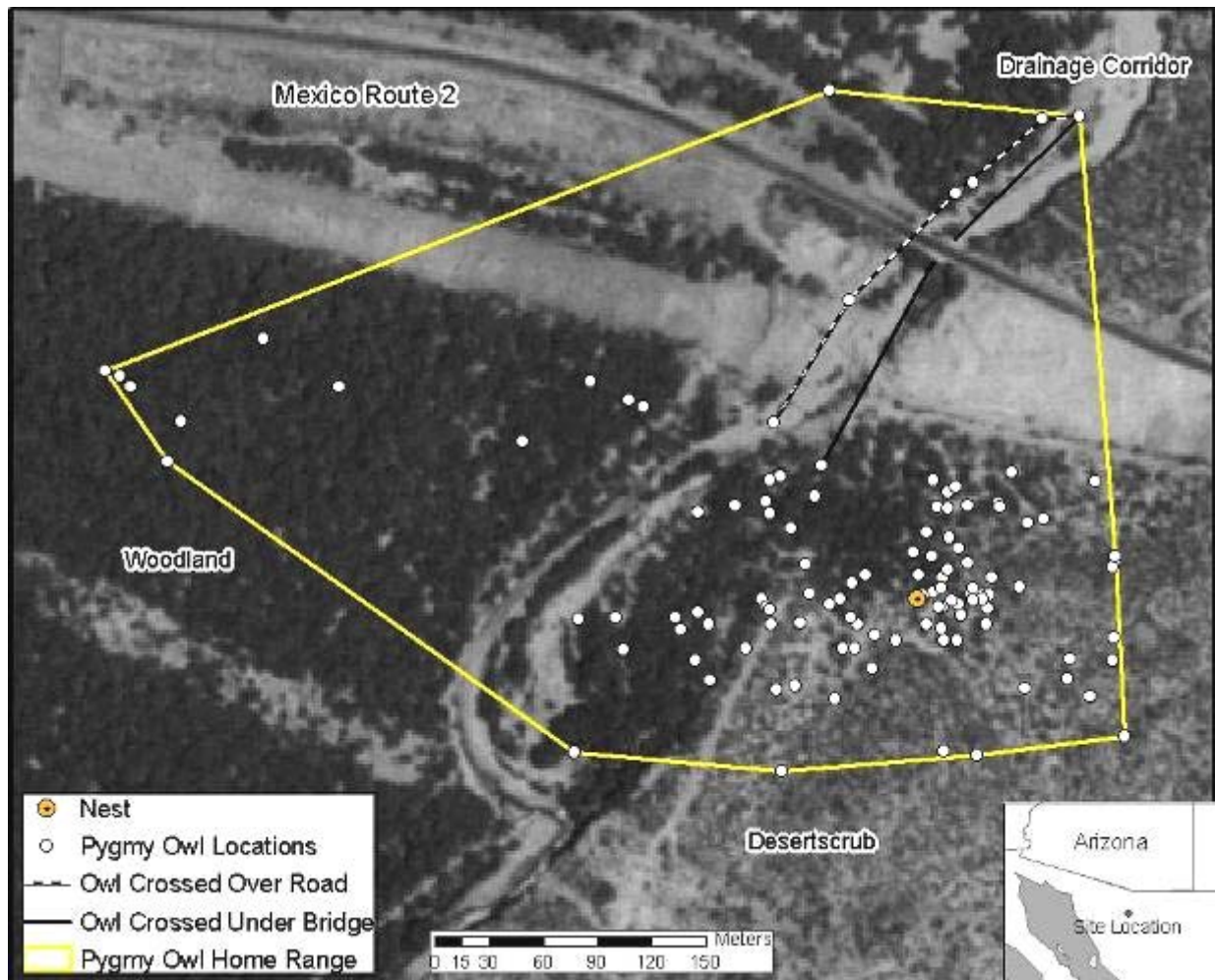


Figure 8: Overhead view of perch locations, home range, vegetation, and road crossing locations of a radio-marked male ferruginous pygmy-owl that nested along Mexico Route 2 in northern Sonora, Mexico, 2003. Home range was based on 100% minimum convex polygon and was 14.0 ha. Figures 6 and 7 depict this area from the ground. Note that the base map is from before the second overpass and paved roadway closest to the nest (Fig. 7) was completed.

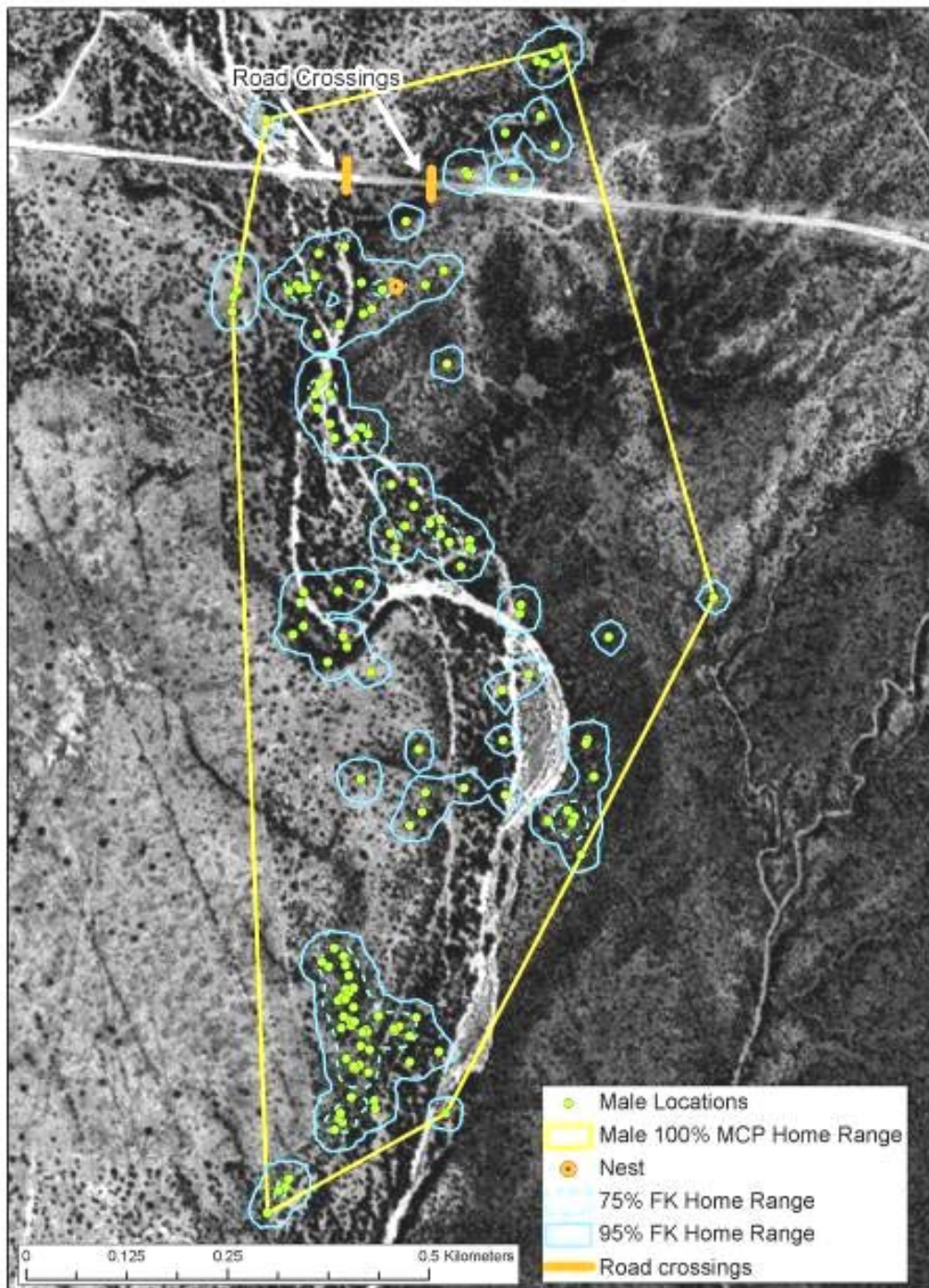


Figure 9: Overhead view of perch locations, home range, vegetation, and road crossing locations of a radio-marked male ferruginous pygmy-owl that nested along a moderate-use paved road in northern Sonora, Mexico 2004. Home range was based on 100% minimum convex polygon and 75% and 95% fixed-kernel estimates. Note that road crossing locations were associated with woodland vegetation along the drainage.

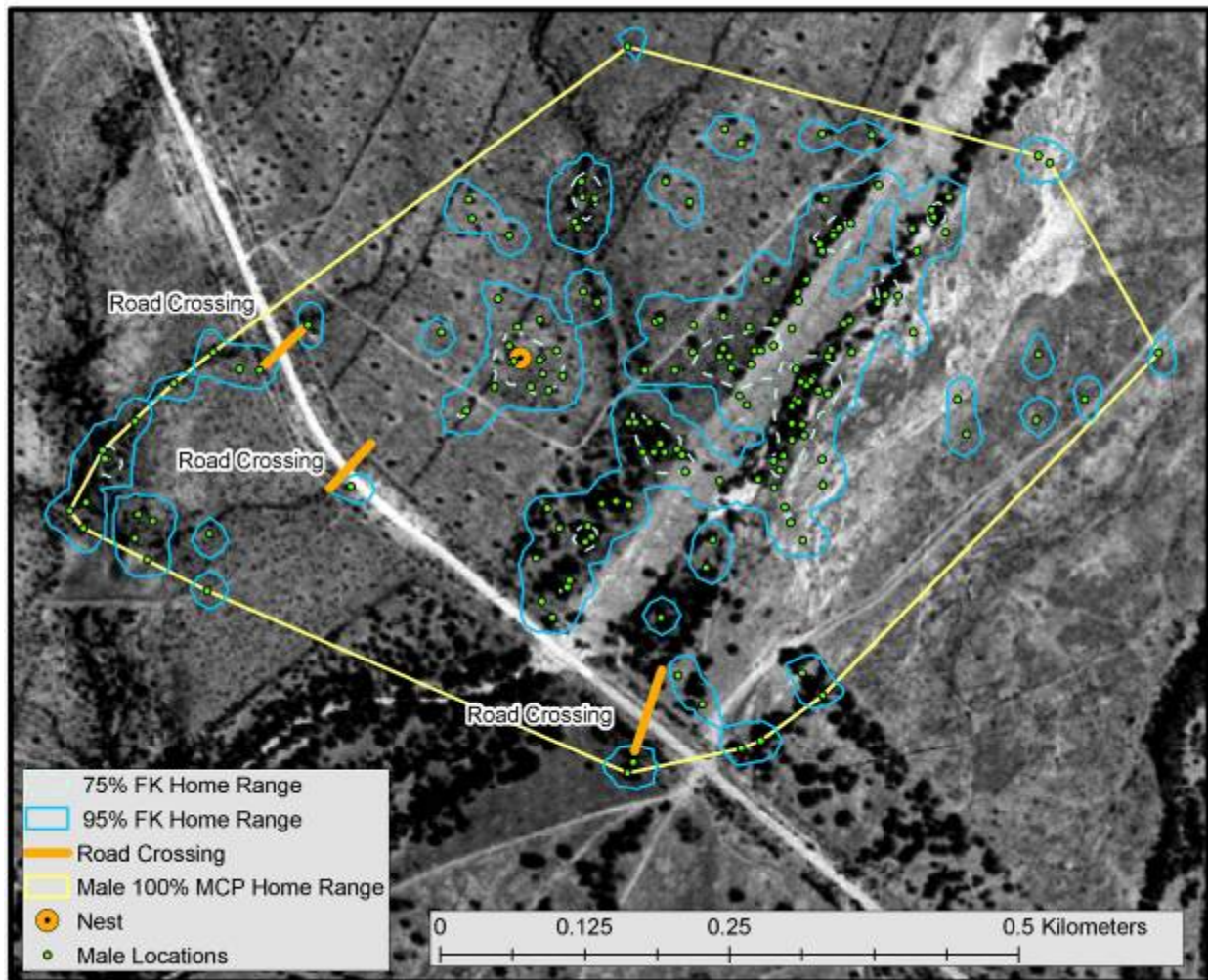


Figure 10: Overhead view of perch locations, home range, vegetation, and road crossing corridors of a radio-marked male ferruginous pygmy-owl that nested along a moderate-use paved road in northern Sonora, Mexico 2004. Home range was based on 100% minimum convex polygon and 75% and 95% fixed-kernel estimates. Note that all three road crossing corridors were associated with woodland vegetation along drainages.

