

Cactus Ferruginous Pygmy-Owl Monitoring and Habitat Assessment on Pima County Conservation Lands

Final Report

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ABSTRACT

To address obligations linked to the recently approved Pima County Multi-species Conservation Plan, I identified and estimated the quality of habitat for the Cactus Ferruginous Pygmy-Owl (*Glaucidium brasilianum cactorum*; hereafter “pygmy-owls”) and surveyed owls on Pima County Conservation Lands in south-central Arizona in 2017. To identify habitat and prioritize areas for surveys across a vast region of County lands, I used a model of habitat quality developed in neighboring Sonora, Mexico together with aerial reconnaissance for saguaros and remotely-sensed data on woody vegetation cover. I evaluated the existing survey protocol for pygmy-owls recommended by the U.S. Fish and Wildlife Service, developed a more efficient survey protocol, and used this approach to survey owls along 11 transects three times; once shortly before breeding in March, once during nesting in April, and following breeding in October when young owls are dispersing and selecting home ranges. I documented a fairly large population of pygmy-owls in the northern Altar Valley and detected pygmy-owls along 10 of the 11 transects surveyed during at least one season with occupancy and abundance peaking during October when 46% of survey stations were occupied. I located four nests and three likely nests—all in saguaro cacti—that contained an average of 4.5 eggs and were located between 846 and 1,177 m elevation (mean = 1,038 m). In general, pygmy-owls were found to be more common and broadly distributed than previously known in the northern Altar Valley and in southern Arizona in general. In total, I documented 20 distinct territories occupied by territorial male pygmy-owls including 17 territories that were not known before this effort. These new territories roughly doubled the known population of pygmy-owls in the northern Altar and adjacent Avra valleys in Arizona, and increased the total number of historical (i.e., known within the last 20 years) sites in the broader region by 44%. Importantly, I validated the utility of a useful quantitative tool for identifying areas on the landscape to prioritize for surveys, which is broadly applicable for other management and recovery applications for this species. Despite the rarity of pygmy-owls on the landscape, virtually all transects I identified for surveys were occupied by one or more pygmy-owls during one or more survey events. Moreover, observed pygmy-owl distribution was associated with the estimated quality of space in directions predicted by theory as indicated by a positive relationship between persistence in occupancy across the three surveys and the estimated local quality of habitat. In combination with management strategies that preserve and perpetuate the continued existence of habitat, these results confirm the value of Pima County conservation lands for the pygmy-owl. Baseline data collected during this effort and summarized here provide a strong foundation for long-term trend monitoring of pygmy-owls on Pima County conservation lands.

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INTRODUCTION

Surveying and monitoring populations of rare species across large regions is challenging, especially when resources and baseline data are limited. In southern Arizona, concern for the Cactus Ferruginous Pygmy-Owl (*Glaucidium brasilianum cactorum*; hereafter “pygmy-owls”) helped galvanize regional efforts in conservation planning including the recently approved Pima County Multi-species Conservation Plan (MSCP; Pima County 2016). Pygmy-owls are among 44 species covered under the MSCP, which requires populations on County lands be monitored to assess population trends and distribution. Little is known about the distribution and abundance of pygmy-owls on Pima County’s conservation lands, however, and there are few known historical localities on these lands. Addressing monitoring needs on County conservation lands is further complicated by few recent surveys on these lands, limited resources available for monitoring, and the large spatial extent and location of these lands. To develop an effective monitoring program, advanced tools capable of identifying habitat and quantifying the likelihood of occupancy are needed to focus initial survey efforts.

Information on habitat suitability can inform selection of survey and monitoring sites across large landscapes, even in cases where no prior information exists on distribution and abundance of the focal species. Theoretical models in combination with empirical data indicate that individual animals select the best available habitats first and use these areas more consistently across time because behaviors that promote optimal choices yield higher demographic performance (Fretwell 1970, Sergio and Newton 2003, Flesch 2017). Hence, information on spatial variation in habitat quality can help highlight priority areas on the landscape for surveys, monitoring, and management and recovery activities so that resources are expended efficiently.

To develop an efficient and effective monitoring program for pygmy-owls on Pima County conservation lands, I began by using a model of pygmy-owl habitat quality derived in similar environments in nearby Sonora, Mexico and developed a spatially-explicit approach to identify areas most likely to support pygmy-owls. This model estimated expected reproductive output of pygmy-owls as a function of various territory-specific habitat resources and conditions and was developed using data from observed reproductive output of pygmy-owls from nearly 500 nesting events within 107 territories in Sonora over a 10-year period (Flesch et al. 2015). For the current project, I applied this model in areas with saguaro cacti and in one instance large trees (>10 m tall) on lands managed by Pima County in the Altar and Avra valleys because these structures provide essential nest cavities for pygmy-owls. I then used resulting estimates to select a sample of potential survey areas and surveyed these areas three times between March and October 2017.

Information from this effort are important beyond the areas surveyed because identifying areas not previously known to support pygmy-owls in southern Arizona is useful for understanding the distribution and status of populations and for guiding recovery efforts. Although now removed from the endangered species list for reasons unrelated to recovery (USFWS 2006), populations of pygmy-owls have declined to extirpation in two of the three watershed regions in which they recently occurred in south-central Arizona and there is no recent evidence of occupancy near Tucson (Flesch et al. 2017). Similarly, focused monitoring and research efforts in neighboring northern Sonora indicate marked declines in abundance between 2000 and 2011 but some important increases in these same areas since 2012 (Flesch and Steidl 2006, Flesch 2014, Flesch et al. 2017). Recent modeling efforts suggest these patterns are being driven by drought and extreme weather (possibly linked to climate change), natural variation in habitat quality, urban growth, and interactions among these factors (Flesch 2014, Flesch et al. 2015, 2017). Efforts to conserve populations of pygmy-owls in Arizona promote the long-term success of regional conservation plans such as the Sonoran Desert Conservation Plan, but focused monitoring and research are needed to realize those goals.

This report summarizes results of habitat assessments and surveys for pygmy-owls on Pima County conservation lands in the Altar and Avra valleys west and southwest of Tucson. Specifically, goals of this project were to: 1) identify areas of potential breeding habitat for pygmy-owls on County conservation lands, and estimate the relative quality of that habitat, 2) establish 10 survey transects in areas that support habitat for pygmy-owls, 3) survey points along these transects three times (once during the territorial establishment period, once during the breeding season, and once during the post-breeding dispersal period), 4) describe the distribution, abundance, and breeding status of pygmy-owls observed along survey transects, and 5) provide information to guide future monitoring and conservation of pygmy-owls on County conservation lands. Additionally, to increase the efficiency of the surveys, and with input from USFWS species experts,

I revised the USFWS survey protocol for pygmy-owls (USFWS 2000) based on data from extensive observations of pygmy-owls in Sonora (Flesch and Steidl 2007a).

METHODS

Study Area—In coordination with staff of the Pima County Office of Sustainability and Conservation, I considered areas owned or managed by Pima County in the Altar and Avra valleys (Figure 1). These areas were selected because they are closest to areas with recent, known occupancy by pygmy-owls and thus most likely to support a population. This region includes large County-owned and leased properties: Tucson Mountain Park and Lord's Ranch to the north of AZ State Route 86, and Rancho Seco, Marley Ranch, Diamond Bell Ranch, and Old Hayhook Ranch located south of Route 86. Within these properties I focused on identifying priority survey sites in areas with mature saguaro cacti or large trees capable of providing nesting habitat for pygmy-owls.

