Population and Demographic Trends of Ferruginous Pygmy-owls in Northern Sonora Mexico and Implications for Recovery in Arizona

FINAL REPORT

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February 2007

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ABSTRACT

Recovery of cactus ferruginous pygmy-owls (*Glaucidium brasilianum cactorum*) in Arizona will likely depend on efforts to restore habitat and foster immigration from neighboring northern Sonora, Mexico where pygmy-owls are more abundant. Because populations of pygmy-owls have declined in Arizona, information on population and demographic trends in neighboring Sonora, Mexico has important implications for management and recovery. In 2006, I continued to monitor pygmy-owls in northern Sonora within 75 km of Arizona where an estimated 30% decline in abundance was observed between 2000 and 2005. In 2006, I surveyed all 54 km of transects that have been surveyed each year since 2000, estimated occupancy in 102 territories, and monitored 47 nests within 110 km of Arizona. Between 2000 and 2006, abundance of pygmy-owls within 75 km of Arizona has declined by $4.4 \pm 1.9\%$ ($\pm$ SE) per year ($P = 0.0027$) or 26% overall. Between 2002 and 2006, territory occupancy within 110 km of Arizona declined $3.2 \pm 1.2\%$ per year ($P = 0.010$) or 13% overall. Clutch size and productivity were low in 2002 and 2006 and high between 2003 and 2005 ($P \leq 0.0087$), with much less evidence of similar trends in nest success ($P = 0.15$). Annual estimates of clutch size and nest success increased with quantity of winter or annual rainfall that occurred before the nesting season ($P \leq 0.097$), productivity increased from low to moderately high levels of winter rainfall and decreased sharply thereafter ($P = 0.018$), and abundance increased with quantity of winter rainfall after a 2-year time lag ($P = 0.047$). These trends and those of other studies in arid environments suggest rainfall may be driving regional population and demographic dynamics of pygmy-owls, likely by influencing food availability. Continued declines of pygmy-owls in northern Sonora may reduce recovery prospects in Arizona unless active measures are taken.

INTRODUCTION

Cactus ferruginous pygmy-owls (*Glaucidium brasilianum cactorum*, hereafter pygmy-owls) were described as common in portions of lowland central and southern Arizona in the late 1800's and early 1900's (Bendire 1888, Fisher 1893, Breninger 1898, Gilman 1909, Swarth 1914, Bent 1938). In the mid 1990's, however, large-scale modifications of the environment by humans are thought to have caused the extirpation of pygmy-owls from much of their former range in Arizona (Johnson et al. 2003). In 1997 pygmy-owls were listed as endangered by the U.S. Fish and Wildlife Service (USFWS 1997), yet despite conservation concerns driven by recent declines in Arizona, pygmy-owls were removed from the endangered species list in 2006 for reasons unrelated to recovery (USFWS 2006). Recently in Arizona, pygmy-owls have occurred in Cabeza Prieta National Wildlife Refuge (Flesch and Steidl 2001), Organ Pipe Cactus National Monument (T. Tibbitts, personal communication 2004), Tohono O'odham Nation (S. Bailey, personal communication 2001), Altar Valley (Flesch 1999, 2003a), and near Tucson (Abbate et al. 1999, 2000). Surveys in Arizona suggest that pygmy-owls continue to decline near Tucson where nesting has not been documented recently and where the only pygmy-owl known to occur was removed from the wild by the Arizona Game and Fish Department in 2006 to establish a population for captive breeding (Davis 2007).

Immediately south of Arizona in northern Sonora, Mexico, pygmy-owls occupy Sonoran desertscrub and semidesert grassland vegetation communities where woodlands occur near large saguaro cacti (*Carnegiea gigantea*) (Flesch 2003b). Because pygmy-owls are more common in northern Sonora, these populations may prove critical for recovery efforts in Arizona and for long-term persistence of pygmy-owls in the Sonoran Desert ecoregion. Natural or facilitated dispersal of pygmy-owls from Sonora may augment populations in Arizona especially when combined with efforts to restore and enhance habitat (USFWS 2003). However, numerous threats to habitat of pygmy-owls exist in northern Sonora, including loss and limited regeneration of saguaro cacti, woodcutting, and vegetation clearing for

agriculture and buffelgrass (*Pennisetum ciliare*), and there are few regulatory mechanisms to protect habitat (Flesch and Steidl 2006a). If populations of pygmy-owls in northern Sonora decline, recovery strategies in Arizona that rely on these populations may be jeopardized.