When crossing large drainages that created natural openings in vegetation similar to roadway corridors ($n = 8$ observations), males flew an average of 52 ± 8 m (max = 81 m) with minimum flight height averaging 3.0 ± 0.6 m (min = 1.0 m) and maximum flight height averaging 6.3 ± 1.0 m (max = 11). Several of these flights crossed drainages with large cut banks such that the bottoms of drainage corridors were 3 to 8 m below the height of the ground where flights began. In these situations, males did not reduce the height of their flights so minimum flight heights were much higher than those typically observed.

Spatial Use: Home-range size of males that nested successfully and were monitored ≥ 12 weeks ($n = 15$) averaged 27.4 ± 3.3 ha (range = 10.9-52.1 ha) based on 95% MCP and 122 ± 11 locations per male (range = 55-190). Home-range sizes averaged 35% larger (37.1 ± 4.0 ha) based on 100% MCP (range = 14.0-58.9 ha). No male traveled $> 1,156$ m from its nest during the monitoring period (mean = 712 ± 63 m, min. = 375 m). On average, nests were located 195 ± 29 m from the geographic center and 116 ± 15 m from the nearest edge of home ranges based on 95% MCP ($n = 15$). One male whose nest failed late in incubation used 92.9 ha ($n = 164$ locations, 37 visits) and another whose nest likely failed early during incubation used 66.7 ha ($n = 40$ locations, 12 visits) based on 100% MCP.

Males monitored ≥ 12 weeks spent an average of 50, 75, and 95% of their time within areas that were 3.1 ± 0.8 (range = 0.2-8.3), 8.5 ± 1.8 (range = 0.8-19.9), and 27.0 ± 4.3 ha (range = 4.5-59.1), respectively, during the monitoring period based on fixed-kernel estimates and an average of 65 ± 6 locations per male (range = 32-103). Bandwidth averaged 34 ± 4 m (range = 15-64) and there was no relationship between home-range size and the number of locations used to estimate home-range size at all probability contours ($t_{13} \leq 1.31$, $P \geq 0.21$, test of slope from linear regression). Males that did not nest successfully ($n = 2$) spent an average of 50, 75, and 95% of their time within areas of 2.4 ± 0.6 , 6.0 ± 0.6 , and 17.1 ± 0.9 ha, respectively, based on fixed-kernel estimates and 30 and 90 locations per male.

Habitat Selection: Environmental factors explained an average of $42 \pm 2\%$ of variation (R^2) in habitat selection by pygmy-owls within home ranges ($n = 17$). As the probability of use increased relative to availability, the amount of variation in selection that was explained by environmental factors increased ($t_{15} = 8.04$, $P < 0.001$). Overall, eight factors explained selection by owls: tree height, canopy diameter, height and distance to nearest neighbors, vegetation volume, distance to vegetation edge, presence of riparian vegetation, and grazing intensity. For three owls, the effect of these factors on selection was nonlinear (quadratic) and for two owls the range or standard deviation of the factor was important to selection (Table 5). Between one and five environmental factors explained selection for each individual, with factors often varying among individuals probably because of differences in resource availability within their home ranges.

Height and canopy diameter of the perch tree, which were highly correlated ($r = 0.74$, $P < 0.001$), were the only factors that explained selection for all owls, with tree height being more influential than canopy diameter. Each 1-m increase in tree height increased the odds of selection by a factor of 2.2 to 4.7; each 1-m increase in canopy diameter increased the odds of selection by a factor of 1.2 to 5.2 (Table 5). Tree and shrub density, as indicated by mean distance to nearest neighbors, influenced selection of 41% ($n = 7$ of 17) of individuals; for 6 of 7 owls, the odds of selection declined as density decreased and for one individual, that occupied the largest and densest woodland vegetation in our sample, odds of selection was highest at moderate density ($P = 0.05$, for test of quadratic term).

Because resource selection is dependent on the specific resources available to each individual, the effect of some environmental factors on selection varied considerably among individuals. As volume of mid-story vegetation increased, the odds of selection increased for four individuals, decreased for one individual, were highest at moderate vegetation volume for two individuals, and decreased with increasing variation in volume for one individual (Table 5). Similarly, as distance to the nearest vegetation edge increased, the odds of selection increased for two individuals and decreased for two other individuals. The effect of height of nearest-neighbor plants on selection was important for 41% of individuals and its effect complex. As height increased, odds of selection increased for one owl, decreased for another owl, and was highest at moderate height for another owl. As the range of plant heights increased, odds of selection increased for one owl, decreased for two other owls, and

was lowest at a moderate range for another owl. These patterns reflected high among-home range variation in tree heights around used and available perches ($F_{16, 498} \geq 7.79$, $P < 0.001$, ANOVA).

Pygmy-owls used woodlands in greater proportion than other available vegetation formations within home ranges and there was strong evidence that woodlands were selected ($P \leq 0.055$) by 53% of owls and suggestive evidence ($P = 0.069-0.10$) for 12% of owls. Home ranges of other males for which there was no evidence that woodlands were selected (35%) were composed mainly of woodlands.

Pygmy-owls did not select species of perch trees in proportion to their availability ($G^2 = 102.4$, $P < 0.001$). Mesquite was selected for 79% ($n = 391$ of 493) of perches, 20% more than available, whereas shrubs were selected for only 4% of perches ($n = 18$ of 94), 14% less than that available. For shrubs, pygmy-owls selected only desert hackberry (*Celtis pallida*, 78%) and condalia (*Condalia* sp., 22%). The most common available shrubs were desert hackberry (30%), white-thorn acacia (*Acacia constricta*, 17%), graythorn (*Zizyphus obtusifolia*, 11%), and creosote (*Larrea tridentata*, 10%); condalia comprised just 6% of available shrubs.

Table 5: Factors that explained habitat selection within home ranges of 17 male pygmy-owls during the nesting season in northern Sonora, Mexico 2003 and 2004. Odds ratios and *P*-values based on logistic regression comparing used and available resources within each home range as defined by 95% minimum convex polygons. Use was based on perch-centered hourly locations of radio-marked males monitored between early May and early August. For odds ratios a 1-unit increase in the explanatory variable results in a change in the odds of selection

Site	Height (m)			Canopy Diameter (m)			Mean nearest neighbor height (m)			Mean nearest neighbor distance (m)			Vegetation volume 0.5-1.5 m above ground (%)			Distance to vegetation edge (log m)			Presence of riparian vegetation			Grazing intensity		
	Odds	SE	<i>P</i>	Odds	SE	<i>P</i>	Odds	SE	<i>P</i>	Odds	SE	<i>P</i>	Odds	SE	<i>P</i>	Odds	SE	<i>P</i>	Odds	SE	<i>P</i>	Odds	SE	<i>P</i>
Alamito	4.7	1.5	<0.01																					
Atil	2.5	1.3	<0.01																					
Bruja	3.3	1.4	<0.01				0.3 ^a	0.6	0.02															
Cerro Alejos				5.2	1.9	0.01									8.4	3.0	0.05							
Cerro Prieto				3.4	1.4	<0.01				0.1 ^c	0.3	0.04												
Carrizal	2.2	1.4	0.02				2.4 ^a	1.7	0.10				3.2	1.5	<0.01	0.6	1.4	0.11						
Coyotillo	2.2	1.3	<0.01				29.3 ^{a,b}	4.3	0.02	0.4 ^b	0.6	0.05	1.7	1.3	0.08	0.3	1.6	0.01						
Cucurpe Lower				3.5	1.5	<0.01	0.1 ^b	0.4	<0.01				0.4 ^d	0.6	0.02									
Cucurpe Pintor	3.5	1.4	<0.01							0.6	0.8	<0.01	1.5	1.3	0.09									
Molinos Lower				3.3	1.4	<0.01				0.5	0.8	<0.01				2.3	1.6	0.08						
Molinos Upper	3.1	1.4	<0.01										0.6	0.8	0.06									
Magdalena Upper				1.2	1.1	0.11	0.5 ^a	0.7	0.03				1.6	1.3	0.02									
Oquitoa				1.7	1.2	<0.01																		
Pozo Nuevo	3.4	1.4	<0.01				0.4	0.7	0.01	0.8	0.9	0.01	0.96 ^b	0.98	0.05									
Saric				3.7	1.5	<0.01				0.1 ^c	0.3	0.08	0.91 ^b	0.97	<0.01						0.2	0.4	0.09	
Sasabe Lower	3.5	1.5	<0.01															2.1	1.5	0.07				
Sasabe Upper	2.9	1.5	<0.01				2.8	1.9	0.12	0.7	0.9	0.02												
% of owls where factor selected	59			41			41			41			47			24			6				6	

a Range in height(m) of four nearest neighbors.

b Factor squared in model.

c Natural logarithm of the factor used in model.

d Standard deviation of vegetation volume.

Objective 2: Effects of Roadways on Movements of Juvenile Pygmy-Owls during Dispersal**METHODS**

Field Monitoring: To assess the effects of roadways on movements by pygmy-owls during natal dispersal, we radio marked 54 juveniles that fledged from 19 nests located within 2 km of paved roadways. We trapped owls by hand within 24 hrs of fledging and determined their sex based primarily on plumage coloration and secondarily on mass. We fitted owls with a harness-mounted radio transmitter (Holohil Systems Ltd. Ontario Canada) that weighed up to 2.2 g and averaged $4.1 \pm 0.06\%$ of female body mass and $4.4 \pm 0.04\%$ of male body mass. Throughout most of the natal period, we monitored movements and behavior of each owl at least once per week for approximately 1 hr before directing effort to another sibling; observation periods were the same as those used to monitor adults (Objective 1). Because mortality rates were often highest the week after fledging, we increased frequency of observations to once per day or every other day during this period. Because our objective was to observe owl behavior if and when owls encountered roadways, we increased frequency of observations to once per day just before the expected onset of natal dispersal.