Design and Habitat Assessments—To determine survey sites on County conservation lands, I employed a stepwise process. First I mapped the general distribution of saguaro cacti because they provide nest cavities and are a fundamental component of pygmy-owl habitat. Saguaros in this region are uncommon and distributed very patchily in singles or small groups often near rocky outcrops or the upper portion of outwash plains. Given this distribution and because saguaros are difficult to detect and map using remote-sensing tools, project coordinator Brian Powell and I enlisted the services of [LightHawk](#) to fly us over potential habitat in a small plane from which we identified and photographed areas with saguaros (Figure 1). Areas with saguaros were subsequently mapped in Google Earth, which I used together with aerial photographs taken from the plane to estimate the approximate number and location of mature saguaros in and adjacent to County conservation lands. This process identified a sample of 92 patches on the landscape where one or more adult saguaro occurred on or immediately adjacent to County lands, and 6 patches with large trees with cavity potential (>10 m tall), which could support nesting pygmy-owls on County conservation lands within the study area. Second, at each of these locations, I placed a 400-m radius circular plot around a centrally-located saguaro (or large tree) in a way that minimized overlap among plots and maximized coverage of areas with saguaros the landscape. A 400-m radius circular plot (e.g., 50 ha) was used because it is the approximate size of a breeding pygmy-owl home range (Flesch et al. 2015). Finally, within each plot, which represented a potential breeding home range, I used a model developed in adjacent Sonora to estimate the relative quality of habitat based as indexed by predicted reproductive output.

In addition to saguaros, both the quantity and spatial arrangement of woodland vegetation and presence of semi-desert grasslands (vs. desert-scrub) are important drivers of habitat quality for pygmy-owls (Flesch 2014, Flesch et al. 2015). More specifically, the model of habitat quality I used to estimate habitat quality indicates that long-term reproductive output of pygmy-owls is positively associated with increasing abundance of saguaro cacti, moderate to high levels of woody vegetation cover, low levels of woodland fragmentation, and presence of semi-desert grasslands (Flesch 2015). Thus, to apply this model to County lands, I used data on mean woody vegetation cover across each

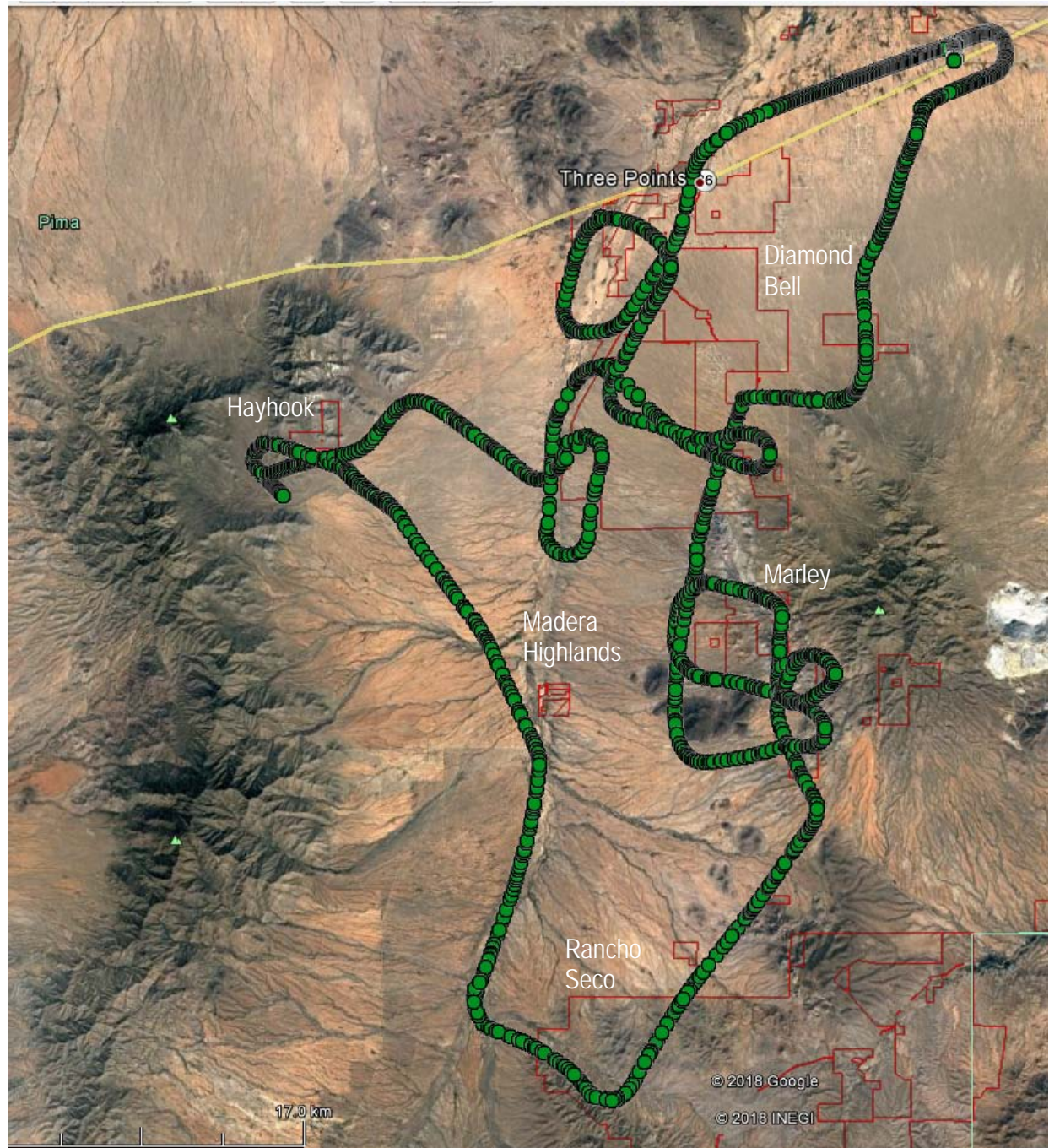


Figure 1: County conservation lands and flight path (green points) used to observe saguaro cacti, inspect woodland cover, and visually identify potential owl habitat from the air in February 2017 in the Altar Valley, Arizona. Red polygons show location of Pima County conservation lands that were considered for surveys. Names of major properties noted in the text are provided in white. Lord's Ranch and Tucson Mountain Park that are County lands that were surveyed for pygmy-owls during this project are located north of the view captured here.

plot representing a potential home range, woodland cover (e.g., proportion of area with >20% woody vegetation cover), and woodland fragmentation developed within each plot with use of a GIS and remote-sensing tools (see details in Flesch et al. 2015). This approach involved extracting spectral vegetation and soil data from 30-m resolution Landsat 5 images from June 2007 (a period with no cloud cover), estimating percent of woody vegetation cover for each pixel, and classifying pixels with $\geq 20\%$ woody vegetation cover as woodland, which, given typical tree spacing, distinguishes open woodland or scrub (<20% canopy cover) from woodland that has a more closed canopy (>20% canopy cover). To quantify woodland fragmentation independent of woodland amount, I scaled density of woodland patches by mean woody vegetation cover (see details in Flesch et al. 2015). Data on woody vegetation cover and fragmentation in these regions were already available from past efforts based on imagery from 2007 (e.g., Flesch et al. 2015). Finally, to estimate saguaro abundance and large tree abundance, I counted the number of adult saguaros (or large trees) within each plot with use of Google Earth imagery and aerial photos from over flights.

Because data on woody vegetation cover for estimating habitat quality were from 2007 when the focus was on adjacent northern Sonora (Flesch et al. 2015), collaborator Dr. Chris Jarchow (U.S. Geological Survey, Southwest Biological Science Center, Tucson) used the same process to estimate woody vegetation cover based on more recent imagery. This effort was focused on obtaining more recent data for the current project area to better index vegetation cover conditions at the time of the surveys. Four Landsat 8 surface reflectance (SR) scenes from the Earth Resources Observation and Science (EROS) Center Science Processing Architecture (ESPA) on Demand Interface were obtained from spring 2015 (Table 1; <http://espa.cr.usgs.gov>). These scenes were combined into a single image that was used to sample spectra corresponding to pure woody vegetation following methods outlined in Flesch et al. (2015). Spectral Mixture Analysis (SMA) in ENVI v5.0 was used to determine the sub-pixel abundance of woody vegetation and discriminate it from soil and other landcover types. Accuracy of the SMA technique for estimating woody cover was facilitated by woody cover estimates based on high-resolution (1 m) National Agriculture Imagery Program imagery covering areas near Tucson from Earth Explorer (<https://earthexplorer.usgs.gov/>).