Because of the importance of populations of pygmy-owls in northern Sonora, I initiated a program to monitor population and demographic parameters (e.g. nest success and productivity) of pygmy-owls in 2000 and 2001 in Arizona-Sonora borderlands. These data indicated that between 2000 and 2005 abundance of pygmy-owls had declined by an estimated 30% (Flesch and Steidl 2006b). To provide information important for management and recovery efforts in Arizona, I continued to monitor population and demographic parameters of pygmy-owls in northern Sonora in 2006.

STUDY AREA

I estimated trends in abundance of pygmy-owls in northern Sonora within 75 km of Arizona and trends in territory occupancy and demographic parameters within 110 km of Arizona (Fig. 1). Vegetation was dominated by the Arizona Upland subdivision of the Sonoran Desert and semidesert grassland (Brown 1982). Upland desertscrub in the Arizona Upland subdivision is dominated by open woodland of short leguminous trees and shrubs; uplands in semidesert grassland are dominated by open woodland and savannah of mesquite (*Prosopis velutina*) and sub-shrubs. Riparian areas in both vegetation communities are dominated by woodlands of mesquite and acacia (*Acacia* sp.), and occasionally Mexican ebony (*Havardia mexicana*). Saguaros, the typical nest substrate used by pygmy-owls in the region, occurred in both vegetation communities.

METHODS

Design

Trends in abundance.—I surveyed 71 transects clustered around 23 randomly selected points in northern Sonora in 2000 (Flesch 2003b). In 2001 I randomly selected 6 of 14 random points where ≥1

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male pygmy-owl was detected per transect as a baseline to monitor abundance (Flesch and Steidl 2006a) and surveyed these transects once each year through 2006. Transects were located 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. These 6 points included a total of 18 transects located in 4 geographic regions: in the watersheds of the Upper Rio Altar, Upper Rio Plomo, Middle Rio Sasabe, and Upper Rio Sasabe-Vamori (Fig. 1). All 18 transects combined totaled 53.7 km in length and were located between 740 and 1,035 m elevation in or at the edge of the Arizona Upland subdivision ($n = 7$) and semidesert grassland ($n = 11$).

Trends in territory occupancy and demographic parameters.—I searched for nests along occupied transects and incidentally in areas of potential habitat that I surveyed and found to be occupied between 2001 and 2004 (Flesch 2003b, Flesch and Steidl 2007a). Each year I selected a random sample of areas occupied during previous years to survey and search for nests. At most occupied areas, I located nests by observing owls, searching for sign (pellets, scat, and prey remains) around potential nests, and using a small pole-mounted video camera and video display to confirm and monitor nesting. I visited most nests 2-4 times per season to record nest contents, age of nestlings, and estimate nest success (≥ 1 young within 1 week of fledging) and productivity (no. young within 1 week of fledging/ successful attempt). I attempted to locate nests as soon after clutch completion as possible, although I found nests throughout the entire nesting cycle. I considered nest locations that changed in successive years to be within the same nest area when locations among years occupied discrete areas relative to neighbors; mean distance among nests occupied in successive years within a nest area ($n = 53$) averaged 143 ± 25 m (range 0-640), more than 7 times less than mean distance between neighboring nests ($1,064 \pm 73$ m, $n = 39$) (A. Flesch, unpublished data).