When an owl died before dispersal, we classified the cause of mortality as: *raptor* if the owl was observed being killed, if we found the owl plucked, found a regurgitated transmitter or owl remains in or near active raptor nests or known habitual perches, or if transmitters were found >1 km from previous owl locations which indicated that they had been carried from the air; *mammal* if the owl had not been plucked and the body cavity had been torn open and consumed near recent owl locations; *snake* if we observed a snake below the nest with an obvious body bulge, if the transmitter was taken underground within 1 m of a burrow, shed snake skin, or other snake sign, which we confirmed by excavation of the area; or *unknown* if the owl was found whole within 3 days of fledging with no sign of predation.

For young that survived until dispersal, we attempted to locate individuals every 24 hrs during dispersal to document the path and trajectory of movement. Because dispersing owls typically move for only a few hours during low light of dawn and dusk and during nights near the full moon, and can move out of receiver range rapidly, we estimated locations using radio telemetry during nights to determine the path and trajectory of movement. When we lost an owl's signal, we attempted to locate signals from hilltops near the last known location and worked outward focusing on the last known direction of movement. After owls settled, we continued to monitor movements and behavior on new home ranges and document any additional dispersal movements. We considered owls that engaged in bill contact, preening, feeding, or vocalizations typical of courtship with an owl of the opposite sex as paired if these behaviors were observed after an owl had settled. After transmitter batteries failed, we trapped owls and removed transmitters from all but four individuals that could not be lured into mist-nets. We recorded perch, flight, behavioral, and road-crossing information for juveniles in the same manner as for adults (Objective 1).

ANALYSES

We counted the number of times juvenile owls crossed roads in natal areas before dispersal. For young that eventually settled, we calculated dispersal distance as the straight-line distance between nests and the furthest edge of new use areas. For young that settled in less well-defined use areas, we calculated dispersal distance as the maximum distance traveled from nest sites. We calculated the total distance moved by each dispersing owl by summing the linear distance between successive

groups of locations. Because some owls settled temporarily in finite-use areas for several weeks and then continued to disperse, we used the center of each of these use areas to calculate total distance moved. We considered the onset of natal dispersal as the time of the first movement >300 m from natal areas or adult home ranges; dispersal was usually initiated with one-way movements that were direct, rapid, and from which owls did not return. To estimate the number of roads crossed by each juvenile during dispersal, we inferred road crossing based on the location of roads in relation to the path and trajectory of successive owl locations.

To estimate post-fledging survival, we used the Kaplan-Meier (1958) product-limit method and considered t_0 the time the owl was radio-marked that was always within 24 hrs of fledging. To compare fledgling mass, age, sex, and brood size of young that survived until dispersal with those that died during the natal period we used t -tests. We adjusted mass based on its difference from the population mean for each sex separately. To estimate fledgling age, we considered the number of exposed tail bands at time of fledging. To describe conditions around nests, we classified woodland cover around nests as none, low, medium, and high and recorded distance between nests and roads in 100-m bands for nests within 400 m of a road. To describe factors that explained survival during the natal period, we first averaged the number of days that owls in a brood survived because survival was not independent among brood members. We then assessed whether average survival of each brood varied with adjusted mass, number of tail bands, woodland cover within 90 m of nests, and distance between nest and roads with use of linear regression. To assess the relationship between the minimum number of roads crossed during dispersal and both total distance moved during dispersal and dispersal distance, we used linear regression.

Because understanding factors that explain the timing of natal dispersal could be valuable to managers attempting to foster connectivity among populations of pygmy-owls isolated by major highways (e.g. Interstate 10) or other landscape features (e.g. urban areas), we assessed factors that explained the age that owls initiated natal dispersal as measured by number of days between fledging and dispersal. As explanatory factors, we considered brood size, sex, mass, number of tail bands, year, woodland cover around nests, and the number of days from the full moon when owls began to disperse in a multiple linear regression with stepwise selection. We reported all means \pm 1 standard error.

RESULTS

Effort: We radio marked 54 juveniles (30 males, 23 females, 1 unknown) from 19 broods between 1 and 25 June, 14 in 2003, 18 in 2004, and 22 in 2005. We visited juveniles that survived the natal period an average of 1.5 ± 0.1 times per week ($n = 24$) and those that did not survive the natal period an average of 4.3 ± 0.4 times per week ($n = 30$).

Owl Interactions with Roadways: Seven juveniles (13%) from four broods (21%) crossed paved roadways during natal movements before dispersal. Of the 24 owls that survived until dispersal, the number of roads crossed during dispersal averaged 2.2 ± 0.3 (range = 0-5) for all owls and all classes of roads combined and all except one owl (96%) crossed a roadway during dispersal (Figs. 11-14). Number of roads crossed during dispersal increased with both dispersal distance and total distance moved during dispersal ($t_{22} \geq 2.96$, $P \leq 0.0072$, Fig. 15), suggesting that small- to moderate-sized roads typically encountered in the study area did not pose a significant barrier to dispersing pygmy-owls. No juveniles seemed to change dispersal direction in response to encountering low- or moderate-use dirt or paved roads. One owl that encountered a 4-lane

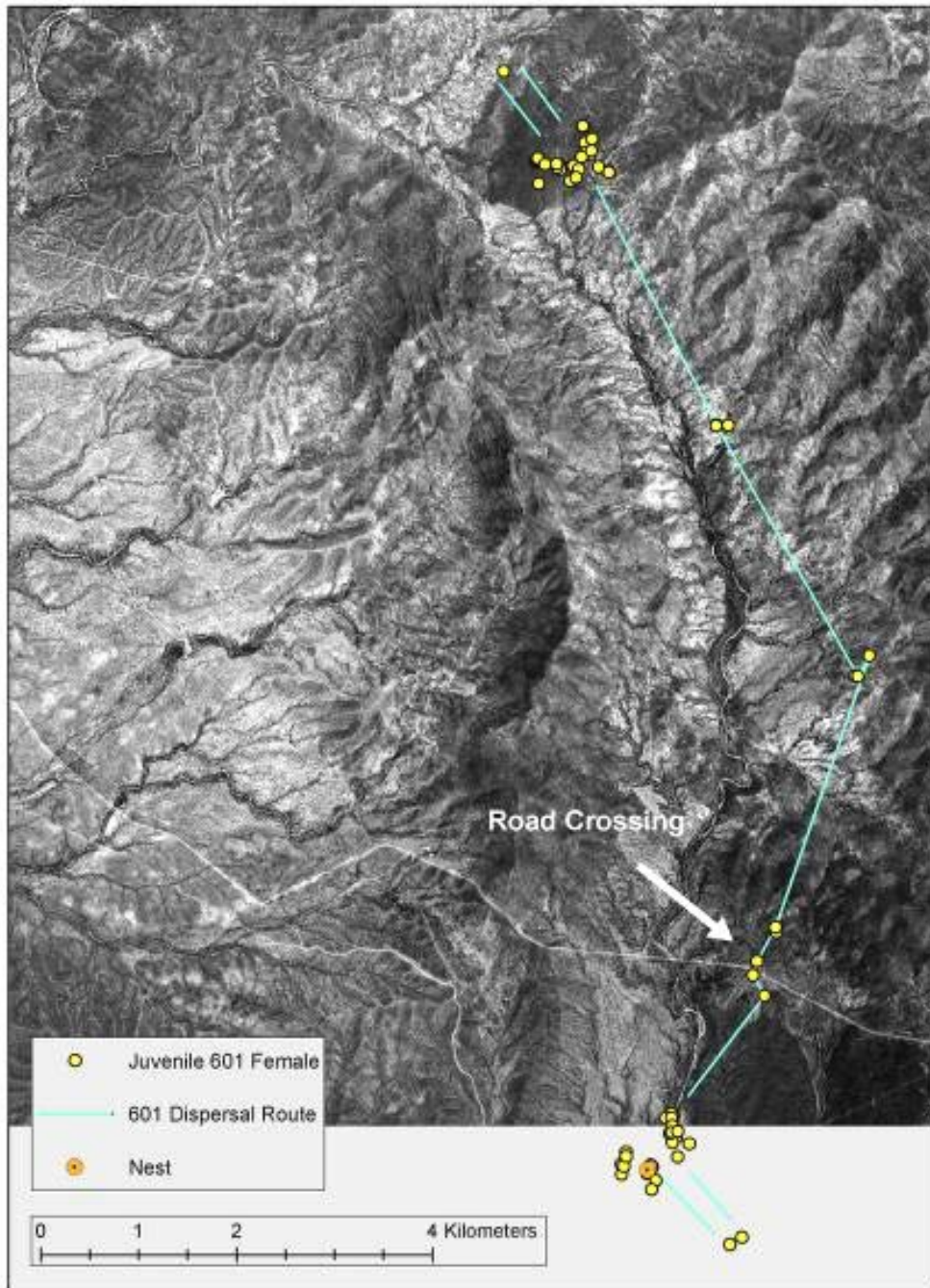


Figure 11: Overhead view of perch locations and landscape features along the dispersal route of a radio-marked juvenile female ferruginous pygmy-owl in northern Sonora, Mexico, 2005. This owl initially moved southeast where it encountered a large disturbed river bottom with little vegetation then returned to its natal area and dispersed 10.7 km north across a moderate-use paved road over 3.5 days. This owl settled for 30 days before transmitter batteries failed and moved a total of 16.0 km during natal dispersal.