The final step in the process of estimating habitat quality was combining data on saguaros with that on woody vegetation cover and other factors, and predicting habitat quality within each of the 98 potential home ranges. To predict habitat quality, I used the “predict.lme” function in the *nlme* library in program R together with the original model from Sonora, and based predictions on values of habitat covariates (e.g., percent woody cover, saguaro abundance) measured within each of the 98 plots (Pinheiro and Bates 2000, R Development Core Team 2017). This procedure used the best linear unbiased predictions of the response variable (in this case, reproductive output estimated for owls in Sonora) based on the best supported model from this system (see details in Flesch et al. 2015). When estimating habitat quality for potential home ranges on County lands, I used woody cover estimates derived from both the 2007 and 2015 Landsat data and compared the resulting model predictions to identify any potential sensitivity of model results to temporal differences in imagery.

Once areas of breeding habitat were delineated and the relative quality of those areas estimated, I placed survey transects on the landscape in a way that overlapped as many areas of moderate- to high-quality breeding habitat as possible, while also covering some lower-quality adjacent areas. I placed transects on the landscape in a manner that maximized coverage of such areas so that all survey stations along a single transect were on lands owned or leased by the County. Placement involved positioning single transects along drainages or linear stretches of associated riparian woodlands, subdividing single transects so as to cover multiple drainages in close proximity, or placing survey stations in other arrangements and along roadways to cover existing habitat so that each survey route could be efficiently surveyed during one complete morning or evening survey period. In a few cases, I placed transects in areas County staff selected for surveys based on past

Table 1: Landsat 8 surface reflectance scenes used to prepare 2015 woody vegetation cover layer.

Date	Sensor	Path-Row
23 May, 2015	Landsat 8 OLI	37-38
25 May, 2015	Landsat 8 OLI	35-39
1 Jun., 2015	Landsat 8 OLI	36-39
1 Jun., 2015	Landsat 8 OLI	36-38

observations (e.g., at the base of the Coyote Mountains and on Lord's Ranch), however these areas largely matched estimates of medium to high habitat quality. In total, I established 11 transects of ≥ 2 stations per transect, and placed survey stations at 300-400 m intervals along transects. A small number of survey stations were repositioned, renumbered, or dropped after initial surveys in March 2017 so that transects could be more efficiently surveyed and achieved optimal coverage of target areas.

Pygmy-Owl Surveys—To increase survey efficiency and coverage, I developed a modified version of the research survey protocol approved by the USFWS (2000) and obtained approval for proposed modifications from USFWS staff with the help of County staff (Appendix A). This protocol uses broadcasts of recorded territorial pygmy-owl vocalizations at survey stations placed along point transects to elicit responses from pygmy-owls. Modifications to the USFWS protocol were guided by detailed survey information based on detection of over 600 pygmy-owls throughout Sonora, Mexico. Those data indicate that detectability of pygmy-owls during the nesting season is very high (e.g., 0.89-1.0) from 100-300 m from nests, that owls respond rapidly to call broadcasts (e.g., mean response time = 2.6 min, 99.6% of owls detected in ≤ 8 min), that response rates and detectability remain high at times 2-hours after local sunrise and 1-hour before local sunset, and that owls respond readily before and after nesting (Flesch and Steidl 2007a). Thus, small modifications to the existing protocol to increase its efficiency without altering its effectiveness are possible and desirable from an efficiency perspective. These changes included an initial listening period before call broadcasts at stations of 1 (vs. 2) minute, alternating 30 seconds of call playback at stations with 30-45 (vs. 90) seconds of listening for a total of approximately 6 minutes, and extending survey hours to 3 (vs. 2) hours after sunrise, and 2 (vs. 1) hours before local sunset unless the moon is visible and within ± 3 days of being full in which case surveys may be completed all night as long as the moon is visible (Appendix A). Including a listening period of 1 minute at the end of the final broadcast at stations, each station was visited for a minimum of 8 minutes, and often longer while field gear were being placed in backpacks etc., or due to extending some survey periods due to wind gusts. No surveys were conducted during adverse weather conditions as noted in the established protocol (USFWS 2000).

I surveyed transects two times in spring and once in fall 2017. This effort included one survey during the spring territory-establishment and pre-nesting period in March 2017, one survey during the nesting season in April 2017, and one survey during the dispersal and post-breeding territory-establishment period between in September and October 2017. All surveys of transects were >14 days apart. Because occupancy by pygmy-owls during each of these time periods is indicative of different activities during the life cycle of this species, survey results can help determine the status of owls at sites. Within these periods, myself and occasionally 2 biologists from Pima County surveyed all transects. Effort was focused during periods when the moon was full or nearly full to reduce travel time (i.e., surveys could be completed throughout the night) and multiple transects were often surveyed in single nights.

For all pygmy-owls detected, I noted the time of detection, the estimated distance and bearing to all detections, the time elapsed from the start of broadcasts to detection, sex of owls (where known

based on vocalizations; Cornell Lab of Ornithology 2006), and whether owls were likely calling on or off of County lands. To estimate the number of individual pygmy-owls along each transect, I used information on the distance, direction, and timing of vocalizations, and made special effort to determine if responsive owls were calling simultaneously. In some cases, I remained at stations for longer than eight minutes to estimate number of respondents. Following surveys in April, I also observed owls and searched for nests in occupied areas to confirm pair and nest occupancy. For nests located on lands owned by Pima County and on federal lands, I inspected nest contents with a small, pole-mounted video camera (see [link](#)).

Analyses—I summarized survey results for each season and at the scale of each individual transect among seasons. Information on pygmy-owls observed during surveys was presented as the number of total detections, which did not attempt to differentiate whether responsive owls were the same or different individuals among stations, and the estimated number of individuals, which I determined based on the distance, direction, and timing of vocalizations of responsive owls and any vocalizations heard simultaneously. To assess the efficacy of the habitat-quality model for guiding selection of survey sites, I used *t*-tests to compare estimated habitat quality at stations that were occupied versus those unoccupied within each season. Moreover, across all three survey events, I used Analyses of Variance (ANOVA) to compare estimated habitat quality of stations that were unoccupied versus those that were occupied once, twice, or three times. Because some survey stations were located near more than one of 98 plots in which I estimated habitat quality, I averaged estimates of habitat quality for these points and used these averages for comparisons. Because habitat quality was estimated based on woody vegetation cover measured from both 2007 and 2015 imagery, I compared each set of results in contrasts of occupied versus unoccupied habitat across time.

RESULTS

Effort—I surveyed 11 transects and 87 to 91 stations in each of the three survey periods (Table 2). Although the County called for 10 transects because of budget constraints, an additional short transect of two stations in the Coyote Mountains was surveyed because a pygmy-owl was detected by County staff there in past years and additional survey effort was minimal. Seasonal variation in survey effort (e.g., number of stations surveyed) across time was due to an additional station being added to the Marley 2 transect after initial surveys in March, and one station being removed from the Marley 3 transects after initial surveys in March because it was off of County lease lands. Additionally, on Lord's Ranch only 9 of 13 stations were surveyed in October due to timing issues and personnel availability, although coverage of the best areas was largely unaffected (Table 3). Across the region, effort was greatest on Diamond Bell Ranch (4 transects; 39 stations) and Marley Ranch (3 transects; 18 stations) and lower in the Coyote Mountains and Lord's Ranch, where County properties are small, and in Tucson Mountain Park, where estimates of habitat quality were generally low (Table 3). No transects were placed on Rancho Seco, Madera Highlands, or other, smaller properties in the region due to estimates of low habitat quality.

Survey Results—I detected pygmy-owls along the vast majority of transects selected for surveys, but there was significant seasonal variation in observed patterns of occurrence and abundance (Table 2). In March and October, a remarkable 82% of transects ($n = 9$ of 11) were occupied by one or more territorial pygmy-owls. In October, however, a total of 46% of stations were occupied, which was much higher than in other months (Table 2). During the nesting season in April, occupancy patterns contracted somewhat with only 55% of transects and 30.8% of stations occupied. Across all seasons, pygmy-owls were detected along 91% of transects ($n = 10$ of 11). The only transect without any detections was in the Tucson Mountain Park. The total number of estimated individuals also varied seasonally but less so than occupancy patterns due likely to seasonal differences in movements in response to broadcasts. Abundance peaked in October when 20 estimated

individuals were detected including 3 likely females, whereas in March, 17 individuals were detected including 2 likely females. In April, all 16 individuals I detected were territorial males. Across all seasons, I located a total of 20 distinct territories occupied by territorial males that constitute actual known breeding or potential breeding sites for pygmy-owls.