Owl Surveys

To estimate occupancy and abundance, I broadcast territorial calls to elicit responses from pygmy-owls during the incubation and nestling stages of the breeding season. I placed 5-10 stations per

transect spaced 350-400 m apart along drainage channels and within 300 m of nests used during previous

seasons, arrangements for which detection probability of pygmy-owls approaches 1.0 (e.g. perfect

detectability; Flesch and Steidl 2007b). At each station I alternated listening and calling sequences every

30-45 sec with listening periods during the first and last 30-60 sec. I remained at stations for 8 min or

until 1 min after an owl was detected. If I detected an owl during initial surveys along transects, I

increased spacing of the next station to 550-600 m to reduce the probability of detecting the same bird

more than once and used these same stations in successive years. I surveyed transects during mornings (1

hr before to 3 hrs after sunrise) and nest areas at all times of day because detectability remains high

throughout the day (Flesch and Steidl 2007b). I did not survey during rain or when wind exceeded 20

kph. Once I located an owl I determined its sex based on vocalization patterns and I used distance and

direction of responses to differentiate among owls that did not respond simultaneously.

Environmental Measurements

I noted whether nests were located in semidesert grasslands or desertscrub. For each territory, I

recorded nest locations (UTM) with use of a GPS and elevation with use of 1:50,000 m topographic

maps. I noted the watershed and reach in which each nest site or transect was located, and categorized

them into 11 regions based mainly on watershed boundaries: Upper and Lower Altar, Upper Magdalena,

Middle Magdalena-Coyotillo, Upper and Lower Plomo, Upper San Miguel, Busani, Middle Sasabe,

Upper Sasabe-Vamori, and Sonoyta. To quantify regional patterns of precipitation I used data from two

weather stations located near Sasabe and Lukeville on the Arizona-Sonora border (Western Regional

Climate Center 2006) because these were the only data available. I assessed trends in rainfall since 1960

so that these trends could be compared to those during the study. I calculated annual precipitation for the

12-month period from June 1 of the previous year to May 31, winter precipitation from 1 October-30

April, and summer precipitation from 1 May-31 September because these periods corresponded with the

nesting cycle.

Analyses

   Parameter estimation.—I estimated abundance of pygmy-owls by calculating the number of males detected per station along each transect for each year. I estimated occupancy by calculating the proportion of areas found to be occupied each year and only considered areas the year after they were found to be initially occupied. I considered nests successful if they contained ≥1 nestling within a 1 week of fledging (≥21 days old) and nests to have failed if they did not contain eggs or young during a subsequent visit provided young could not have obtained an age ≥25 days old because young that fledge earlier do not survive (Glenn Proudfoot, personal communication 2002). Because successful nests have a greater probability of being found than those that fail (Mayfield 1961), I considered only those nests found within 2 weeks of clutch completion when assessing trends in nest success and excluded years for which ≤10 nests were found (2001). To estimate nest-initiation dates, I averaged estimates of median nestling age from all visits during brooding to estimate median hatch date, then subtracted 25 days for incubation (A. Flesch, unpublished data based on $n = 15$ nests) and 1.5 days for each egg in a clutch (Proudfoot and Johnson 2000). To estimate initiation date when clutch size was unknown ($n = 62$) I used average clutch size rounded to the nearest whole number. When nests failed during incubation such that I could not estimate timing of initiation, I used the mean initiation date among all nests for that year because within-year variation in timing was consistently low (Flesch and Steidl 2007b). To estimate clutch size, I (1) confirmed clutches were complete based on the age of young during subsequent visits, (2) considered nestlings ≤6 days old an indication of clutch size because unhatched eggs were always visible when nestlings were small and adults had left cavities, and (3) assumed no egg loss. To estimate productivity, I counted the number of nestlings within 1 week of fledging and excluded nest events when median age of nestlings was >25 days unless all individuals could be accounted for.

   Modeling.—To assess trends in population and reproductive parameters of pygmy-owls across time I used generalized linear models to regress each parameter against year and blocked on transects (abundance) or areas (all other parameters) because they were measured repeatedly. I used logistic models for parameters that were binary (occupancy and nest success) and ordinary least squares models

for parameters that were continuous. I treated year, region, and vegetation community as fixed effects and transects or areas as a random effect. To assess nonlinear trends, I fit quadratic terms. To assess if trends varied among regions and vegetation communities I fit time × location interactions where sample sizes were sufficient. To compare trend estimates of abundance with those of occupancy, I used linear regression on proportions based on the logistic model for occupancy. To describe regional patterns of rainfall and associations between population and demographic parameters of pygmy-owls and quantity of annual, winter, and summer rainfall, I used least squares regression and considered linear, quadratic, and cubic terms.