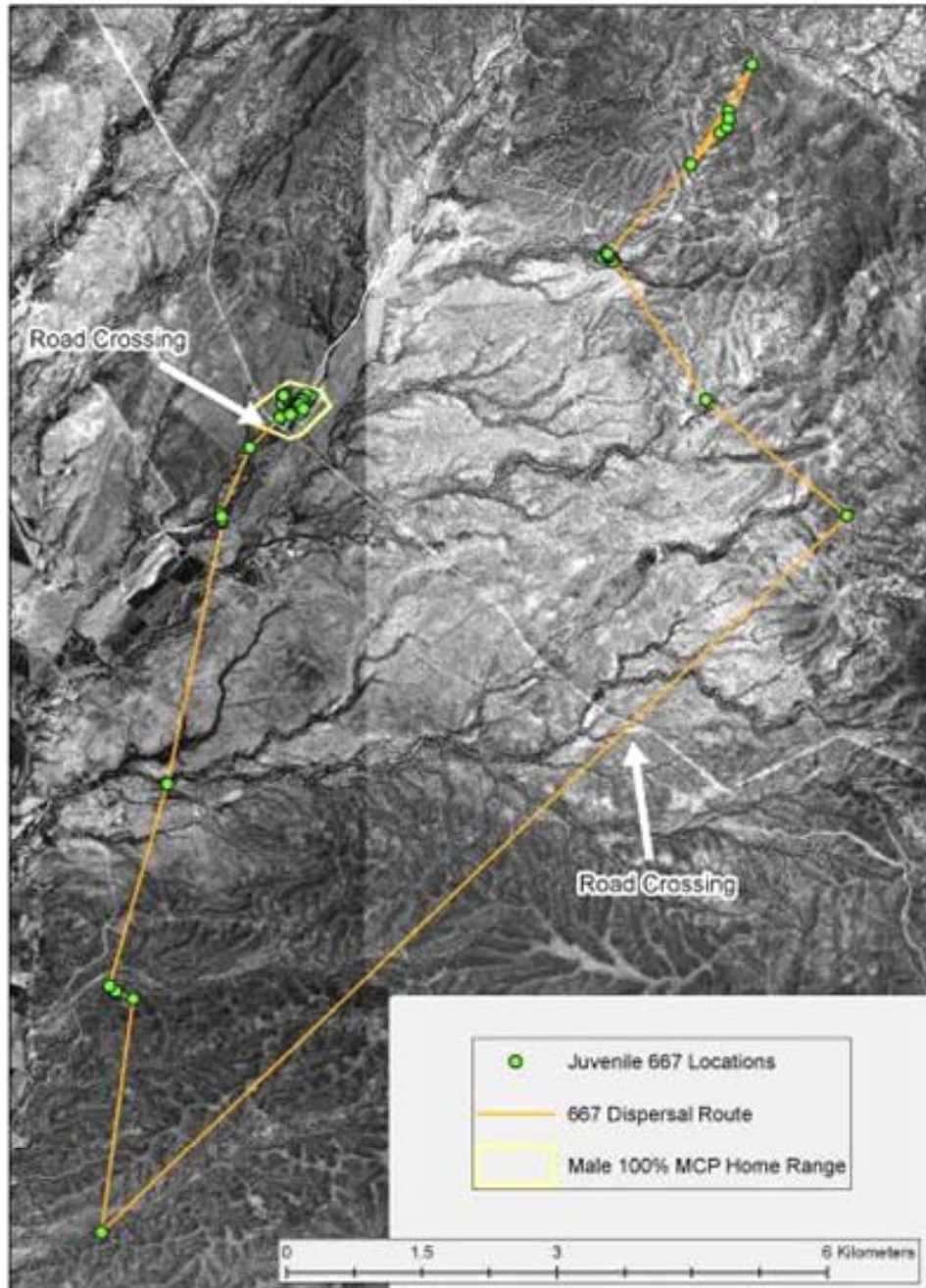


Figure 12: Overhead view of perch locations and landscape features along the dispersal route of a radio-marked juvenile female ferruginous pygmy-owl in northern Sonora, Mexico, 2004. This owl initially moved south and crossed a moderate-use paved road until heading northeast where it again crossed the same road. Total movement during dispersal was 22.3 km over 20 days. This owl settled and paired with 5.7 km from its nest and was monitored for 17 days until transmitter batteries failed. Polygon indicates adult male's home range.

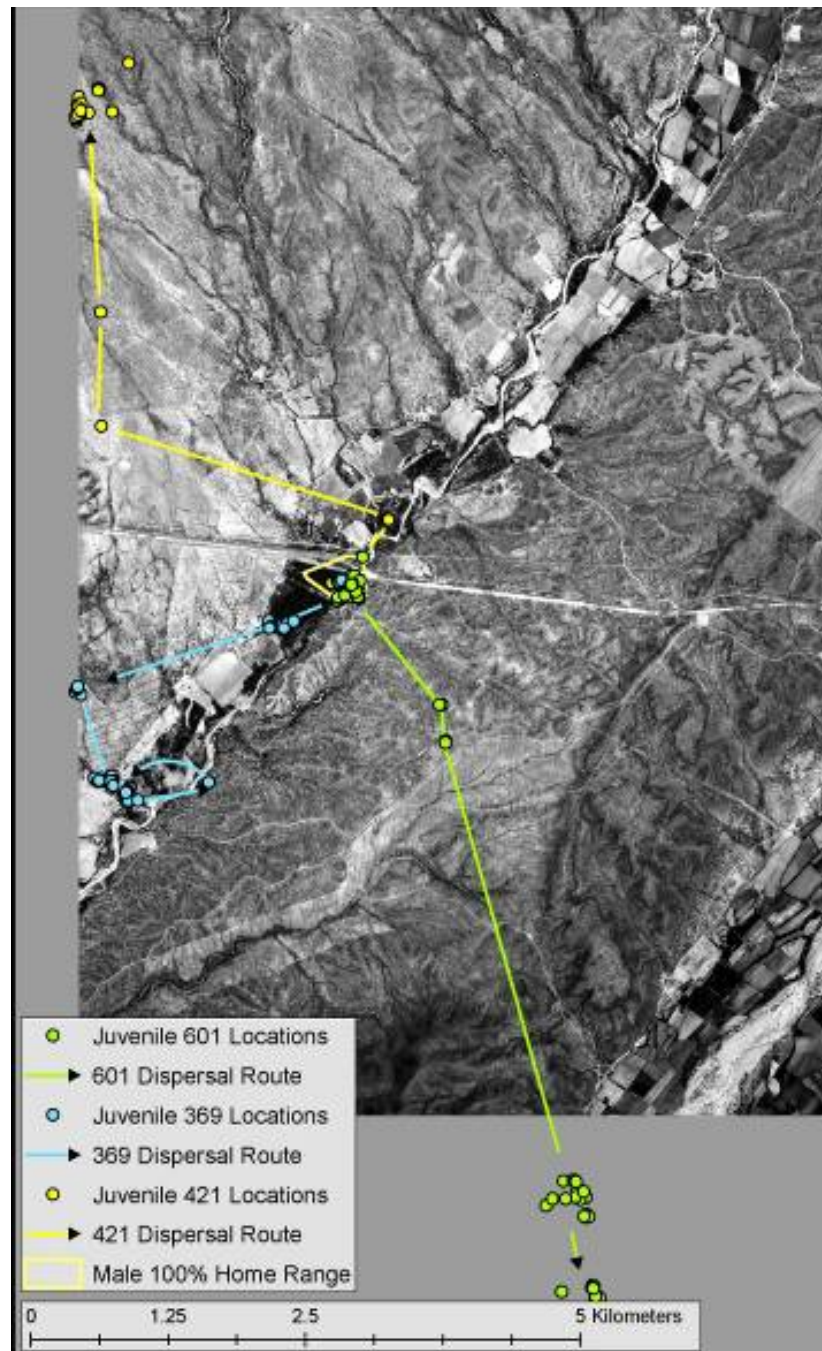


Figure 13: Overhead view of perch locations and landscape features along the dispersal route of three radio-marked juvenile ferruginous pygmy-owls from the same brood in northern Sonora, Mexico, 2003. One male dispersed 5.2 km north and crossed a high-use paved highway during its first movement out of the natal area (Figs. 6 and 7). Another male dispersed 2.8 km southwest whereas a female dispersed 6.8 km south and both crossed large agricultural fields and smaller dirt roads. All males paired and owls remained settled after dispersal for 21 to 24 days.

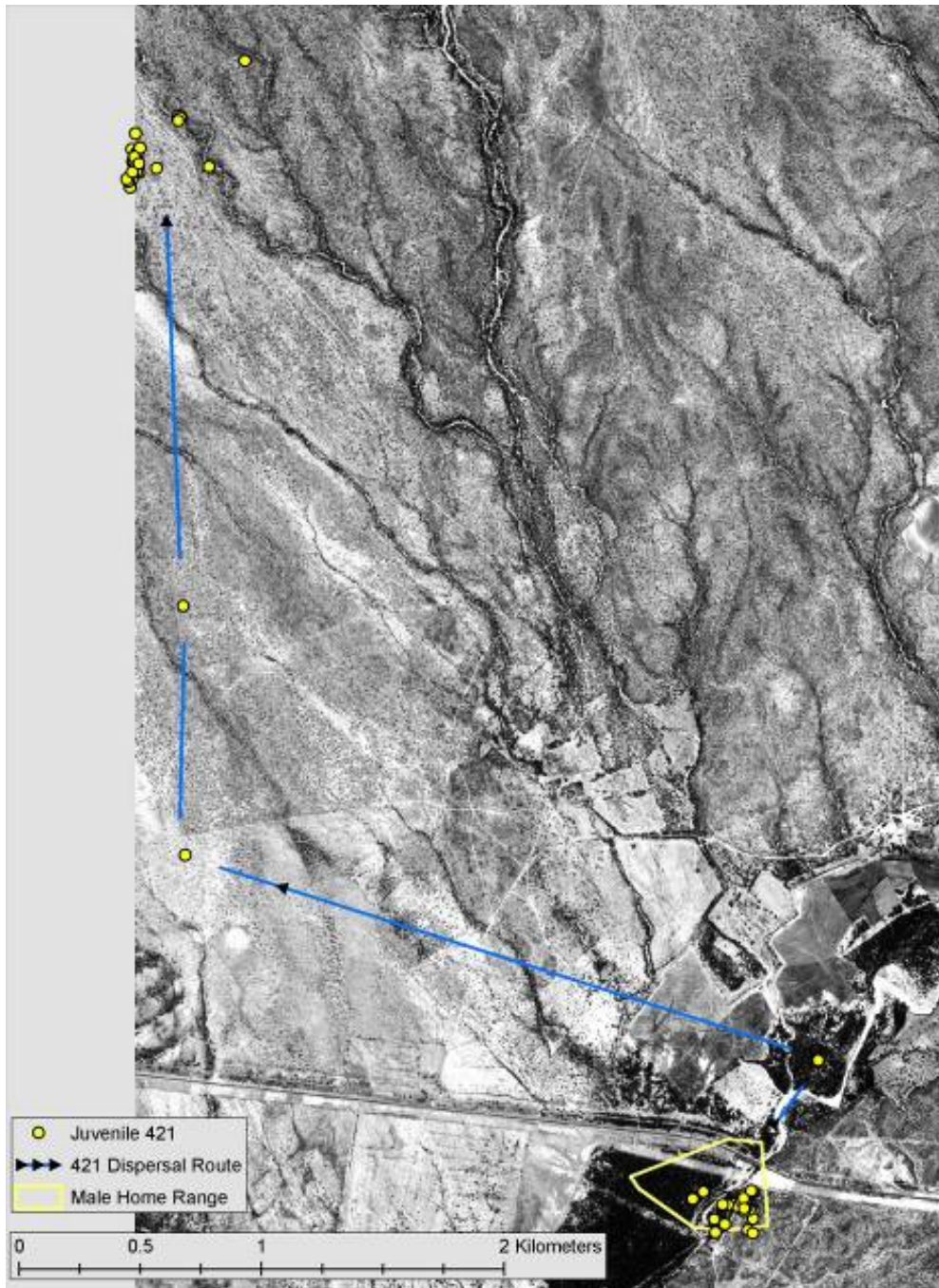


Figure 14: Overhead view of perch locations and landscape features along the dispersal route of a radio-marked juvenile male ferruginous pygmy-owl depicted in Fig. 14 that crossed a high-use paved highway in northern Sonora, Mexico, 2003. This male dispersed 5.2 km. Moved 6.8 km total, and crossed the roadway during its first movement out of the natal area (Figs. 6 and 7).

divided highway roosted for 24 hrs within 50 m of the road edge and moved away from the road before crossing (see below). Two other owls that moved to the edge of large agricultural fields changed direction and did not return; in one of these cases agricultural fields were associated with a large paved highway.

The largest road crossed during dispersal for 36% of owls was a low-use paved road and for 9% of owls was a high-use paved road; other individuals crossed only dirt roads. Only one owl moved toward and crossed Mexico Route 15, the largest paved road in northern Sonora, despite five other owls that dispersed from a nest with 1.2 km of this road. Before crossing Route 15, this owl first roosted in a small patch of woodland at the road edge during daylight hours, suggesting that it hesitated before crossing. The owl crossed Route 15 sometime near dawn the following day, flying a minimum of approximately 150 m across this large four-lane divided highway. This same owl crossed back over Route 15 within three days at an unknown location.