At the scale of individual transects and specific properties, abundance was greatest along the Coyote Mountains 2 transects where I detected between 4 and 5 individual pygmy-owls during each survey including up to 5 territorial males (Table 3). Abundance was also often high along two of the four transects on Diamond Bell Ranch with an average of 2.7 males detected per survey. Although at least one pygmy-owl was detected along each of three transects on Marley Ranch, abundance was greatest on the Marley 2 transect where 2 males were detected during each of three surveys, with an additional female detected in a new, formally unoccupied area in October. Despite recent release of numerous pygmy-owls bred in captivity on Lord's Ranch five months prior to surveys, no pygmy-owls were detected in the area in spring. One owl was observed by Iris Rodden during surveys on 4 October 2017 on this property, but the presence of a leg band (all of the released owls on this property were banded) could not be ascertained. Survey results standardized by levels of effort (no. stations surveyed) are summarized at the seasonal and transect level in Appendix B.

Pygmy-owls I observed during surveys called from as far away as approximately 1 km from stations. Some of the more distant individuals, however, typically moved closer to stations after initial detection in response to call broadcasts. Thus, although some owls were initially detected off of lands managed by Pima County, in most cases, movement toward survey stations in response to call broadcasts suggested portions of their home ranges included some County conservation lands. Exceptions to this rule included one of two owls detected along the Coyote Mountains 2 transect, which only used areas on the Tohono O'odham Nation and one of a maximum of two pygmy-owls detected along the Marley 3 transect that only used areas on adjacent State of Arizona Trust Lands.

Model Results and Validation—Efforts to estimate habitat quality (as indexed by reproductive output) indicated the presence and fairly broad distribution of moderate- to high-quality breeding habitat across portions of County conservation lands in the Altar and Avra Valleys. Compared to the distribution of observed habitat quality of territories occupied in adjacent Sonora, overall variation in estimated quality of potential territories in adjacent Arizona was lower based on results of 2007 (range = 1.6-3.4) and especially 2015 (range = 1.7-3.3) imagery (Figure 2). On average, however, estimated habitat quality of territories occupied in Sonora was fairly similar to that on County lands based on 2007 ($t = 1.80$, $P = 0.072$) and ($t = 1.79$, $P = 0.074$) 2015 imagery. Nonetheless, estimates based on 2015 imagery averaged $8.6 \pm 1.0\%$ (\pm SE) higher than those based on 2007 imagery ($t = 8.33$, $P < 0.0001$; paired t -test).

Importantly, observed distribution of pygmy-owls among survey stations was associated with the estimated quality of space in the expected directions. However, the presence and strength of these associations varied seasonally in ways consistent with the natural history and timing of breeding and dispersal. During nesting in April, estimated quality of habitat around stations occupied by pygmy-owls was much higher than that around stations where owls were not observed (Figure 3). In comparison, before breeding in March, contrasts in estimated quality between occupied and unoccupied habitat was somewhat less, especially based on 2007 imagery, due likely to broader owl distribution that included some lower-quality areas not occupied in April. When young-of-the-year were dispersing and selecting home ranges in October, however, there was no difference in the estimated quality of occupied and unoccupied habitat around stations, due likely to broader owl distribution and perhaps territory expansion following breeding. On average, estimated quality of stations increased with the number of seasons stations were occupied indicating pygmy-owls used the best sites more consistently across time (Figure 3).

Breeding Status and Nests—I located four nests and three likely nests (e.g., based on abundant owl sign and behavior immediately around likely nest substrates but not contents) during follow-up surveys in April and early May. All nests were in saguaros that averaged 7.0 m tall (range = 4.3-8.7). Nest cavity heights averaged 6.0 m (range = 4.1-8.6) and nest-cavity dimensions suggested excavation by Gila Woodpeckers (*Melanerpes uropygialis*). Confirmed nests contained an average of 4.5 eggs (3 with 5 eggs, 1 with 3 eggs) and were located on either County-owned or federal lands (Bureau of Land Management; Figure 4). Nests and likely nests were located between 846 and 1,177 m elevation, at an average elevation of 1,038 m, and all sites were in semi-desert grassland environments, with one exception in desert-scrub. Along the Coyote Mountains 2 transect, I located three nests and an additional occupied site in close proximity (Figure 4). An upper-elevation nest along a rocky draw was 595 m away from a neighboring nest in wooded flats at lower elevation below. The latter nest was 735 m above a historical site monitored by the USFWS on and off since 2000 (e.g., Mendoza south) that was occupied by a territorial male during this study (that could have—but did not appear—to be nesting nearby), and 1,255 m above another nest located in the same broad wooded flat but at lower elevation. On Diamond Bell Ranch, two nests were located 570 m apart along adjoining wooded drainages. Another likely nest was located 615 m from a formally occupied nest and apparently the same historical site monitored by USFWS since 2012 (e.g., SR 286). In addition to the site at Lord's Ranch where numerous pygmy-owls bred in captivity were released in 2016, the two aforementioned historical sites were the only documented localities for pygmy-owls on County lands known by USFWS before this work.

Except where noted above, most pygmy-owls I detected in April were paired, nesting, or exhibiting behaviors suggesting nesting. One additional exception was observed along the Coyote Mountains 2 transect where a territorial male and a female were present but did not seem to be nesting in two nearby saguaros I inspected with a pole-mounted video camera. These birds could have possibly nested in saguaros located approximately 300 m away but immediate responses from around the two aforementioned saguaros suggested otherwise. Another exception was at the Marley 2 transect where one of two territorial males was apparently not paired or nesting based on focused observations and nest searches. The majority of this owl's likely territory was on adjacent State of Arizona Trust Lands that supported a few saguaros that this owl may have been nesting in, but it was not nesting in saguaros on the portion of its territory that was on County lands.

Table 2: Summary of effort and survey results for each of three visits to 11 transects located on Pima County conservation lands in the Altar and Avra valleys, Arizona, that were surveyed for Cactus Ferruginous Pygmy-owls in 2017. M denotes males and F denotes females as determined based on vocalizations.

Survey period	Dates	Transects (no.)	Stations (no.)	Occupied transects		Occupied stations		Detections		Individuals		M	F
				no.	%	no.	%	total	no./effort	total	no./effort		
March	9-14	11	91	9	0.82	32	35.2	38	0.42	17	0.19	15	2
April	11-26	11	91	6	0.55	28	30.8	31	0.34	16	0.18	16	0
October	4-18	11	87	9	0.82	40	46.0	44	0.51	20	0.23	17	3