RESULTS

Abundance

Effort and detections.—Transect length averaged 2,983 ± 116 m (± SE) (range = 2,300-3,850) with 6.8 ± 0.2 stations per transect and a total of 123 stations along all 18 transects. I detected a total of 255 males over 7 years; 55 in 2000, 32 in 2001, 36 in 2002, 37 in 2003, 28 in 2004, 34 in 2005, and 33 in 2006.

Trends in abundance.—Across the study area, abundance of pygmy-owls declined by an average of 0.020 ± 0.0065 males/station/year from 2000 to 2006 (t_{107} = 3.07, P = 0.0027), the equivalent of a 4.4 ± 1.9% decline per year (95% CI = 1.2-8.1%) or 26.4% decline over all 7 years (Fig. 2). There was also evidence (P = 0.059) that abundance declined more in the Upper Altar watershed and near Sasabe, regions that are closest to Arizona. In contrast, relative abundance was stable in the Middle Sasabe, the southernmost region sampled (Fig. 2). Despite continued evidence of an overall decline, abundance was similar to that in 2005 when it increased from to a 7-year low in 2004. Overall, abundance averaged 0.32 ± 0.04 males/station or 2.7 times higher in Arizona Upland desertscrub than in semidesert grasslands (t_{107} = 4.05, P < 0.0001).

Occupancy

Effort and detections.—Between 2001 and 2006, I estimated occupancy in 110 areas located between 360 and 1030 m elevation; 55% of areas were in Arizona Upland desertscrub ($n = 60$). I estimated occupancy 409 times in years after areas were found to be initially occupied and surveyed most areas across 4 (44%) or all 5 (25%) years. Occupancy averaged $61.3 \pm 2.4\%$ across all years combined.

Trends in occupancy.—Occupancy varied across time ($\chi^2_{298} = 6.58$, $P = 0.010$) and declined by an average of $3.2 \pm 1.2\%$ per year between 2002 and 2006 (95% CI = 0.9-5.5%) or 12.8% over all 5 years (Fig. 3). Occupancy averaged $71.2 \pm 6.3\%$ in 2002 ($n = 37$ of 52), $63.6 \pm 5.9\%$ in 2003 ($n = 42$ of 66), $64.1 \pm 5.0\%$ in 2004 ($n = 59$ of 92), $67.0 \pm 4.8\%$ in 2005 ($n = 65$ of 97), and $53.9 \pm 4.9\%$ in 2006 ($n = 55$ of 102). Although I lacked sufficient degrees of freedom to assess if trends varied among regions or vegetation communities, mean occupancy across all years combined varied among regions ($\chi^2_{397} = 27.40$, $P = 0.0023$) and vegetation communities ($\chi^2_{397} = 3.85$, $P = 0.050$). Occupancy was higher in the Upper San Miguel ($n = 88.9 \pm 7.4\%$ of 18, $P = 0.012$), somewhat higher in the Middle Sasabe ($n = 84.0 \pm 7.3\%$ of 25, $P = 0.089$), and much lower in the Busani region ($n = 24.0 \pm 8.5\%$ of 25, $P < 0.0001$) than in the Upper Sonoyta region ($n = 76.9 \pm 11.7\%$ of 13) where occupancy was similar to that in other regions ($n = 62.5 \pm 2.7\%$ of 328, $P \geq 0.25$) (Fig. 3). Occupancy averaged $59.8 \pm 3.4\%$ ($n = 122$ of 204) in semidesert grasslands and $66.3 \pm 3.3\%$ ($n = 136$ of 205) in Arizona Upland desertscrub.

Demographic Parameters

Effort and detections.—I located 316 nests within 114 areas between 2001 and 2006 and determined outcome of 84% of nests. Nests were located an average of 24 ± 1 days after initiation and apparent nest success was 82.3% ($n = 218$ successful nests) across all years. Of the 132 nests located within 2 weeks of clutch completion, apparent nest success was 74.2% ($n = 98$ successful nests). Clutch size averaged 4.2 ± 0.04 eggs/clutch (range = 2-6, $n = 229$) with most clutches (56.8%) containing 4 eggs and fewest containing 6 (0.9%) or 2 (0.4%) eggs. Productivity averaged 3.7 ± 0.1 young within 1 week of fledging per successful attempt and 47.8% of nests produced 4 young (range = 1-5, $n = 186$).