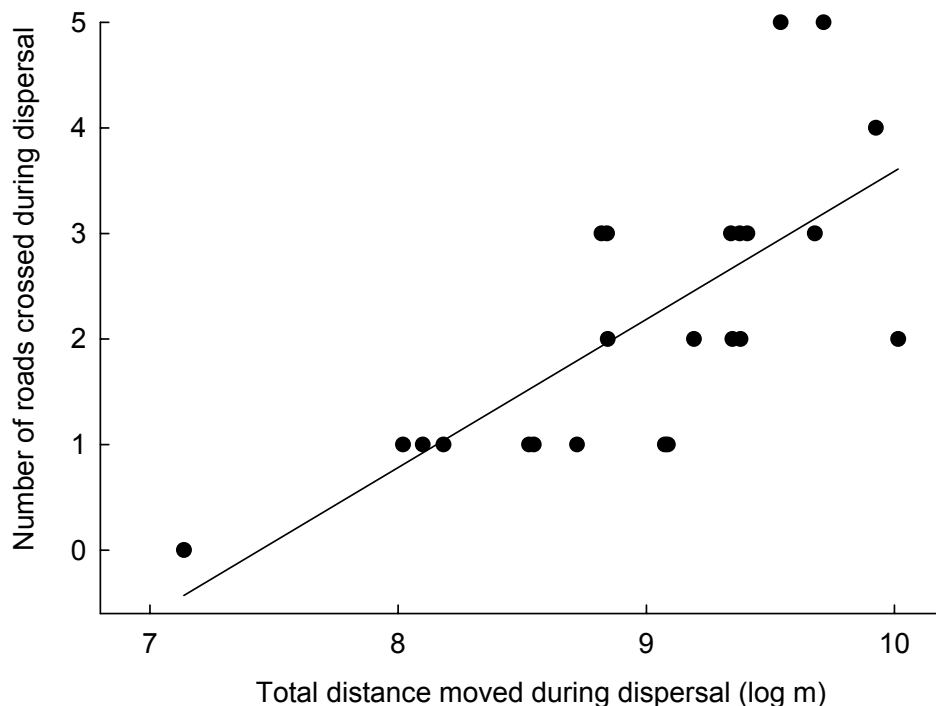


Figure 15: Number of roads crossed during natal dispersal by 24 radio-marked ferruginous pygmy-owls increased as the total distance moved during dispersal (log m) increased ($P = 0.0001$) in northern Sonora, Mexico, 2003-2005. Total distance moved during dispersal was equal to the linear distance between successive groups of locations during dispersal.

Seven owls crossed areas with extensive agricultural development, dominated by large open fields devoid of perch substrates. In these regions, owls used narrow (<15 m) hedgerows of native vegetation that bordered fields and were observed flying between these vegetation patches when crossing open environments.

Flight Behavior: Flight distances of juveniles averaged 26 ± 3 m for all observations ($n = 103$) and ranged from 3 to 335 m. Minimum flight height averaged 1.6 ± 0.1 m and ranged from 0.1 to 5.0 m. Maximum flight height averaged 3.5 ± 0.2 m and ranged from 0.7 to 10.0 m. Flight distance and minimum and maximum flight height did not vary before and after dispersal ($P \geq 0.25$) yet flight distances of juveniles increased by an average of 0.5 ± 0.3 m with each successive day from fledging to onset of natal dispersal ($t_{38} = 1.85$, $P = 0.071$).

The longest flight that we observed by a dispersing juvenile was 335 m across a large agricultural field just before dusk. The only available perches along the flight corridor were brush piles in which the owl perched after a previous flight of 56 m. We observed only one flight over a paved road by a dispersing juvenile that was 32 m in length and between 0.5 and 1 m above ground. One juvenile that dispersed from a natal area near a high-use paved roadway may have crossed the roadway by flying under a large overpass (Fig. 7).

Survivorship: Mortality was high during the period between fledging and 10 days after fledging, moderate between 10 and 53 days, and stable thereafter (Fig. 16). Overall, 56% of juveniles (30 of 54) died during the natal period before initiating dispersal and survived an average of 12 ± 3 days (range = 1-53) after fledging. Only 25, 50, and 75% of these juveniles survived >2, 5, and 20 days after fledging, respectively.

Of juveniles that died during the natal period ($n = 30$), 77% were depredated, one was killed by a coachwhip snake (*Masticophis flagellum*), two by mammals, and 20 by raptors including gray (*Asturina nitida*) and Harris (*Parabuteo unicinctus*) hawks. Two of 17 other juveniles that we monitored after fledging but did not radio-mark were also depredated by a coachwhip snake immediately after fledging. No juveniles were killed by collisions with vehicles.

Only 44% of radio-marked juveniles (13 males and 11 females) survived the entire natal period and all dispersed. Owls that initiated natal dispersal were from 13 broods from which an average of 1.8 ± 0.2 owls per brood survived to dispersal. All juveniles that initiated dispersal survived until transmitter batteries failed an average of 13.3 ± 0.1 weeks after fledging. Owls that survived that natal period were $21 \pm 6\%$ older at time of fledging (as indicated by number of tail bands; $t_{48} = 3.06$, $P = 0.0036$), $5 \pm 2\%$ heavier (after adjusting for differences due to sex; $t_{48} = 2.69$, $P = 0.010$), and had $38 \pm 13\%$ greater coverage of woodlands with 90 m of their nests ($t_{52} = 2.79$, $P = 0.0073$) than juveniles that died during the natal period. There was no difference in sex, brood size, year, day of year, or order fledged between owls that survived until dispersal and those that did not ($P \geq 0.26$, t -tests). Average number of days survived during the natal period per brood increased somewhat as fledging age ($P = 0.080$), woodland cover ($P = 0.072$), and distance between nests and roads increased ($P = 0.10$). Woodland cover increased as distance between nests and roads increased ($r = 0.27$, $P = 0.052$).

Dispersal Timing: Onset of dispersal averaged 58.9 ± 0.9 days after fledging (range = 53-67) and was similar for males and females ($P = 0.41$). For all three years combined, onset of dispersal averaged 12 Aug (SE = 1.3 days, range = 28 July-18 Aug) yet varied markedly among years ($F_{2,21} = 32.3$, $P < 0.001$). In 2003, dispersal began 3.2 ± 1.8 days earlier than in 2005 ($t_{22} = 1.94$, $P = 0.067$,

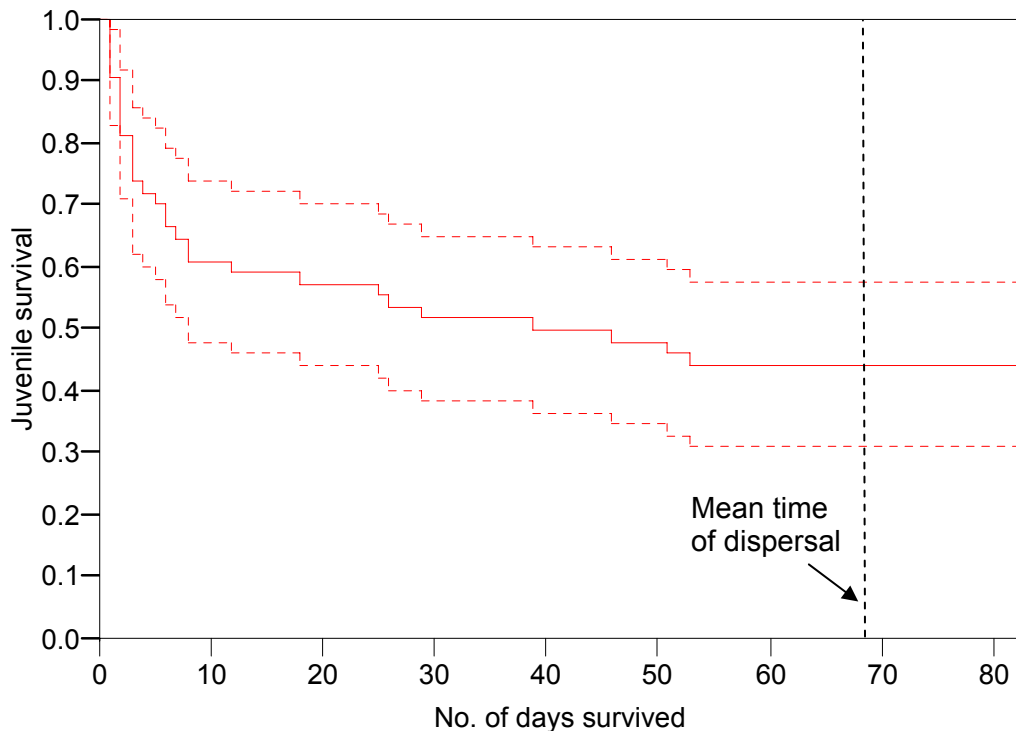


Figure 16: Kaplan-Meier survival curve (\pm 95% confidence interval) for 54 juvenile ferruginous pygmy-owls from 19 broods that were radio-marked within 24 hours of fledging in northern Sonora, Mexico, 2003-2005. Time of natal dispersal is depicted by the vertical dashed line and began an average of 58.9 ± 0.9 days after fledging (range = 53-67). All owls that began to disperse survived until transmitter batteries failed an average of 93.1 ± 0.7 days after fledging. Survival is illustrated up to the minimum time that radio-transmitter batteries functioned for all owls; all owls that dispersed survived until transmitter batteries failed.

linear contrast) despite nearly identical timing of fledging. In 2004, however, owls dispersed an average of 11.1 ± 1.5 days earlier than in other years, yet owls fledged only 7.0 ± 1.0 days earlier ($t_{22} \geq 6.76$, $P < 0.001$, linear contrasts).

All young began to disperse near dawn, dusk, or at night. Age at which young initiated dispersal was explained strongly by moon phase after adjusting for differences among years, with owls waiting one additional day before initiating natal dispersal with each 0.7 ± 0.2 day increase in time until the full moon ($P < 0.001$), a relationship that explained 75% of variation in dispersal timing. After considering the effect of moon phase, neither brood size, sex, mass, or age at fledging was associated with dispersal timing ($P \geq 0.29$). There was also some evidence that the influence of moon phase on age of dispersal depended on year ($P = 0.080$, for moon \times year interaction). For example, in 2004, 57% of young initiated dispersal after an early 31 July full moon, whereas in 2005, all young initiated dispersal before a much later 19 August full moon. Overall, young initiated dispersal an average of 3.3 ± 0.9 days before full moon (range = -12-+6 days), 2.3 ± 1.4 days before full moon (Aug. 12) in 2003, 0.1 ± 1.3 days after in 2004, and 5.9 ± 1.0 days before in 2005.

Dispersal Movements: We monitored owls for an average of 34.0 ± 0.7 days (range = 28-40) after onset of natal dispersal. Most young (79%) never returned to natal areas after initiating dispersal, but those that did return did so 1 to 5 days later and remained in natal areas an additional 1 to 3 days. All individuals initially dispersed in a single direction and explored vegetation patches in varying directions while often moving in the same general direction during each daily dispersal bout. During the first 24 hrs of dispersal, young moved an average of 1.3 ± 0.2 km (range = 0.6-4.7 km, $n = 19$) from the last location in natal areas and most moved through upland rather than riparian vegetation.