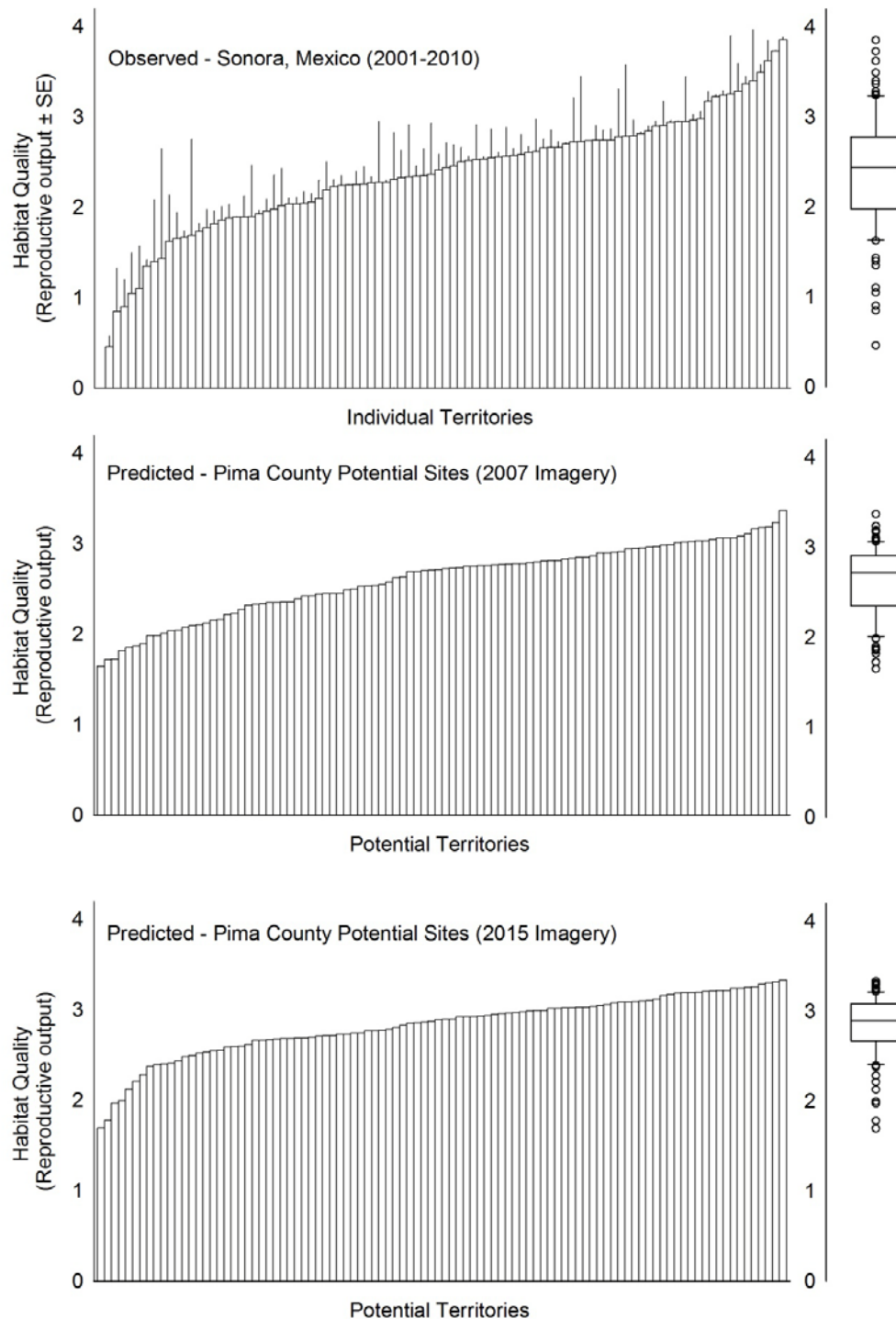


Figure 2: Observed and predicted territory quality as indexed by model-based estimates of annual reproductive output of Cactus Ferruginous Pygmy-owls. Bars are actual (Sonora) or potential (Arizona) individual territory patches ordered from low to high. Estimates are based on a model from Sonora and observed reproductive output at almost 500 nests over 10 years (Flesch et al 2015). Box plots show distribution of observed and estimated reproductive output with center lines noting medians and boxes 75% of data. Middle figure noted estimates based on woody vegetation cover from 2007 Landsat imagery whereas those on bottom from 2015 imagery.

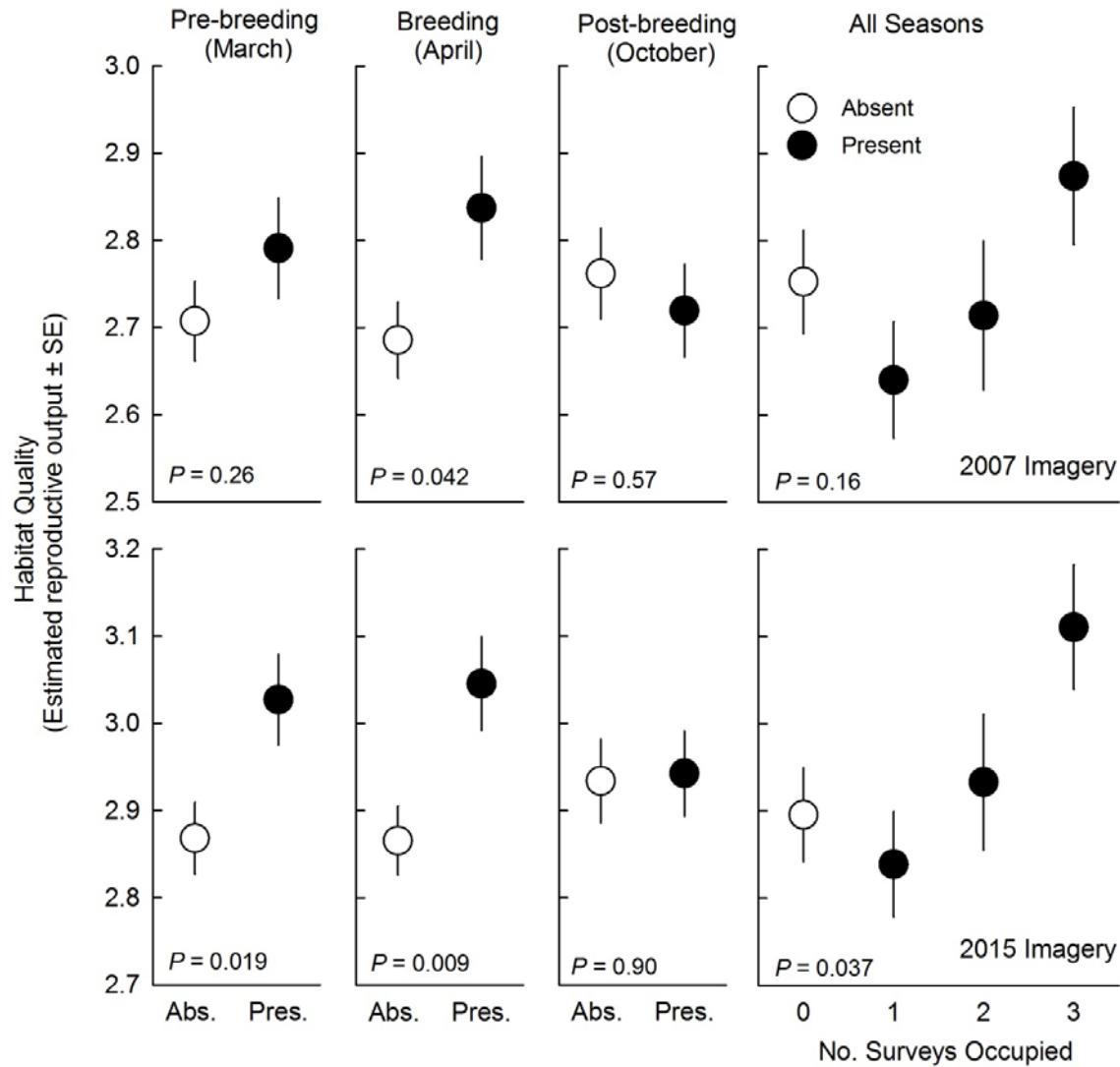


Figure 3: Estimated habitat quality (as indexed by predicted reproductive output) of areas where Cactus Ferruginous Pygmy-owls were present and not detected during surveys of Pima County Conservation lands in the Altar and Avra valleys, Arizona across three different seasons in 2017. Right figures show estimated habitat quality of areas where pygmy-owls were detected zero, one, two, or three times across the three survey events. Top panel shows predictions of habitat quality based on estimates of woody vegetation cover from 2007 Landsat imagery whereas those in the bottom panel are based on 2015 Landsat imagery. *P*-values are based on two-sample *t*-tests (left) or Analysis of Variance (right).



Figure 4: Cactus Ferruginous Pygmy-owl nest sites, nesting habitat, and nest contents on Pima County conservation lands in the Coyote Mountains, Arizona, April 2017. Nest saguaros in the top left, and middle panels were located 595-1,255 m apart with arrows indicating location of nest cavities, whereas top right panel shows nest habitat along a rocky drainage around the same nest shown in the adjoining panel. Nest contents within saguaro cavities are shown for the top- and middle-left panels. Contents of the nest in the middle-right panel were not visible due to small cavity entrance area.