Trends in demographic parameters.—There was little evidence that success of nests detected within 2 weeks of clutch completion varied across time ($\chi^2_{78} = 2.06$, $P = 0.15$, $n = 132$, for test of quadratic term) (Fig. 4). Nest success averaged $67 \pm 13\%$ in 2002 ($n = 12$), $82 \pm 12\%$ in 2003 ($n = 11$), $76 \pm 8\%$ in 2004 ($n = 29$), $77 \pm 7\%$ in 2005 ($n = 35$), and $71 \pm 7\%$ in 2006 ($n = 45$).

Clutch size was lower during 2002 and 2006 than during other years ($t_{126} = 2.66$, $P = 0.0087$, for test of quadratic term) (Fig. 4). Clutch size averaged 4.2 ± 0.14 in 2001 ($n = 25$), 4.0 ± 0.10 in 2002 ($n = 38$), 4.2 ± 0.16 in 2003 ($n = 20$), 4.4 ± 0.09 in 2004 ($n = 48$), 4.3 ± 0.09 in 2005 ($n = 52$), and 3.9 ± 0.10 in 2006 ($n = 46$). Clutch size did not vary among regions or vegetation communities ($t_{115} \leq 0.32$, $P \geq 0.75$).

Productivity was greater between 2003 and 2005 than during 2001, 2002, and 2006 ($t_{89} = 3.87$, $P = 0.0002$, for test of quadratic term) (Fig. 4). Productivity averaged 3.2 ± 0.23 in 2001 ($n = 18$), 3.5 ± 0.12 in 2002 ($n = 46$), 3.8 ± 0.12 in 2003 ($n = 11$), 4.0 ± 0.13 in 2004 ($n = 37$), 4.0 ± 0.12 in 2005 ($n = 43$), and 3.4 ± 0.20 in 2006 ($n = 31$). In 2004 and 2005, 27% of successful nests produced 5 young whereas in other years combined only 4% of successful nests produced 5 young. Productivity was higher in the Upper San Miguel (4.6 ± 0.3, $n = 10$, $P = 0.038$) than in the Upper Sonoyta region (3.7 ± 0.3, $n = 11$) where productivity was similar to that in other regions (3.6 ± 0.1, $n = 165$). Productivity did not vary between vegetation communities ($t_{78} = 0.75$, $P = 0.45$).

Rainfall

Historical trends.—After 1960 annual rainfall along the northern edge of the study area declined until the mid 1970's, then increased gradually until the mid 1990's, and declined sharply thereafter ($t_{43} = 2.63$, $P = 0.013$, for test of cubic term), with similar but less evident trends for winter rainfall ($P = 0.14$) (Fig. 5). Over the course of the study, rainfall was relatively high during 2001, 2004, and 2005 and low during 2002 and 2006.

Pygmy-owls and rainfall.—Annual estimates of abundance and occupancy of pygmy-owls did not vary with annual, winter, or summer rainfall measured the year before and during the nesting cycle ($t_4 \leq 1.05$, $P \geq 0.37$). However, abundance increased with winter rainfall after a lag time of 2 years ($t_5 \leq 2.62$,

$P = 0.047$) (Fig. 6). There was also evidence that clutch size increased with annual rainfall ($t_4 = 2.15$, $P = 0.094$), that nest success increased with winter rainfall ($t_4 = 2.76$, $P = 0.051$), and that productivity increased from low to moderately high levels of winter rainfall and decreased sharply thereafter ($t_3 = 4.70$, $P = 0.018$) without any lag time (Fig. 6).

