Population Trends and Implications for Monitoring Cactus Ferruginous Pygmy Owls in Northern Mexico

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Key words

Although once described as common in lowland central and southern Arizona (Bendire 1888, Fisher 1893, Breninger 1898, Gilman 1909, Bent 1938), cactus ferruginous pygmy owls (Glaucidium brasilianum cactorum; hereafter, pygmy owls) have been extirpated throughout much of their former range in Arizona. As a result, this northernmost subspecies of ferruginous pygmy owls (Van Rossem 1937, Johnsgard 1988) are now listed as endangered by the U.S. Fish and Wildlife Service (USFWS 1997, Hardy et al. 1999).

Immediately south of Arizona in northern Sonora, Mexico, pygmy owls occur primarily in desert-scrub and grassland vegetation communities where woodlands are near stands of large saguaro cacti (*Carnegia gigantea*) (Flesch 2003*a*). Because pygmy owls are thought to be abundant in northern Sonora, these populations may prove critical for recovery in Arizona as well as for long-term persistence of pygmy owls in the Sonoran Desert. Natural or facilitated dispersal of pygmy owls from Sonora may augment populations in Arizona, especially when combined with habitat management (USFWS 2003). Numerous threats to pygmy-owl habitat exist in northern Sonora, however, including woodcutting, vegetation clearing for agriculture or buffelgrass (*Pennisetum ciliare*), and overgrazing, and there are few regulatory mechanisms in place to protect habitat.

Despite the importance of pygmy-owl populations in northern Sonora, there are currently no data on population trends or on design parameters for population monitoring. Therefore, between 2000 and 2004 we monitored relative abundance of pygmy owls in northern Sonora, estimated temporal variation in relative abundance, and assessed the efficacy of different sampling designs for monitoring population trends. Our goals were to assess population trends, determine environmental factors that explained variation in trends, and evaluate the statistical power of our monitoring program for future monitoring efforts.

Study Area

We studied pygmy owls in northern Sonora within 75 km of Arizona (Fig. 1). Vegetation was comprised of the Arizona Upland subdivision of the Sonoran Desert and Semidesert Grassland (Brown 1982). Uplands in the Arizona Upland subdivision were dominated by open woodland and scrub of short

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leguminous trees and shrubs; uplands in Semidesert Grassland were dominated by open woodland and savannah of mesquite (*Prosopis velutina*) and subshrubs. Riparian areas in both vegetation communities were dominated by woodland of mesquite and acacia (*Acacia* sp.). Saguaros, a large columnar cactus that often contain cavities excavated by woodpeckers and used as nests by pygmy owls, occurred in both vegetation communities.

Methods

As part of a statewide survey to document distribution, abundance, and habitat of pygmy owls in Sonora, we surveyed 71 transects clustered around 23 randomly selected points in northern Sonora in 2000 (Flesch 2003*a*). We located transects along drainages >2 m wide and began within 1 km of a road in as many as 4 topographic formations (valley bottoms, lower bajadas, upper bajadas, and canyons) that occurred within 20 km of random points. In this initial sample we detected ≥1 male pygmy owl per transect at 14 of 23 points. We then randomly selected 6 of these 14 points that included 18 transects across 4 geographic regions: in the watersheds of the Upper Rio Altar, the Middle Rio Sasabe, and the Upper Rio Plomo and near the town of Sasabe (Fig. 1). All 18 transects combined totaled 53.7 km in length and were located between 740 and 1,035 m elevation in the Arizona Upland subdivision of the Sonoran Desert ($n = 7$) or Semidesert Grassland ($n = 11$). We surveyed the same transects once each year between 2000 and 2004.