Table 3: Summary of effort and survey results for each of 11 transects located on Pima County conservation lands in the Altar and Avra valleys, Arizona, surveyed for Cactus Ferruginous Pygmy-owls in March, April, and October 2017. Transects are names based on the ranches or regions they traversed and are listed alphabetically. All owls detected along transects are included despite the fact that some owls noted in the text were largely using lands adjacent to County lands, but not managed by Pima County. Thus, in some cases, individual owl's territories likely included lands both on and off of County lands.

Transect	Stations	Occupied Stations			Detections			Individuals			Males		
	no. or range	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Coyote Mountains 1	2	2.0	2	2	2.3	2	3	2.0	2	2	2.0	2	2
Coyote Mountains 2	7	7.0	7	7	8.7	7	10	4.3	4	5	3.7	3	5
Diamond Bell 1	10	3.3	3	4	3.3	3	4	1.0	1	1	1.0	1	1
Diamond Bell 2	11	5.7	0	9	6.3	1	10	2.7	1	4	2.7	1	4
Diamond Bell 3	9	3.3	0	5	3.3	0	5	1.0	0	2	0.7	0	1
Diamond Bell 4	9	4.3	3	5	5.0	3	7	2.7	2	3	2.7	2	3
Lord's Ranch	9-13	0.3	0	1	0.3	0	1	0.3	0	1	0.0	0	0
Marley 1	6	1.0	0	3	1.0	0	3	0.3	0	1	0.3	0	1
Marley 2	6-7	4.7	3	6	5.7	3	8	2.3	2	3	2.0	2	2
Marley 3	5-6	1.7	0	4	1.7	0	4	1.0	0	2	1.0	0	2
Tucson Mt. Park	12	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0

DISCUSSION

I located a fairly large population of pygmy-owls on Pima County conservation lands in the northern Altar Valley in 2017. This achievement was fostered by quantitative tools developed in adjacent Sonora, Mexico, data from aerial reconnaissance and remote sensing, and a well-formed search image for pygmy-owl habitat developed over two decades of experience in the Sonoran Desert. Importantly, many sites occupied by pygmy-owls that I located were unknown to scientists, managers, and policy makers in the recent past. With the exception of two known historical sites monitored by USFWS in the Altar Valley and a site at Lord's Ranch where pygmy-owls bred in captivity were recently released, 17 territories occupied by pygmy-owls that I documented were not known before work presented here (Flesch 1999, 2003a, Flesch et al. 2017, S. Richardson, USFWS, pers. comm.). These new sites roughly double the known population of recently occupied sites in the northern Altar and adjacent Avra valleys in Arizona ($n = 18$). Moreover, these results also expand the spatial extent of the known distribution of pygmy-owls in Arizona, and increased the population of historical sites monitored by USFWS and collaborators since the early 1990s ($n = 39$) by 44%. In combination with management strategies that preserve and perpetuate the continued existence of habitat, these results confirm the value of Pima County conservation lands for the Cactus

Ferruginous Pygmy-Owl. Importantly, baseline data reported here also provide a strong foundation upon which to build subsequent monitoring efforts, which was a major goal of this effort.

Auspiciously, among the more important findings of this work is that pygmy-owls are somewhat more common and broadly distributed than was previously known in the northern Altar Valley, and in southern Arizona in general. This result combined with recent observations from long-term monitoring in Arizona, which indicates territory occupancy of populations in the lower Brawley (Altar) Valley has increased recently (Flesch et al. 2017), offers excellent prospects for recovery and conservation of pygmy-owls in southern Arizona. These results, however, sharply contrast patterns near Tucson, in the upper Brawley Valley, and in areas to the north and east of Tucson where populations of pygmy-owls have been extirpated recently or during the past century and there is no recent evidence of occupancy (Johnson et al. 2003, USFWS 2011, Flesch et al. 2017). Such results are especially noteworthy given the relatively low levels of survey effort implemented here (e.g., 91 stations along 11 transects) and suggest numerous additional territories remain to be discovered on lands managed by Pima County and perhaps other entities in this region. To this end, more survey effort on Diamond Bell Ranch, which is vast and supports a broadly distributed population of saguaros, and of lower quality sites assessed but not surveyed (most of which are on Diamond Bell), are likely to yield additional territories and nesting locations.

I largely validated the utility of an important quantitative tool for estimating habitat quality for pygmy-owls in southern Arizona and identifying areas on the landscape to prioritize for surveys. Despite the relative rarity of pygmy-owls across the broader landscape, virtually all transects I identified for surveys with use of this tool were occupied by one or more pygmy-owls at some point in the sampling period, and more than half of transects I selected for surveys were occupied during the breeding season. Importantly, distribution of pygmy-owls observed during surveys was associated with the estimated quality of space in the expected directions, further validating the utility of such modeling efforts to identify priority survey sites. In fact, estimated habitat quality of areas occupied by pygmy-owls was higher on average than that of areas where pygmy-owls were not detected during most seasons (particularly during the breeding season), with strong evidence of the expected positive relationship between persistence in occupancy and estimated habitat quality based on theory (Fretwell 1970, Sergio and Newton 2003, Flesch 2017). Such results provide strong evidence this approach is both sufficiently sensitive and based on appropriate indicators of habitat suitability to be broadly applicable for this and other applications. Nonetheless and not surprisingly, more recent measurements of woody vegetation cover yielded better estimates of habitat quality because they best matched observed owl distribution in the field. Given observed successes, the techniques used here should also offer a rigorous, evidence-based approach to identify and select optimal sites for habitat restoration, habitat enhancement, and sites for releases of pygmy-owls bred in captivity or via facilitated dispersal.

Monitoring Implications—Presence of a fairly large and broadly distributed population of pygmy-owls on Pima County conservation lands in the Altar Valley offer excellent prospects and strong foundations upon which to build subsequent monitoring efforts. To this end, monitoring both territory occupancy (no. of territories occupied), abundance (total number of males), and relative abundance (no. per unit effort) along transects is possible with the methods and data described here. Additional information on the extent, nest locations, and status of some territories, however, will aid development of rigorous occupancy monitoring, which can be pursued in future years and is described in detail by recent nearby efforts (e.g., Flesch et al. 2015, 2017). These parameters and similar methods have been highly effective for monitoring and illuminating the patterns and drivers of population dynamics of pygmy-owls in adjacent northern Mexico (Flesch and Steidl 2006, Flesch 2014, Flesch et al. 2017), and offer great promise for subsequent monitoring on Pima County conservation lands.

In advance of future efforts, a number of design and methodological considerations are useful to guide monitoring. With regard to the seasonal timing and frequency of surveys, monitoring inferences do not necessarily need to be based on three repeated surveys of the same transects in different seasons, even though such effort is helpful for determining persistence of occupancy. Given high detection probability of pygmy-owls using the methods described here (Flesch and Steidl 2007a) reducing survey intensity to one or perhaps two surveys per year seems warranted. This is especially the case if it liberates resources for surveying more area within a given year or the same areas with greater frequency of every year or every two years (e.g., instead of every three years as currently written into Pima County's MSCP). Limiting surveys to the nesting season (April and May) will focus inferences on territorial males that are potentially breeding, which is likely the most useful population attribute for monitoring (particularly over the 30 year term of the MSCP) despite higher abundance before and especially after the breeding season (Flesch and Steidl 2006, 2007). In Sonora, one survey per year during the nesting season at both the transect and territory-patch scale has proven to be an effective index for monitoring (Flesch and Steidl 2006, Flesch 2014, Flesch et al. 2017). However, surveys before and after the nesting season are useful for identifying occupied areas on the landscape even if these areas are more likely to be of lower quality than those occupied during the nesting season. Surveys following breeding and after the initiation of dispersal, however, may be useful for indexing annual reproductive output and subsequent survival, which may be desirable in some contexts. Finally, integrating monitoring on Pima County conservation lands with that conducted opportunistically by USFWS and their collaborators in the region, and more consistently in adjacent Sonora (see Flesch et al. 2017), could greatly bolster the success, scope and quality of inferences of efforts. This is because the dynamics of population units in some areas are likely influenced by similar drivers, given greater travel efficiency, and because larger sampling frames and sample sizes can augment statistical power and precision of trend and other estimates.