Dispersal distance averaged 5.6 ± 0.8 km, ranged from 1.1 to 19.2 km, and did not vary between males and females ($P = 0.89$, $n = 24$). Total distance moved during dispersal averaged 9.7 ± 1.2 km and ranged from 5.5 to 22.3 km ($n = 22$); females moved $56 \pm 29\%$ farther than males ($t_{20} = 1.97$, $P = 0.063$) excluding one male that dispersed >3.4 times farther than the average across the population.

Post-Dispersal Behavior: After dispersal, owls settled in fixed-use areas for an average of 23 ± 2 days, with 75% having been settled for >16 days when transmitter batteries failed. Only one owl was known to have continued dispersing after its transmitter failed and began to move about 18 days after initially settling. Most owls (54%) paired with pygmy-owls of the opposite sex and more males paired (62%) than did females (36%) ($P = 0.21$, Fisher's Exact test, one-tailed test). Males that paired called territorially and were all lured into mist-nets using recorded owl calls indicating that they were territorial. Three males that did not pair inhabited areas in or at the edge of territories occupied by adult males. One male that settled and paired was displaced by another male then settled 1.5 km away. Although most males paired and defended territories, females often used larger areas that were associated with large woodlands in valley bottoms and often occupied by ≥ 1 territorial males.

Objective 3: Effects of Roadways on Nest-Site Selection by Pygmy-Owls

METHODS

Design: We searched for nests of pygmy-owls along transects located within 120 km of Arizona (Flesch and Steidl 2002, Flesch 2003a) and in areas that represented potential habitat for pygmy-owls that were within approximately 2 km of roadways that varied in size from small dirt roads to large paved highways. When we detected owls, we searched for nests by observing owls and searching for sign (pellets and scat) near potential nest cavities. To determine cavity contents and monitor nests we used a small pole-mounted video camera attached to a video display.

To determine whether owls selected or avoided roadways when placing nests, we first needed to identify environmental factors that explained nest-site selection and control for these factors before assessing the influence of roads. Therefore, we compared the environment around nests to available sites selected at random within estimated home ranges. Home-range size of nesting pygmy-owls varies from 9.2 to 52.1 ha in Arizona and northern Sonora (Flesch 2003b, this study), which, assuming a circular home range, equals a maximum radius of approximately 404 m. Therefore to quantify resources available to pygmy-owls, we selected the closest available nest substrate (columnar cactus or tree) with a suitable cavity from a random point located within 400 m of nests. Because pygmy-owls had not been documented using cavities <4 cm in diameter or those without a sufficiently excavated chamber (Flesch and Steidl 2002), we only considered substrates as available if they had a cavity ≥ 4 cm in diameter and ≥ 10 cm deep. Although we measured some available sites after the nesting season, we assumed that all cavities were available to pygmy-owls despite potential competition with American kestrels (*Falco sparverius*), western screech-owls (*Megascops kennicottii*), and perhaps gilded flickers (*Colaptes chrysoides*) as pygmy-owls nest early and appropriate cavities from most other species.

Environmental measurements: We measured environmental features at three spatial scales defined by circular plots with radii of 15 m (0.07 ha), 30 m (0.28 ha), and 90 m (2.54 ha) centered on both nest and random substrates. We counted each species and measured height (m) of all woody and succulent plants ≥ 2 m tall within 15- and 30-m plots. We measured the distance (m) between nests and random substrates and the nearest vegetation edge (upland or riparian), drainage channel (≥ 2 m wide), and all roads out to a limit of 1 km using rangefinders or a GPS. We measured distance and height (m), and recorded species of the closest woody plant (≥ 2 m tall) and saguaro (≥ 3 m tall) in four, 90° quarters delineated by the cardinal directions and centered on nest and random substrates (Cottam and Curtis 1956). We estimated percent cover of each vegetation formation (desertscrub, woodland, savannah, grassland, or thornscrub) within 15, 30, and 90 m of nest substrates. We estimated cover to the nearest 10% when values were between 20 and 80% and to the nearest 5% otherwise. We recorded whether substrates were located in upland or riparian areas, and in woodland, desertscrub, savannah, or thornscrub vegetation formations. We classified roadways into four classes: low-use dirt, moderate-use dirt, low-use paved, or high-use paved highways.

ANALYSES

We compared distances to the nearest and largest road class between nests and random substrates with paired t-tests. To determine factors that best explained nest-site selection, we used case-

controlled logistic regression (Hosmer and Lemeshow 1989). We first screened explanatory variables to reduce redundancy; when variable pairs were correlated ($r > 0.7$) we retained the variable with the most direct biological interpretation. Because composition of plant species varied, we assessed selection by owls in desert scrub and semidesert grasslands separately. Because the number of potential explanatory variables was high, we first fit several smaller models with groups of related variables to eliminate those with little explanatory power ($P < 0.25$) (Ramsey and Schafer 2002) and used stepwise selection ($P < 0.25$ to enter, $P < 0.10$ to stay) and drop-in-deviance tests to guide model selection (Hosmer and Lemeshow 1989). We fit models separately for the three plot sizes and assessed the influence of distance to the nearest and largest road using drop-in-deviance tests after first adjusting for all factors with explanatory power ($P < 0.10$). To assess the relationship between nest success (nests that produced at least 1 young) and roadway conditions, we used logistic regression and considered distance to road, type of road (paved vs. dirt), their interaction, and year as explanatory variables. For this analysis, we excluded nests >400 from a road. Means are reported ± 1 standard error.

RESULTS

Nest Distribution: We located 106 nests, 58 along transects and 48 in areas surveyed along roads. Nests were located between 360 and 1,085 m elevation and all were in saguaros except two that were in large Mexican ebony trees (*Havardia mexicana*). Most nests were in the Arizona Upland

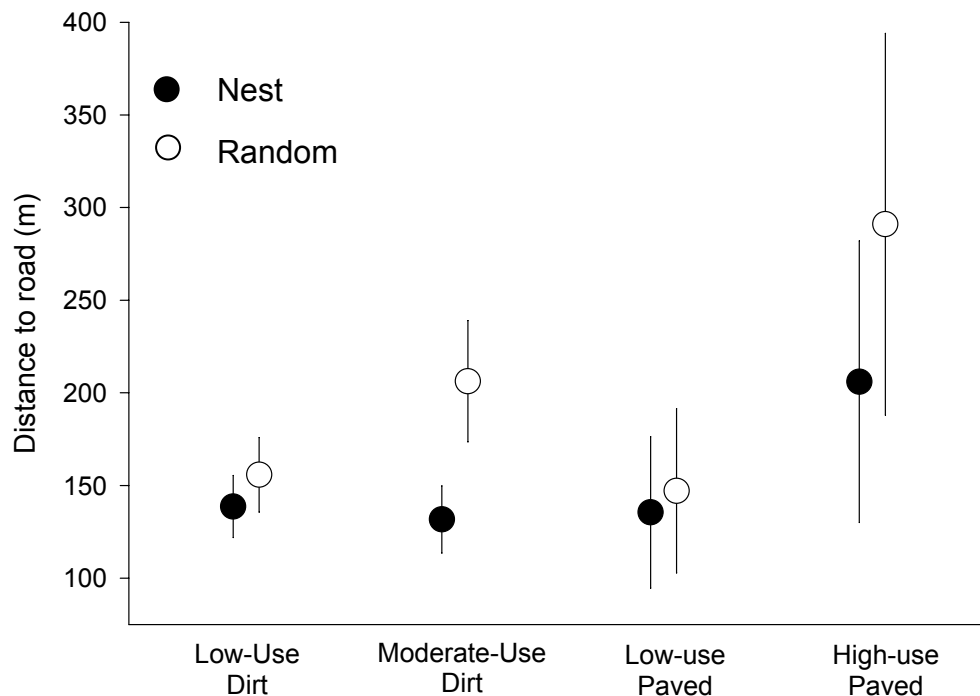


Figure 17: Average distance (\pm SE) between 81 pygmy-owl nests and paired random substrates and roadways of varying sizes in northern Sonora, Mexico for nests within 400 of a road. Pygmy-owls selected nest substrates that were closer to roads than available potential nests.

subdivision of the Sonoran Desert (52%) and semidesert grasslands (46%), with two (2%) in Lower Colorado River Valley desertscrub. Approximately 80% ($n = 85$) of nests were in areas of upland vegetation and 20% ($n = 21$) were in areas of riparian vegetation. Most nests were in savannah (41%) and desertscrub (35%) vegetation formations and fewer were in woodland (23%) and thornscrub (1%).

Distance between Nests and Roads: Of the 81 nests within 400 m of a road, the distance between nests and the nearest road averaged 128.3 ± 11.6 m, with 48% of nests located within 100 m of roads. Relative to random substrates, nests within 400 m of roads were located an average of 42.8 ± 16.2 m closer to the nearest road ($t_{80} = 2.64$, $P = 0.010$), 41.8 ± 16.2 m closer to the largest road ($t_{78} = 2.58$, $P = 0.012$) and were closer to all classes of roadways than were random substrates (Fig. 17). Nests within 400 m of roads averaged 138.6 ± 12.0 m from dirt and low-use paved highways and 206 ± 76 m from high-use 2- to 4-laned paved highways (Fig. 17). Twenty percent of nests located with 400 m of a road were located near 2 to 4-laned paved highways.

The nearest a nest was to a low-use dirt road was 2 m, to a moderate-use dirt road was 12 m, to a low-use 2-laned paved highway was 14 m (Fig. 18), and to a high-use 2 to 4-laned paved highway was 49 m. The nearest a nest was to a cleared roadway corridor was 1 m for low-use two-lane paved highway and 18 m for a high-use two-lane paved highway.

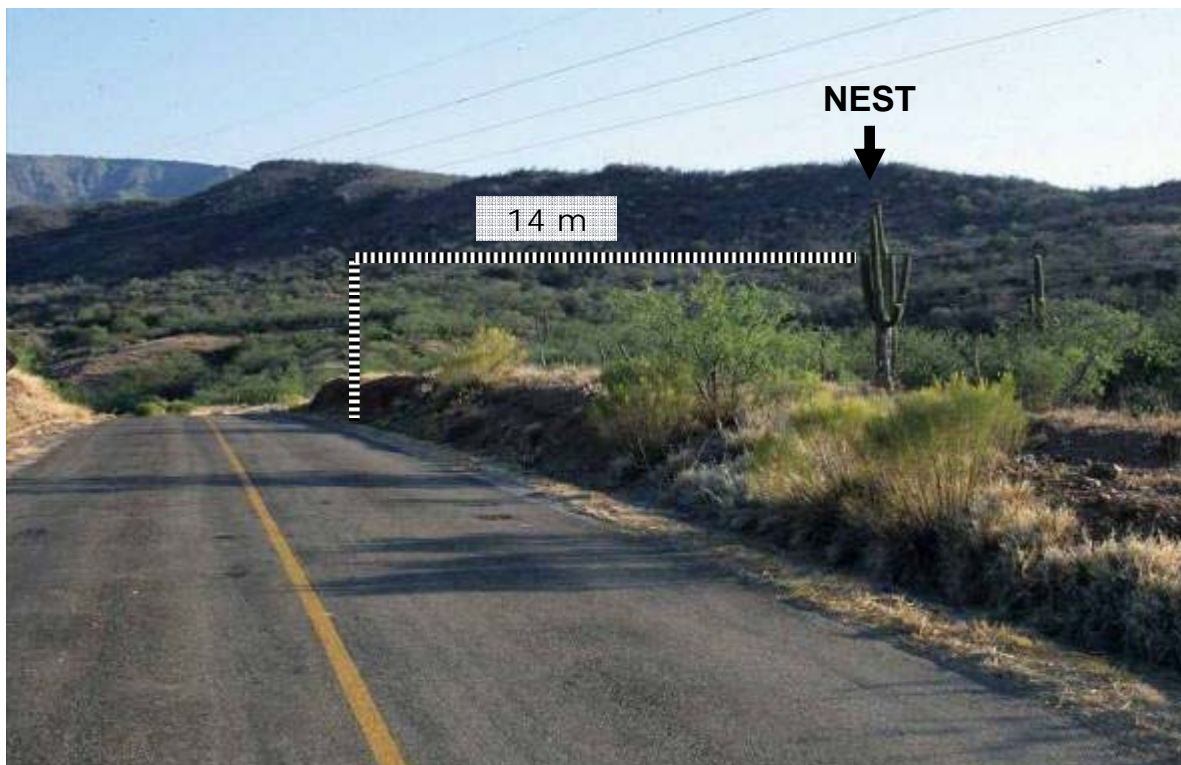


Figure 18: Pygmy-owl nest placed 14 m from a low-used paved roadway and 1 m from the associated roadway corridor in northern Sonora, Mexico, 2001. Traffic volume along this road averaged 7.2 ± 0.9 vehicles per 20 minutes. A territorial male owl that occupied this territory in 2004 and nested 490 m from this roadway crossed the road during 15.4% of 39 3 to 5 hour observation periods.