DISCUSSION

Trends in Abundance and Occupancy

Between 2000 and 2006, abundance of pygmy-owls in northern Sonora, Mexico declined by an estimated 4.4% per year or 26% over 7 years (Fig. 3). Although the magnitude of this decline is lower than that observed after 2004 and 2005 (Flesch and Steidl 2006a, b), estimates from 2006 were mixed. Abundance remained high in 2 geographic regions that recovered from a 7-year low in 2004, yet abundance in 2 other regions closest to Arizona remained low. Similarly, between 2002 and 2006, territory occupancy of pygmy-owls declined by an estimated 3.2% per year or 13% over 5 years (Fig. 2). Notably, this annual rate of decline did not differ from that for abundance (based on 95% CI), even though occupancy was estimated across a much larger area (Fig. 1). Because estimates of occupancy at the scale of individual territories should be equivalent to those of abundance sampled at larger spatial scales (MacKenzie et al. 2006), trend estimates of occupancy may provide more precise population estimates in northern Sonora because a larger sampling frame was considered. However, because abundance was estimated in regions that are closest to Arizona (Fig. 1), trends in abundance may be more relevant to management and recovery in the Arizona-Sonora borderlands. Importantly, however, similar estimates for trends in occupancy and abundance, provides an additional line of evidence that populations of pygmy-owls are declining in northern Sonora. Should this apparent decline continue, recovery strategies that rely on pygmy-owls from northern Sonora and persistence of pygmy-owls in the Sonora Desert could be jeopardized.

Determining whether the observed trends represent short-term natural variation in population size or represent a long-term systematic decline will require continued study because declines in abundance

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over short periods may not indicate systematic declines (Robinson 1992). The estimated decline in abundance was influenced strongly by the year 2000 that if excluded from the analysis reduced the magnitude of the estimated decline from 4.4% to 0.4% per year. Nonetheless, because pygmy-owl populations have declined to endangered levels in Arizona and occupancy declined similarly across an inclusive yet larger area, estimated declines of pygmy-owls in northern Mexico are causes for concern and continued study.

I found evidence that trends in abundance and estimates of occupancy varied geographically. For example, abundance was relatively high and declined less in the Middle Sasabe region than in other regions (Fig. 2) and territory occupancy was much higher in the San Miguel, somewhat higher in Middle Sasabe, and lower in Busani than in other regions (Fig. 3). Such variation is likely related to differences in habitat characteristics that explained variation in population trends between 2000 and 2004 (Flesch and Steidl 2006a). For example, cumulative effects of land-use activities by humans have been associated with greater declines in abundance in northern Sonora (Flesch and Steidl 2006a). This pattern may, in part, explain lower occupancy in the Busani region where much of the woodlands along the river bottom have been converted to agriculture likely reducing habitat quality for pygmy-owls.

Population monitoring programs must quantify temporal variation in population parameters despite spatial variation and sampling error (Yoccoz et al 2001, Pollock et al. 2002). For organisms that are difficult to detect or that respond unpredictably, variation in detectability will increase sampling error and may preclude trend detection. Consequently, most monitoring efforts use capture-recapture, distance, or repeat-sampling methods (Buckland et al. 1993, Williams et al. 2002, MacKenzie et al. 2006) so that variation in detectability can be used to correct counts. Because detectability of male pygmy-owls approaches 1.0 during the nesting season and males respond rapidly from a wide range of distances when responses are solicited with broadcast calls, occupancy and abundance of pygmy-owls can be efficiently monitored using single-occasion sampling (Flesch and Steidl 2007b). Further, because most male pygmy-owls seem to settle for life on territories (Proudfoot and Johnson 2000), systematic temporal

trends in occupancy or abundance likely represents loss of adults without replacement. These properties make pygmy-owls an efficient choice for monitoring and suggest trend estimates are accurate.

Trends in Demographic Parameters

Monitoring demographic parameters can provide an early warning of potential and developing population declines and thereby promote faster response time and more efficient conservation and management. For pygmy-owls in the Sonoran Desert region, monitoring both population and demographic parameters will increase understanding of population dynamics and provide a strong foundation for developing conservation and recovery strategies. Between 2001 and 2006 there was strong evidence that clutch size and productivity of pygmy-owls varied across time, trends that corresponded for both parameters (Fig. 4). For nest success, although few nests were found soon after initiation during early years, there was still suggestive evidence that temporal trends corresponded with those for clutch size and productivity. Estimates of all demographic parameters were low in 2002 and 2006 and relatively high between 2003 and 2005. Because estimates of most demographic parameters reached 5- or 6-year lows in 2006, monitoring these parameters in 2007 is especially important.