We broadcast territorial calls to elicit responses from pygmy owls along a series of 5 to 8 stations spaced 350 to 400 m apart along drainage channels. If we detected an owl, we increased spacing of the next station to 550 to 600 m to reduce the probability of detecting the same bird more than once and used these same station locations in subsequent years. At each station we alternated listening and calling sequences every 30 to 45 s with listening periods during the first and last 30 s. We remained at stations for 8 min or until 1 min after an owl was detected, an approach adequate to detect 99% of territorial male pygmy-owls (Flesch 2003*a*). Detectability of male pygmy owls during the breeding season approaches 100%; in Texas 9 of 9 radiomarked males responded to territorial calls from 550 m away (Proudfoot et al. 2002), and in Sonora 19 of 19 males responded during the breeding season when challenged from in or at the edge of their
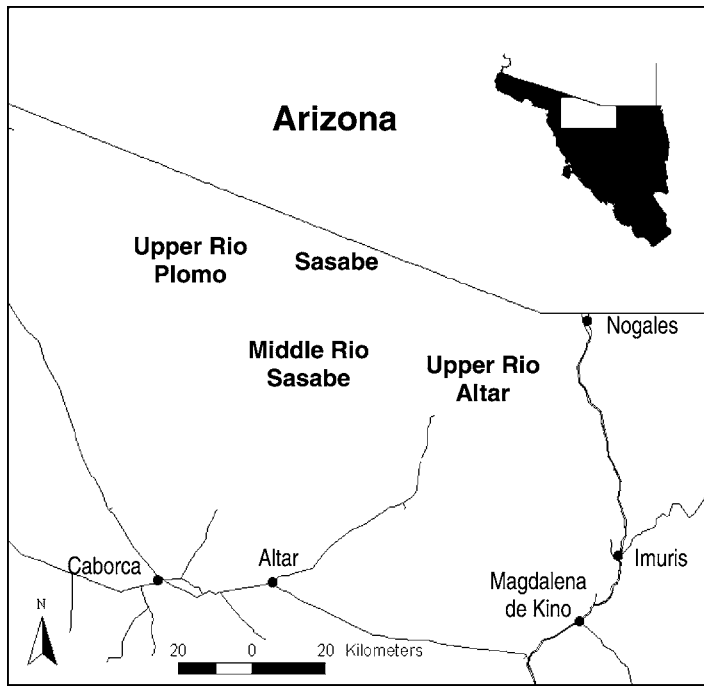
Figure 1. Map of study area for monitoring ferruginous pygmy owls in northern Sonora, Mexico, 2000–2004, illustrating 4 geographic areas monitored, major cities, and roadways.

home ranges (A.D. Flesch, University of Arizona, Tucson, Ariz., USA, unpublished data). We surveyed from 1 hr before to 3 hr after sunrise and between 17 April and 5 June during the incubation and nestling stages of the breeding period. We did not survey during rain or when winds exceeded 20 kph (Beaufort scale ≥3). We determined the sex of each owl based on vocalization patterns (Proudfoot and Johnson 2000) and used distance and direction of responses to differentiate among owls that did not respond simultaneously.

We characterized physiographic features, land-use intensity, and vegetation features at survey stations and averaged measurements for each transect. For physiographic features, we estimated transect slope (total elevation change/transect length), topographic complexity (cumulative elevation change within 400 m), and drainage density (number of drainages within 1 km) from 1:50,000-m topographic maps. For land-use intensity, we ranked intensity of vegetation disturbance from 0 to 3 (none, low, medium, high) for agriculture, wood-cutting, buffelgrass planting, grazing, and housing density. We generated an index of overall disturbance along transects by summing ranks for all land-use categories except grazing because most land uses were uncommon. Because grazing occurred on all transects, we treated vegetation disturbance from grazing as a separate variable. For vegetation features, we measured width of riparian vegetation (perpendicular to drainage orientation) with the use of a rangefinder and estimated abundance of 2 types of potential cavity substrates by calculating percentage of stations where saguaros (>3 m tall) and large trees (>6 m tall) were present. We ranked dominance of vegetation formations (e.g., woodland, desertscrub, savannah, etc.) by percent cover and estimated mean vegetation height visually (to nearest meter) in both upland and riparian vegetation areas. We also estimated

vegetation volume to the nearest 10% when values were between 20% and 80% and to the nearest 5% otherwise in 5 height strata: 0–1 m, 1–3 m, 3–6 m, 6–12 m, and >12 m above ground in both riparian and upland vegetation areas (Flesch 2003a). We considered vegetation within 400 m of survey stations for all measurements. We made all measurements in 2000 only because we quantified major structural and compositional features of the vegetation that did not change over the duration of our study.