Nest-Site Selection: For nests within 400 m of a road in desertscrub, the odds of a nest area being selected increased by a factor of 1.3 with each 1-m decrease in distance to a road ($\chi^2_{235} = 6.33$, $P = 0.012$) after adjusting for other factors that influenced selection (tree height, cavity density, and vegetation volume). Nests in semidesert grasslands were not placed closer to roads than random substrates after adjusting for other factors yet few nests ($n = 6$) in this vegetation community were near paved roads and none occurred near high-use two- to four-lane paved highways.

Reproductive Performance: Distance to the nearest road affected nest success, although the effect varied somewhat with size of roads (paved or dirt) (distance x road interaction: $\chi^2_{263} = 2.83$, $P = 0.093$) after controlling for annual variation in nest success. Although only 10 failures were recorded, nests within 200 m of larger roads were more likely to fail than those farther from smaller roads (Fig. 19). Nests that were >200 m from dirt roads had 100% success ($n = 15$ of 15) whereas nests within 400 of paved roads had 73.3% success ($n = 11$ of 15) (Fig. 19).

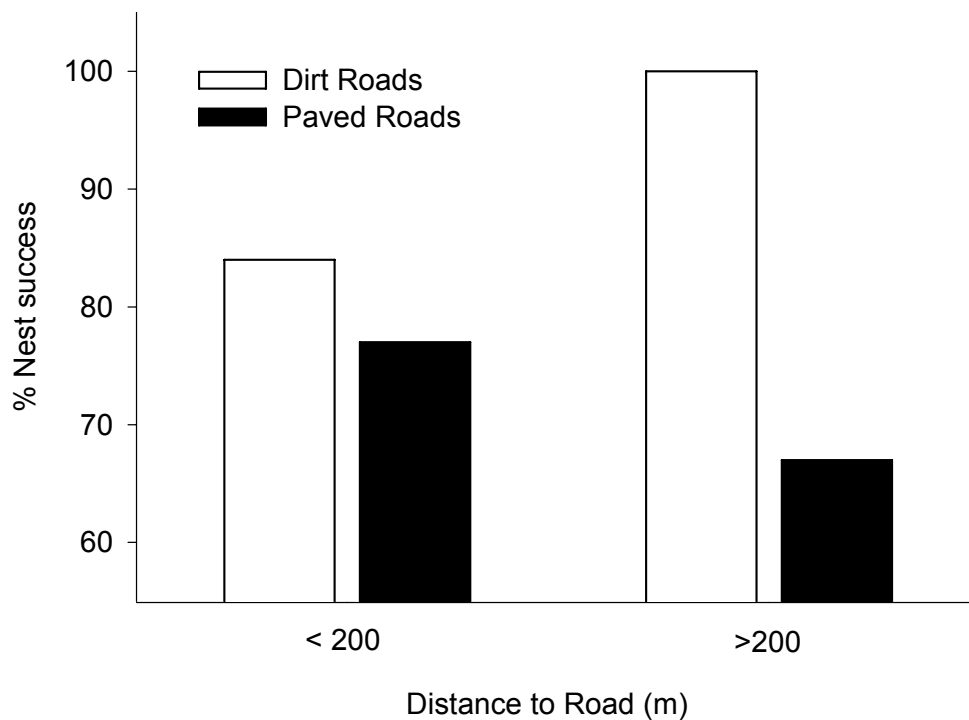


Figure 19: Percent nest success (nests that produced at least 1 young within a week of fledging) of pygmy-owls versus distance to and type of adjacent roadways in northern Sonora, Mexico, 2001 to 2003. Only nests within 400 of a road were considered ($n = 67$). Dirt roads were often narrower with lower traffic volume and paved roads were wider with higher traffic volume. Nest success was lower for nests placed closer to roadways and nests within 400 m of larger paved roads.

Objective 4: Document Intensity and Variation in Noise Levels at Pygmy-Owl Nests Adjacent to Roads with the Assistance of ADOT Staff

METHODS

We attempted to measure intensity of noise levels at nests near roadways in summer 2003. After meeting at the field site with Fred Garcia from ADOT, variation in topographic and vegetation obstructions near nests were deemed too variable to facilitate measurements with ADOT equipment. Should the Department wish to make these measurements in the future, we will provide detailed on-site coordinates of former nest locations near large roadways.

RESULTS

Although no quantitative measurements were made, pygmy-owls did use nest sites adjacent to roadway corridors where traffic volume exceeded 5 vehicles per min (see Objectives 1 and 2). In these areas, noise from truck brakes and tractor trailers were common especially in early morning and late afternoon hours when owls were often active. Because these disturbances were present at the time when owls selected nest sites near roadways they did not represent novel stimuli which are likely much more disruptive than consistent, existing disturbances.

DISCUSSION

Fostering persistence of wildlife populations in landscapes that have been altered significantly by human activities is a major conservation challenge. Roadways and their corridors, for example, fragment landscapes by creating openings in vegetation that may reduce the permeability of landscapes by wildlife; however, the influences of roadways on wildlife are not well understood (Forman and Alexander 1998, Transportation Research Board 2002). Studies of the effects of roadways on wildlife, especially on large and medium-sized mammals (e.g. Brody and Pelton 1989, Beier 1993, Haas 2000, Riley et al. 2006), suggest that the size, traffic volume, crossing features, and vegetation along roads can affect movements and behavior of wildlife in complex ways (Bennett 1991, Forman and Alexander 1998, Ng et al. 2004). As more information becomes available, there is increased potential to develop transportation plans that meet the needs of humans and minimize adverse effects on wildlife. In southern Arizona, information on ferruginous pygmy-owls, a species of profound conservation concern, is critical because populations have declined to near extinction (USFWS 1997, Johnson et al. 2003).

Habitat Quality and Roadways: By comparing locations selected by owls for nesting to those available, we found that pygmy-owls did not avoid roadways when selecting nests. Instead, owls often placed nests closer to roadways than would be expected by chance regardless of the size of roads. Because roads were equally likely to be parallel or perpendicular to dense vegetation along drainages near where owls often placed nests, this result was not an artifact of the spatial arrangement of roads and drainages in the study area. Owls may place nests near roadway corridors because of the increased visibility created by edge conditions. Like many other raptors, pygmy-owls are associated with vegetation edges, especially those between mesquite woodlands or tropical deciduous forest and arborescent scrub or savannah in Sonora (Flesch 2003a). Vegetation edges increase access to and visibility of prey (Johnston 1970, Szaro and Jakle 1985) and offer close proximity to both woodlands and large columnar succulents that contain nest cavities that typically occur in uplands.

Selecting nests closer to roadways may have consequences for reproduction and survival of pygmy-owls. Although no radio-marked owls ($n = 63$) were killed by collision with vehicles, habitat quality may be lower at nest sites near roads. Nests placed closer to large roads were more likely to fail (Fig. 19) and survival of fledglings seemed lower at nest sites that were closer to roads. Consequently, selecting nests closer to roads may represent an “ecological trap” (Gates and Gysel 1978) for pygmy-owls. Both road-induced mortality (Mumme et al. 2000) and noise disturbance (Reijnen and Foppen 1994) have been shown to reduce habitat quality of birds nesting near roadways. For pygmy-owls, lower habitat quality along roads is likely a result of changes in habitat characteristics induced by roads rather than a direct result of vehicle traffic or noise.

Quantitative Thresholds of Roadway Permeability: When landscape features such as large roadways limit movements of wildlife, the loss of landscape connectivity that results can reduce population size, movements, and genetic diversity, and can interact with stochastic factors to increase extinction risk (Wilcox and Murphy 1985, Soulé 1986, Riley et al. 2006). For pygmy-owls, understanding factors that explain the rate at which owls cross roads and relationships between flight behavior and the surrounding environment have enabled us to address whether roadways will limit movements. We found that the chances of a nesting pygmy-owl crossing a roadway were influenced by the proximity of nests to roadways and by characteristics of the roadways themselves. Although owls that nested closer to roadways were more likely to cross them, both the width of roadway corridors and traffic volume reduced the rate of crossing roadways located in or adjacent to their home ranges. For owls nesting 200 m from a road, we estimated that an average of 6 vehicles

per minute would prevent an owl from crossing the road. For owls nesting 100 m from a road, this threshold increased to 20 vehicles per minute, emphasizing that rate of road crossing was influenced strongly by the spatial arrangement of nest sites and roads and the frequency with which owls encounter roads. Similarly, for owls nesting 200 m from a road, a road corridor approximately 170-m wide would prevent an owl from crossing. When supplemented by direct observations of pygmy-owls near roadways, these data suggest clearly that owls both perceive vehicle traffic and actively seek to avoid collisions with vehicles.

Although our results suggest potential thresholds to mitigate the influence of roadways on pygmy-owls, they should be interpreted cautiously. We obtained few observations of pygmy-owls along the largest roadways in Sonora because these features are not common on the landscape and few pygmy-owls nest along these roadways due to limited habitat. Few sites at this end of the gradient reduced the precision of our estimates. Therefore, to determine traffic volume and road-corridor width that would preclude crossing by pygmy-owls, we extrapolated beyond the range of data (Figs. 1-2) which assumes that these relationships remain linear at high levels of both factors. Further, because width of road corridors and traffic volume were highly correlated, we could not distinguish between the effects of these factors.

Habitat Selection and Implications for Roadway Permeability: When selecting habitat within home ranges, pygmy-owls almost always selected larger trees and areas with moderate to high vegetation volume and tree density than were available at random, and these characteristics were often associated with woodland vegetation. Further, pygmy-owls selected mesquite more often than other tree species such as paloverde (*Parkinsonia* sp.) and shrub species less often than available. When crossing roads, these patterns of selection were expressed as an important pattern: adult owls often used patches of woodland vegetation or dense arborescent scrub that were associated with drainages before, during (in medians), and after crossing roadways (Figs. 6-10). Therefore, presence of woodland vegetation such as that selected by owls within home ranges is likely an important factor identifying potential crossing corridors as has been found for some mammals (Clevenger and Waltho 2004, Ng. et al 2004). In our region, because woodland vegetation is generally associated with riparian areas and therefore often occurs in linear stands, these areas can form a natural conduit through which movements of pygmy-owls can be directed and targeted for improvement along roadways.