Management Implications—Despite observed associations between occupancy and estimated habitat quality just before and during the nesting season, there was no difference in estimated quality during October when young pygmy-owls are dispersing and selecting home ranges. This contrast provides useful insights into population processes and potentially population limitation in the region that have important implications for management. Animals typically select the best quality territories that are available first and occupy these sites more consistently over time (Newton 1998, Sergio and Newton 2003). Such patterns have been demonstrated in the field over fairly long time periods for pygmy-owls in adjacent Sonora, Mexico (Flesch 2017). Once independent from their parents, young-of-the-year pygmy-owls (and many other resident or non-migratory birds) in the region disperse in late summer and early fall, and settle either as territorial individuals in available territories or become non-territorial floaters in or at the edge of territories occupied by other individuals that are often older and more experienced (Flesch and Steidl 2007b, Flesch et al. 2010). By the time young birds are selecting territories of their own, overall population abundance is typically at its annual peak due to recent breeding activity and generally favorable conditions, and thus the best sites are often occupied by more dominant individuals. If abundance is high, young dispersing pygmy-owls selecting home ranges at this time are therefore often relegated to territories of lower quality. My results corroborate these general patterns by indicating higher overall occupancy rates and abundance in October and no difference in the estimated quality of occupied and apparently unoccupied areas at this time based on assessments of a large number of potential territories that are broadly representative of potential pygmy-owl habitat on County conservation lands. Although to some degree, habitat selection may rely on some different cues following breeding, and territorial expansion may also contribute to these patterns, occupancy of lower quality areas when abundance was high likely influenced these results. In combination with the relatively large and broadly distributed population I documented, these patterns suggest pygmy-owls already occupy some of the better quality potential sites in the northern Altar Valley but other sites mainly off of County lands remain to be detected. As such, habitat area and habitat quality rather than dispersal limitation or lack of adequate landscape connectivity to foster local immigration likely limit population size of pygmy-owls in this region. Hence, introducing new individuals from captive

breeding or facilitated dispersal into this system is likely to have little influence on population size unless managers simultaneously increase habitat area and quality, or if over-winter or potentially drought-induced mortality is high and releases are timed to compensate for such declines. Instead, releases of pygmy-owls should focus on areas where dispersal limitation due to habitat isolation by urban or agricultural growth or where relatively high distances from the nearest breeding populations are driving population limitation (Newton 1998). For pygmy-owls, landscape structures such as major highways, urban development, and large agricultural fields affect both movement and colonization success during dispersal, reduce landscape connectivity, and influence distributional dynamics at among-landscape scales (Flesch and Steidl 2007b, Flesch et al. 2010, Flesch 2017).

Conservation of pygmy-owls and their habitat on Pima County conservation lands can be aided by a number of guiding principles in combination with information on the context they occupy. First, many sites occupied by pygmy-owls in the region are at relatively high elevations for the species (e.g., >1,000 m) or in other areas where abundances of saguaro cacti are also low. In such contexts, availability of nest cavities, not woody vegetation cover, generally limits both the area and quality of habitat (Flesch 1999, 2003b, Flesch and Steidl 2010, Flesch et al. 2015). Thus, many pygmy-owls that occupy this region nest in one of very few, if not the only, potential nest substrates in their home ranges. Without these nest substrates and the cavities they provide, breeding habitat for pygmy-owls would otherwise not exist. In contrast, tree cover especially that dominated by mesquite, which promotes occupancy more than other desert tree species (Flesch 2003b), is fairly abundant across large areas including many that fail to provide habitat due to absences of potential nest sites. Hence, strategies that foster the reproduction, recruitment, and survival of saguaro cacti, and continued existence of primary excavators such as Gila woodpeckers, are the most fundamental guideline for conservation and management of pygmy-owls on Pima County conservation lands in the study region described here. This is especially the case for saguaros that are associated with xeric or mesic riparian woodlands and other wooded areas dominated by mesquite trees, which are more likely to provide habitat for pygmy-owls.

Most Pima County conservation lands I surveyed are grazed by domestic livestock. Assuring this and other ongoing land uses are consistent with the maintenance and continued existence of habitats for pygmy-owls and other listed species is important to strengthen the reliability of existing conservation mechanisms and success of the Sonoran Desert Conservation Plan. Livestock grazing can have both positive and negative impacts on habitat suitability for pygmy-owls. On one hand, grazing effects on pygmy-owl occupancy were greater in areas where saguaros were sparse, but grazing also creates openings and reduces ground cover, which at small scales can enhance visibility and likely habitat selection for pygmy-owls, especially in areas with high vegetation volume (Flesch 2003b, Flesch and Steidl 2010). However, livestock grazing has also been found to negatively influence regeneration of saguaro cacti (Niering et al. 1963, Niering and Whittaker 1965, Steenbergh and Lowe 1977, Abouhaider 1989, 1992), and high levels of grazing negatively influence abundance and diversity of prey taxa including species of lizards and small mammals that are major prey of pygmy-owls (Jones 1981, Fleischner 1994, Hayward et al. 1997, Flesch pers. obs.). Thus efforts to ensure grazing levels and management on Pima County conservation lands will foster recruitment of this keystone species are essential and warrant future studies. Depending on the results of these assessments, efforts to protect areas with high potential for saguaro establishment and recruitment, potentially by erecting localized fenced livestock exclosures, merit consideration.

In areas where potential nest cavities are naturally sparse or have been lost due to fire, invasion of exotic grasses, overgrazing, or natural patterns of infrequent and highly episodic recruitment of saguaros (Pierson and Turner 1998), active efforts to augment nest cavities could have major benefits for pygmy-owls. Such techniques include erecting nest boxes or translocating salvaged saguaros to create new habitat in areas where suitable woodlands are already present, or enhancing existing habitat by augmenting availability of potential nest cavities. Such techniques can be combined with existing information on nest heights and cavity dimensions and orientations selected

by pygmy-owls, which have major effects on reproduction, and used effectively to enhance or create habitat across large areas (see Flesch and Steidl 2010). Moreover, increasing abundances of potential nest cavities will increase the quality of existing habitat by reducing predation, competition, and interspecific aggression with other species of cavity nesters, especially larger heterospecific enemies such as western screech owls (*Megascops kennicottii*; Flesch and Steidl 2010, Flesch et al. 2015).

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APPENDIX A - PIMA COUNTY CACTUS FERRUGINOUS PYGMY-OWL SURVEY PROTOCOL

Developed by: Aaron D. Flesch, University of Arizona, School of Natural Resources and the Environment, Brian Powell, Pima County Office of Sustainability and Conservation, Ian Murray Pima County Office of Sustainability and Conservation

INTRODUCTION

We will follow a similar protocol to that outlined under the large survey area – research protocol described by USFWS (2000). We made various small modifications to this protocol to augment efficiency without reducing its reliability based on research recently completed in neighboring northern Sonora, Mexico (Flesch and Steidl 2007a, Flesch 2013, 2014). Detailed survey information based on >600 individual pygmy-owls in Sonora indicates that detectability of pygmy-owls during much of the breeding season is high (0.89-1.0 from 100-300 m from nests), that owls respond rapidly to call broadcasts (mean response time = 2.6 min, 99.6% of owls detected in ≤8 min), and that response rates and detectability remain high at times 2-hours after local sunrise and 1-hour before local sunset (Flesch and Steidl 2007a). Therefore, we will propose some small modifications to the existing protocol to increase its efficiency without altering its effectiveness. The material below includes original and modified text from USFWS (2000).