We estimated abundance of pygmy owls by calculating number of males recorded per station for each transect for each year. We assessed within-transect trends in owl abundance by regressing abundance against year after blocking on transects, which is equivalent to a univariate repeated-measures ANOVA. We treated year as a fixed effect and transect as a random effect.

To determine if transect-level variation in population trends was explained by environmental factors, we regressed residuals from the analysis for trends described above against the environmental factors we measured. Because the number of explanatory variables was high, we first retained only what we judged to be the most biologically meaningful variables from correlated pairs ($r > 0.7$) and eliminated variables with little explanatory power ($P > 0.25$) established by fitting several smaller models with groups of related variables (Ramsey and Schafer 2002). We then used multiple linear regression with stepwise selection ($P < 0.25$ to enter, $P < 0.10$ to stay) to select a set of explanatory variables. We transformed variables with the use of $log(x)$ or $log(x + 1)$ to better meet assumptions of parametric tests.

To assess the efficiency of our monitoring program, we estimated power for several sampling designs with the use of Program MONITOR (Gibbs 1995) based on the estimates of abundance and temporal variation in counts we observed. To estimate temporal variation in counts we used data from all transects we surveyed for all 5 years. We first removed spatial (among-transect) variation from counts by subtracting mean abundance for each transect averaged for all years (Gibbs and Melvin 1997). We used these normalized counts, which reflected temporal variation and sampling error, to calculate an estimate of standard deviation in abundance. We then estimated power for 6, 8, or 10 years of surveys performed every year or every other year along either 9 or 18 transects. Lastly, we used initial estimates of abundance from year 2000 to calculate power based on 500 simulations for 2-tailed tests and for $\alpha = 0.05$.

Results

Transect length averaged 2,983 ± 116 m (± SE) (range = 2,300–3,850) with 6.8 ± 0.2 stations per transect and 123 stations along the 18 transects. We detected 188 males over 5 years; 55 in 2000, 32 in 2001, 36 in 2002, 37 in 2003, and 28 in 2004. Number of males detected per transect averaged 2.1 ± 0.2 overall and ranged from 0 to 7 for all transects and years.

Across the study area, relative abundance of pygmy owls declined by an average of 0.041 ± 0.011 males/station/year between 2000 and 2004 ($F_{1,71} = 13.94$, $P = 0.0004$), the equivalent of a 9.2 ± 2.5% decline per year. Although there were too few transects ($n = 4$–6) within each of the 4 geographic areas sampled to make quantitative comparisons, relative abundance seemed to decline
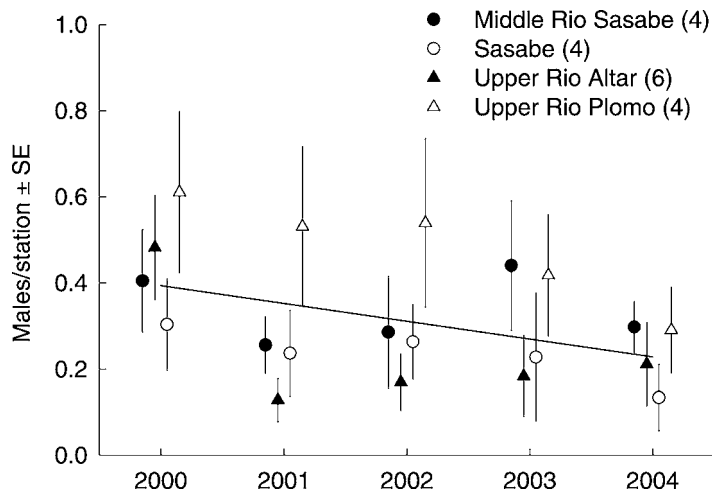
Figure 2. Relative abundance of male ferruginous pygmy owls (males/station) along fixed transects ($n = 18$) in 4 geographic areas across time from 2000 to 2004 in northern Sonora, Mexico. Point and error bars equal mean ±1 standard error and parenthetical numbers are number of transects sampled in each area. Regression line is for all transects combined.