Recent studies evaluating attempts to direct wildlife movements across roadways have focused on assessing the influence of crossing structures, such as overpasses and culverts, on the rate of use by wildlife (e.g. Clevenger and Waltho 2004, Ng et al. 2004). These studies and others (Yanes et al. 1995, Cain et al. 2003) found that intensity of use of these features varied greatly among taxa and that use of these crossing structures by wildlife was affected by elements of the surrounding environment, including culvert dimensions, road width, height of boundary fences, or complexity of the vegetation along the route. We never observed a pygmy-owl using box or pipe culverts to cross roadways likely because these structures were rare or absent in most home ranges. We suspect that owls will not use these structures unless vegetation connectivity and clearance are relatively high and spans are short. We did, however, observe one adult male cross under two large consecutive overpasses along a major highway (Figs. 7-8) and we observed many other individuals using riparian vegetation corridors before and after crossing roads (Figs. 9-10). These observations suggest that maintaining a high degree of vegetation connectivity and woodland vegetation along drainages near road edges and under overpasses will enhance landscape connectivity for pygmy-owls.

Flight Behavior and Roadway Interactions: Previous information on flight behavior of pygmy-owls suggested that they flew only short distances and did not cross large vegetation openings in single flights (Abbate et al. 1999, 2000, G. Proudfoot, personal communication). Roadways, therefore, were assumed to pose a significant barrier to movements by pygmy-owls, potentially isolating subpopulations separated by large roadways. This suggested that pygmy-owls in northwest Tucson, both east and north of Interstate 10, were likely to become isolated because they were at the north-easternmost extreme of their range and habitat was being lost and fragmented due to urban development (USFWS 1997).

We found that although flight distances were typically short (<40 m), pygmy-owls were not limited to short flights. Overall, 3.2% of flights by radio-marked adults were >80 m with few flights >100 m, yet one radio-marked juvenile flew 335 m perch to perch. Because the difficulty of observing these events increases with distance, longer flight events were likely somewhat more common than we report, especially for individuals that occupied open grasslands and savannah or a matrix of woodland and cleared lands. Although uncommon, these flight events illustrate that pygmy-owls occasionally fly long distances and cross large vegetation openings such as agricultural fields within home ranges and during natal dispersal. Despite the potential for longer flights, however, they were not common and areas with large vegetation openings likely deter owls and have consequences for movements.

Flight distances were explained largely by characteristics of the vegetation especially the availability of suitable perches. For example, average flight distances by individuals were explained largely by local tree density within home ranges. Males flew longer distances when they flew from perches higher above ground and flew almost three times further than the nearest potential perch substrate along flight paths, indicating that owls often fly much longer than the minimum distances necessary when traversing their home ranges.

Flight patterns of pygmy-owls were typically U-shaped and involved dropping rapidly from perches and flying just above or through understory vegetation until ascending rapidly just before perching. This pattern is not unique to pygmy-owls and has been described for several other species of owls that inhabit woodlands (see Gehlbach 1994). Although this flight strategy is likely a result of lower predation risk from aerial predators, it imposes a relatively high risk of collision with vehicles because flights are usually near the ground. Importantly, minimum flight heights were lower when tree densities and vegetation volume were lower as is often found along roadway corridors that are managed for high visibility and therefore low vegetation cover. Therefore, establishing taller vegetation along roadway corridors will likely reduce the risk of collisions with vehicles.

Dispersal and Roadways: Juvenile pygmy-owls dispersed between 1.1 and 19.2 km from their natal sites in northern Sonora, distances that were somewhat shorter than those observed in Arizona (2.3-34.8 km, USFWS 2002). Longer dispersal distances in Arizona likely result from lower availability of habitat than in Sonora, requiring owls to move greater distances to locate suitable patches of vegetation. Although we monitored most juveniles for only 2 to 6 weeks after they settled, some owls may have dispersed farther after transmitter batteries failed. The high number of owls that paired and became territorial, however, suggests otherwise. We suspect that our estimates of dispersal distance for some females do not represent actual natal dispersal distances because fewer females paired and some likely moved again in search of males in mid winter. Males, in contrast, rarely move after they settle and become territorial immediately after natal dispersal (Abbate et al. 2000, USFWS 2002). We also found that males that settled, paired, and exhibited territorial behavior rarely continued to disperse unless negative conspecific interactions with other males

occurred. In contrast, males displaying less territorial behavior often continued to disperse after settling initially.

Small- to moderate-sized roadways that were typically encountered by dispersing owls in northern Sonora did not seem to affect movements. If they had, we would not have observed a strong linear relationship between the number of roads crossed and total distance moved (Fig. 15). In contrast, large vegetation openings, such as those along large roadways and agricultural fields, did seem to affect movements. For example, our single observation of a dispersing owl near a large high-use four-lane highway indicated that the owl moved from its natal area directly toward to road's edge. The bird remained within 20 m of the road during its first morning of dispersal, roosting in a patch of woodland during the day. At dusk, the owl moved away and parallel to the road until roosting approximately 500 m from the road during the night and then crossed at dawn. Similarly, an owl that dispersed into a large (>5 ha) remnant patch of woodland in a broad valley surrounded on three sides by agriculture remained there for approximately 48 hrs until it was later located 390 m from the woodland edge in a narrow, isolated hedgerow. This owl continued dispersing the following evening by flying 335 m across another field to the nearest available patch of native vegetation along its northbound dispersal trajectory. In these instances, presence of large openings seemed to slow the pace of dispersal yet the general trajectory did not change. In two other cases, owls that encountered large agricultural fields changed dispersal direction and did not return to these areas.

Compared to adult pygmy-owls during the breeding season, dispersing juveniles crossed roadways and other vegetation openings more frequently, likely because finding vacant habitat patches before conspecifics necessitates tolerating unsuitable environments during this critical life stage. Although most movements across roads by adults involved use of denser vegetation often associated with drainages, juveniles often crossed roadways in uplands far from the nearest riparian vegetation. Therefore, managing vegetation only where roads cross drainages may not necessarily increase landscape connectivity for pygmy-owls.

Noise Disturbance: Close proximity between some nests and larger roadways suggests that moderate to high levels of existing traffic noise did not affect nest-site selection by pygmy-owls. Because traffic noise was present when the owls we studied selected nest sites near roads, this does not preclude the possibility of novel disturbances disrupting nesting activity even if noise levels are lower than at sites where owls are already habituated to traffic noise. Noise has been suggested as reducing habitat quality for willow warblers (*Phylloscopus trochilus*) by reducing mate attraction and retention rates (Reijnen and Foppen 1994).

MANAGEMENT RECOMMENDATIONS

Where roadways traverse areas of high conservation value, concern for wildlife should be an essential element of roadway design. For threatened and endangered wildlife especially, these design elements should allow wildlife to cross roadways easily and minimize risks associated with crossing. Although design of roadway corridors can affect all wildlife, species of moderate size and with moderate area requirements such as pygmy-owls may be affected most. Species with high mobility and large area requirements can usually permeate all but the most fragmented landscapes (Beier 1993, Riley et al. 2006). In contrast, species with low mobility and small area requirements can persist in smaller habitat patches without the need to traverse large areas of non-habitat. Consequently, designing roadways to minimize adverse effects on species of moderate size likely has the greatest potential for overall success.

Initially, USFWS had established a road corridor width of 40 feet (12 m), beyond which projects may adversely influence pygmy-owls. Based on our observations, roads of this size that have low traffic volume should not affect movements of pygmy-owls unless they are associated with other large vegetation openings such as agricultural fields. In contrast, we found that large roadway corridors with high traffic volume may present a more significant obstacle to pygmy-owls. For these roads, principally interstate and large state highways, crossing by pygmy-owls may be facilitated by planting and maintaining large trees as close as is possible to roadway edges and in medians (Fig. 5). Based on flight distances we observed (Fig. 3), placing trees that can support flights from perch to perch of approximately 30 m or less will be most likely to facilitate crossing by pygmy-owls. Planting and maintaining large trees near the edges of roadways and in medians will increase the probability that roads can be successfully traversed by pygmy-owls because tall trees fostered longer flights that were higher above ground (Tables 3-4).

Because crossing corridors are of little value when they do not connect patches of habitat (Ng et al. 2004), presence of woodland vegetation, especially those composed of mesquite, along roadway corridors and in medians (Fig. 6) and below overpasses (Fig. 7), will increase the potential that a corridor will be used by pygmy-owls. Because pygmy-owls often used drainage channels when crossing roads, planting and maintaining woodland vegetation in riparian areas will be especially beneficial.

Efforts to create riparian vegetation in highly fragmented landscapes are likely to be most beneficial when focused in areas that promote connectivity at larger spatial scales. Although maintaining and restoring large trees and riparian vegetation along roads will conflict to some degree with the practice of clearing roadsides of large vegetation to enhance safety and visibility for motorists, even single large trees and small linear stands of riparian vegetation that are placed near potential flight corridors should enhance movements by pygmy-owls. Further, by protecting large trees, saguaros, and woodlands along roadways that traverse pygmy-owls habitat, occupancy by pygmy-owls in these areas can be preserved (Flesch 2003a).

We are uncertain whether tall trees alone will promote flights that are long enough and high enough to allow pygmy-owls to cross wide, open road corridors above traffic. Therefore, another alternative would be to place roadways below the level of the surrounding landscape, similar to situations created by tall vertical cut banks along drainages that may discourage owls from dropping to heights just above the roadway. Similarly, maintaining roads at their present level but creating earthen embankments upon which tall trees are planted both along roadsides and in medians may also promote movements above traffic. These structures, however, may negatively affect movements of other species such as mammals. In all cases, plantings and other structures to enhance roadway

permeability should be placed carefully with respect to potential use by owls and other wildlife. Modifications that we recommend will be most valuable when focused in areas that are essential for connectivity between populations of pygmy-owls, such as those along Arizona Route 86 between Tucson and Quijotoa that connect larger populations of pygmy-owls in Mexico with those in Arizona and along portions of Interstate 10 near Tucson that connect populations east and north of the interstate with those south and west.

In areas where large multi-lane highways are likely limiting movements of pygmy-owls, such as along Interstate 10, enhancing and creating the features that we recommend may be insufficient to ensure that recovery objectives (USFWS 2003) are met. In these situations, we suggest that both passive (connectivity) and active (facilitated dispersal) means for facilitating roadway permeability by pygmy-owls and other sensitive wildlife species be considered at least in the short term. The information we provide on timing of natal dispersal will be useful for determining optimal times to trap soon-to-disperse pygmy-owls for translocation into available habitat that is potentially isolated by large interstates and urban areas.

Although we observed pygmy-owls nesting in areas with moderate to high levels of traffic noise, novel disturbances near nests of owls that are not habituated to noise may disrupt nesting. Until these relationships are understood, we recommend that high levels of noise created by road maintenance and construction activities near existing nests be focused before or after the courtship and nesting seasons and that all potential nesting habitat near proposed maintenance and construction activities be surveyed using existing protocols (USFWS 2000, Flesch and Steidl 2007).

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