PROTOCOL DETAILS

1. A valid Arizona Game and Fish Department Scientific Collecting License outlining relevant permissions to carry out pygmy owl surveys must be held by the primary surveyor for all surveys. Permission to access a property for surveying must be obtained from each private property owner or those having management authority (public lands) prior to conducting surveys. Where permission cannot be obtained from adjacent landowners, call stations should be placed on the property boundary and public roads without trespassing so that coverage may be extended to adjacent areas.
2. Call stations should be surveyed twice during the spring with one survey during the territory-establishment period between approximately February 1 and March 31 and one survey during the nesting season between April 1 and June 15. There should be at least 15 days between each spring survey at a given site. Additionally, stations should be surveyed once in the fall shortly after the period when juveniles are dispersing. These surveys will focus between September 15 and October 31 and allow detection of juveniles that may have recently settled in the area as well as any previously documented resident individuals.
3. Surveys should be conducted in potential habitat from 1 hour before sunrise to 3 hours after sunrise, or from 2 hours before sunset to 1 hour after sunset (use an official sunrise table for correct times). Surveys may also be conducted at night during a full moon or nearly full moon three days on either side of a full moon while the moon is visible. If the moon sets or is obscured by clouds, surveys should not be conducted.
4. Surveys should not be conducted under adverse weather conditions (e.g., moderate or strong winds [greater than 12 mph] or during rain). Under these conditions, owls may not be able to hear broadcasted calls and the surveyor's ability to hear an owl response may be reduced. In addition, surveys should not be conducted at call stations that have loud noises (e.g., traffic, aircraft, barking dogs, etc.) that reduce the effectiveness of broadcasted calls or impair the surveyor's ability to hear responding owls. Call stations should be placed away from noisy areas or rescheduled for another time (e.g., weekends when there is less traffic in urban areas), and where possible placed on elevated wash terraces or other areas that aid listening vs. in deep wash channels or depressions.

that may obstruct sounds. The survey period spent at stations with periodic noise (e.g., aircraft, traffic, etc.) should be extended to compensate for periodic noisy survey conditions if they cannot be avoided.

5. Call stations along survey transects should be spaced at no more than 500 m (0.3 mi) apart with most stations placed 300-400 apart depending on terrain, location of nesting substrates, and coverage needs. Call stations in mesic riparian areas that support tall gallery forest should be no more than 300 m apart due to tree density and noise. In areas where habitat is widely spaced, where a single transect is placed along multiple wash channels so as to cover distant habitat patches, or where land in-holdings are present, stations can be placed further away.

6. At each call station prior to broadcasting a taped call we will listen for a 1-minute period. This will allow the surveyor to detect any spontaneous calling and also to become familiar with features at the station (i.e., large trees or saguaros, residences, water sources, etc.) that may affect pygmy-owl presence or detectability.

7. Following the initial listening period, the surveyor will broadcast CFPO calls for 30 seconds, followed by a 30-45 second listening and observation period. The surveyor should broadcast calls in all directions of habitat. The volume should be set to an adequate level to get complete coverage along a survey route without causing distortion of the call. Equipment used should be able to produce a loud, clear call without distortion and a sound level between 95-105 decibels at a distance of 1 m from the speaker (Proudfoot et al. 2002).

8. Repeat this calling/listening sequence for at least 6 minutes. Extend this sequence for up to an additional 5 minutes or more if noise disturbances such as barking dogs, air traffic or vehicles cannot be avoided and they affect your broadcast or ability to hear (see number 6 above).

9. During the survey/listening sequence, the surveyor should periodically scan trees and cactus (particularly cavities and trees) for pygmy-owls that may be present but not vocalizing. Binoculars should be used to assist the surveyor locate owls. A rangefinder and compass may be used to estimate the direction and distance of any responding owls. Note any mobbing behavior by other birds in response to the tape broadcast and investigate appropriately.

10. After completing the 6-minute broadcast/listening sequence, we will observe and listen for an additional 1 minute before placing gear away and proceeding to the next call station. Any detections following this 1-minute period that occur at the station will be noted as having occurred at the station. Combined with the initial 1-minute listening period, the total time spent at each call station should be a minimum of 8 minutes.

11. For each route surveyed, we will complete a datasheet that includes the following data fields: survey date, survey time, surveyor, weather conditions, moon phase, official sunrise or sunset time, location and elevation of each calling station (UMT), and the distance between successive stations. For each pygmy-owl detection, we will note the time elapsed from the start of broadcasts to detection, the sex of owls based on vocalization, the call type (territorial call, chitter call, alarm call), the initial distance and direction to owls from the station, the final detection distance, the number of pygmy-owls detected, and whether the owl was detected at the prior station or represents a new individual. We will use the distance, direction, and timing of responses to discriminate multiple individual pygmy-owls. For owls detected while walking to neighboring stations, we will record this same information and note the distance to the closest station. Other species of owls detected at stations will also be noted.

12. In order to maximize the efficiency of inter-agency species management efforts, any positive detections of pygmy-owls will be sufficiently documented and communicated to the local USFWS office.

Copies of all datasheets and survey maps will be shared with the USFWS and AGFD during annual scientific collecting license renewal.

If a pygmy-owl is heard or seen:

1. End call broadcast at the station to avoid harassing the owl, unless additional responses are needed to pinpoint location of the pygmy-owl. Estimate the direction and distance of the initial location of pygmy-owl detection (e.g., using a rangefinder and compass), as well as the time required for the initial response. Sex of the responding owl should also be noted where possible.
2. Place the next broadcast station a minimum of 500 m away so that additional owls can be detected in the area and those individuals can be discriminated from owls already observed at prior stations based on distance, direction, and timing of responses.
3. After the survey route is complete and where possible, observe the pygmy-owl without disturbing it (i.e., do not chase the owl or harass it with calls). Record all observations, use of cavities and prey observations are especially important. Listen for female or fledgling vocalizations or other evidence that there may be other pygmy-owls in the area.
4. Record owl locations using UTM (NAD 83) coordinates and ensure all relevant data such as survey date, time, weather conditions, moon phase, official sunrise/sunset times, and responses of any other bird species are accurately and legibly filled out.

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APPENDIX B – SURVEY RESULTS STANDARDIZED BY EFFORT AS MEASURED BY NUMBER OF SURVEY STATIONS FOR EACH SEASON AND TRANSECT.

Table S1: Survey results standardized by effort (no. of stations) across each of three seasonal visits and all visits to 11 transects located on Pima County conservation lands in the Altar and Avra valleys, Arizona, surveyed for Cactus Ferruginous Pygmy-owls in 2017.

Survey period	Occupied Stations/Effort		Individuals/Effort		Males/Effort	
	Mean	St. Err.	Mean	St. Err.	Mean	St. Err.
March	0.462	0.122	0.271	0.089	0.248	0.086
April	0.365	0.122	0.246	0.101	0.246	0.101
October	0.521	0.114	0.301	0.090	0.265	0.088
<i>All Seasons</i>	<i>0.449</i>	<i>0.045</i>	<i>0.273</i>	<i>0.016</i>	<i>0.253</i>	<i>0.006</i>

Table S2: Survey results standardized by effort (no. of stations) across each of three seasonal visits and on average for each of 11 transects located on Pima County conservation lands in the Altar and Avra valleys, Arizona, surveyed for Cactus Ferruginous Pygmy-owls in 2017.

Transect	Occupied Stations/Effort			Individuals/Effort			Males/Effort		
	Mar.	Apr.	Oct.	Mar.	Apr.	Oct.	Mar.	Apr.	Oct.
Coyote Mountains 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Coyote Mountains 2	1.00	1.00	1.00	0.57	0.71	0.57	0.43	0.71	0.43
Diamond Bell 1	0.30	0.30	0.40	0.10	0.10	0.10	0.10	0.10	0.10
Diamond Bell 2	0.00	0.73	0.82	0.09	0.27	0.36	0.09	0.27	0.36
Diamond Bell 3	0.56	0.00	0.56	0.22	0.00	0.11	0.11	0.00	0.11
Diamond Bell 4	0.56	0.56	0.33	0.33	0.33	0.22	0.33	0.33	0.22
Lord's Ranch	0.00	0.00	0.11	0.00	0.00	0.11	0.00	0.00	0.00
Marley 1	0.50	0.00	0.00	0.17	0.00	0.00	0.17	0.00	0.00
Marley 2	1.00	0.43	0.71	0.33	0.29	0.43	0.33	0.29	0.29
Marley 3	0.17	0.00	0.80	0.17	0.00	0.40	0.17	0.00	0.40
Tucson Mountain Park	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Average</i>	<i>0.46</i>	<i>0.36</i>	<i>0.52</i>	<i>0.27</i>	<i>0.25</i>	<i>0.30</i>	<i>0.25</i>	<i>0.25</i>	<i>0.26</i>