Figure 3. Estimated power to detect declines in relative abundance (males/station) of ferruginous pygmy owls with 9 and 18 transects with surveys annually or every other year for 10 years in northern Sonora, Mexico. Estimates based on 2-tailed tests, $\alpha = 0.05$, and 500 simulations.

more in the Upper Rio Plomo, Upper Rio Altar, and near Sasabe, and remain relatively stable in the Middle Rio Sasabe (Fig. 2).
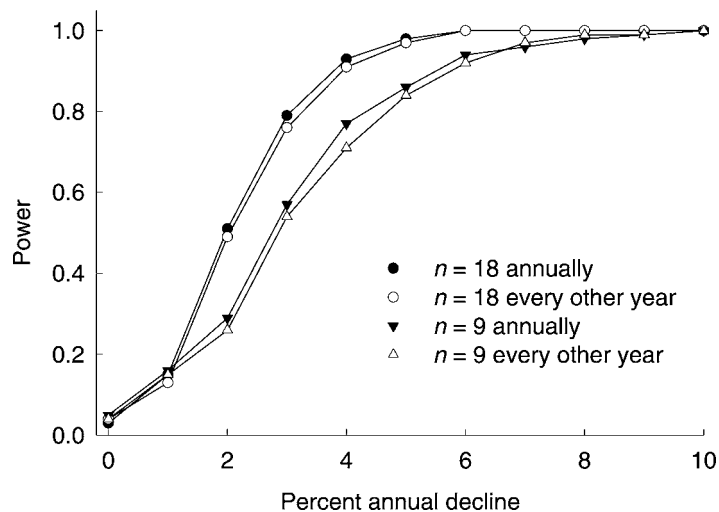
Relative abundance of male pygmy owls declined more in areas where height of upland vegetation was shorter, relative abundance of saguaro cacti was lower, and the zone of riparian vegetation was more narrow ($t_{14} \geq 2.27$, $P \leq 0.040$; Table 1). There was also some evidence that, after adjusting for environmental factors, relative abundance declined more as the combined effects of agriculture, wood cutting, buffelgrass planting, and housing density increased ($t_{13} = 1.81$, $P = 0.093$).

Power to detect annual population declines of up to 10% per year changed little when survey effort was reduced from every year to every other year (Fig. 3). Reducing sampling intensity from 18 to 9 transects per year decreased power to detect population declines by 7% over 10 years, 12% over 8 years, and 14% over 6 years of monitoring. Therefore, a monitoring program based on 9 transects surveyed every other year for 10 years has more than an 80% power to detect population declines of 5% per year. Across all combinations of sampling effort and timing, power to detect population increases averaged 8% greater than power to detect population declines. Temporal variation in counts among years (standard deviation) equaled 0.145 (95% CI = 0.126–0.170) after removing spatial variation.

Table 1. Environmental factors that explained variation in trends in relative abundance (males/station) of ferruginous pygmy owls across time in northern Sonora, Mexico, 2000–2004.

Factor	Estimate[a]	SE	t	P
Relative abundance of saguaro cacti (10%)	0.0036	0.0016	2.27	0.040
Width of riparian vegetation area (ln 100 m)	0.83	0.35	2.33	0.035
Height of upland vegetation (m)	0.021	0.007	2.99	0.0098

[a] P values and parameter estimates from multiple linear regression ($F_{3,14} = 10.56$, $P < 0.0007$, $n = 18$, $r^2 = 0.69$).

Discussion

Between 2000 and 2004, the population of pygmy owls in northern Sonora declined by an estimated 37%. If this apparent decline continues, recovery strategies that rely on pygmy owls from Sonora and continued persistence of pygmy-owl populations in northern Sonora could be jeopardized. Determining whether the trend we observed was a result of short-term natural variation or if it truly represents a long-term systematic decline will require further study, given that short-term declines in abundance may not indicate systematic declines (Robinson 1992). The population decline we observed was influenced strongly by the year 2000, which if excluded from the analysis reduced the magnitude of the estimated decline from 9.2% to 2.5% per year. Nonetheless, because pygmy-owl populations have declined to endangered levels in Arizona (USFWS 1997, Johnson et al. 2003), the decline we observed in northern Mexico is cause for concern.

Bird abundance can vary among years for many reasons, including changes in resource abundance, weather, or interactions with other species (Holmes et al. 1986, Blake et al. 1992, Sillet et al. 2000). Precipitation, an important driver in arid regions such as this, has declined along the U.S.–Sonora border since 1990 (Western Regional Climate Center 2004), which may have influenced owls indirectly, perhaps by affecting food abundance.

Most male pygmy owls settle on territories for life (Proudfoot and Johnson 2000); therefore systematic temporal changes in abundance likely represents loss of adults without replacement. Understanding relationships between abundance and habitat-specific demographic processes will help elucidate whether the observed decline will have long-term negative consequences for populations of pygmy owls (Van Horne 1983, Vickery et al. 1992).

Three environmental factors explained transect-level variation in population trends (Table 1). Because large saguaros support nearly all pygmy-owl nest cavities in northern Sonora, abundance of pygmy owls is related to abundance of cavity-harboring saguaros (Flesch 2003a). Lower cavity abundance likely reduces the range of cavity features available to pygmy owls, reducing the chances

that high-quality cavities occur in areas where other necessary habitat characteristics are present. Further, when cavities are rare, competition between pygmy owls and other larger secondary–obligate cavity nesters such as western screech owls (*Megascops kennicottii*) could be more intense, potentially impacting pygmy-owl populations. Cavity abundance, therefore, may be an indicator of habitat quality for pygmy owls, which would explain why owl populations in areas with high abundance of saguaros declined less than those in areas with low abundance of saguaros. Large areas of riparian vegetation and taller upland vegetation likely provide greater opportunities for foraging and better cover, potentially explaining lower population declines in these areas. These same factors, in part, also explained occupancy and abundance of pygmy owls in northern Sonora (Flesch 2003*a*) and selection of perch sites within home ranges of pygmy owls in southern Arizona (Flesch 2003*b*).

Habitat loss and fragmentation is often considered a primary cause of decline in wildlife populations (Soulé 1986, Bender et al. 1998), yet pygmy owls in northern Sonora declined where vegetation structure and composition have likely changed little. We only observed a single instance along our survey transects where owl habitat was destroyed when riparian vegetation was cleared for agriculture. Because population declines were less in areas where habitat quality seemed higher, persistence of pygmy-owl populations in northern Sonora will depend on conservation of areas of high habitat quality.

Pygmy owls declined more in areas where land-use intensity was higher. In Arizona, decline of pygmy owls has been attributed to elimination of large riparian areas by human activities (Millsap and Johnson 1988, Johnson et al. 2003). In northern Sonora, most riparian areas were altered decades ago, yet habitat loss continues in some areas, especially in perennial river valleys such as the Rio Altar Valley, where land is still being cleared for agriculture. In the long term, factors that negatively influence regeneration of saguaros, such as livestock grazing (Niering et al. 1963, Steenbergh and Lowe 1977, Abouhaider 1989, 1992) could result in loss of this habitat element that is essential for persistence of pygmy-owl populations.

Population-monitoring programs must quantify temporal variation in population parameters despite spatial variation and sampling error. For organisms that are difficult to detect or that respond unpredictably, variation in detectability increases sampling error that may obscure the ability to detect meaningful trends. High detectability of male pygmy owls to broadcast calls (Proudfoot et al. 2002) makes this species an efficient choice for monitoring.

Management Implications

Efficiency of monitoring pygmy owls in this region could be increased with little loss of statistical power by reducing survey effort to every other year. Because of profound conservation and management concern for pygmy owls, we recommend maintaining sampling at its current level for the near term, especially because the cost of surveys is low. Additionally, expanding the study area westward to include areas immediately south of Organ Pipe Cactus National Monument would expand the sampling frame to include other areas important to recovery of pygmy owls in Arizona.

Collecting demographic data in combination with estimates of abundance will contribute to our understanding of the population dynamics of pygmy owls in northern Sonora and provide a strong foundation on which to develop conservation and recovery strategies for pygmy owls. Additionally, in northern Sonora, maintaining stands of saguaro cacti adjacent to riparian woodland and well-developed upland vegetation, while mitigating the adverse influence of land-use practices on vegetation, will likely foster long-term persistence of pygmy-owl populations.

Acknowledgments

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