Rainfall

Although trends in demographic parameters may foreshadow future population declines, assessing relationships between environmental conditions and demographic performance may suggest the causes of declines. To that end, in combination with environmental factors associated with greater declines in abundance (Flesch and Steidl 2006a), I found evidence that rainfall may be driving population and demographic parameters of pygmy-owls, especially winter rainfall (Fig. 6). Winter has been suggested as the season when limiting factors most affect bird populations (Fretwell 1972), often through factors such as food limitation and extreme weather (Lack 1954). In our region, quantity of winter rainfall immediately before nesting is lower and often more variable than that produced by the summer monsoon (Fig. 5), likely augmenting its importance and explaining the stronger associations I observed.

Although additional years of data are needed to assess the strength of these associations, relationships that I observed are not uncommon, especially in arid environments (Sæther et al. 2004) where nest success, clutch size, and other demographic parameters have been found to vary with rainfall immediately before the nesting season (Francis 1970, Rotenberry and Wiens 1991, Heffelfinger et al. 1999, Lloyd 1999, Grant et al. 2000). Population parameters such as abundance may also respond to increases in rainfall but often with time lags (Stouffer and Bierregaard 1993, Dennis and Otten 2000, Thompson and Ollason 2001), presumably because of time required for rainfall to influence food availability, reproductive output, and subsequent survival. Given near-record low rainfall in the year before the 2006 nesting season, followed by above average rainfall produced by the El Niño Southern Oscillation in winter 2006-2007, data for the 2007 breeding season will be particularly valuable for assessing relationships between population and demographic dynamics of pygmy-owls and rainfall.

RECOVERY IMPLICATIONS

Population and demographic trends of pygmy-owls in northern Sonora have important management and recovery implications in Arizona where pygmy-owls have declined to endangered levels and are of profound conservation concern. Natural or facilitated dispersal of juveniles or relocation of adult pygmy-owls from Mexico were identified as preferred alternatives for recovery by a Draft Recovery Plan whereas captive propagation was considered feasible only after other techniques had failed or were expected to fail (USFWS 2003, pg. 123). If populations of pygmy-owls in northern Sonora continue to decline, recovery strategies that rely on Mexican birds may be jeopardized and captive propagation may be necessary. Further, the magnitude and location of these declines have important implications for evaluating the efficacy of potential recovery strategies. For example, pygmy-owls near Sasabe, Sonora are closest to Arizona and therefore are most relevant to recovery. Because occupancy of pygmy-owls near Sasabe has declined from 75 to 32% since 2002 (Fig. 3), relying on natural or passive dispersal from this population may be considerably less efficient than other more active alternatives.

Importantly, augmentation efforts that rely on pygmy-owls from Mexico should remove animals only from areas where populations are stable or increasing so that Mexican populations are not harmed. To this end, removing a small number of owls from the Middle Sasabe region, where trends in abundance have been relatively stable and where occupancy was high, and from the Upper San Miguel region, where occupancy and productivity were high, may be warranted.

Immigration of pygmy-owls from Sonora may not be sufficient to fully recover populations in Arizona without efforts to restore and enhance habitat. To this end, maintaining and restoring woodland vegetation along drainages and tall upland vegetation with saguaros will improve habitat quality for pygmy-owls (Flesch and Steidl 2006a). Continued development of potential habitat near Tucson and in the Altar and Avra valleys will aid recovery of pygmy-owls in southern Arizona.

In addition to habitat management, enhancing and maintaining landscape permeability should foster movement and immigration of pygmy-owls from Sonora to Arizona. Pygmy-owls often fly short distances just above the ground when crossing vegetation openings both during natal dispersal and when traversing their home ranges (Flesch and Steidl 2007a). Recent plans to replace permeable wire fences and vehicle barriers with tall impermeable walls along the U.S.-Mexican border may limit movements by pygmy-owls and other species (Segee and Neeley 2006, Cohn 2007). Should these structures preclude pygmy-owls from crossing the international border, active measures to promote these movements will be necessary.

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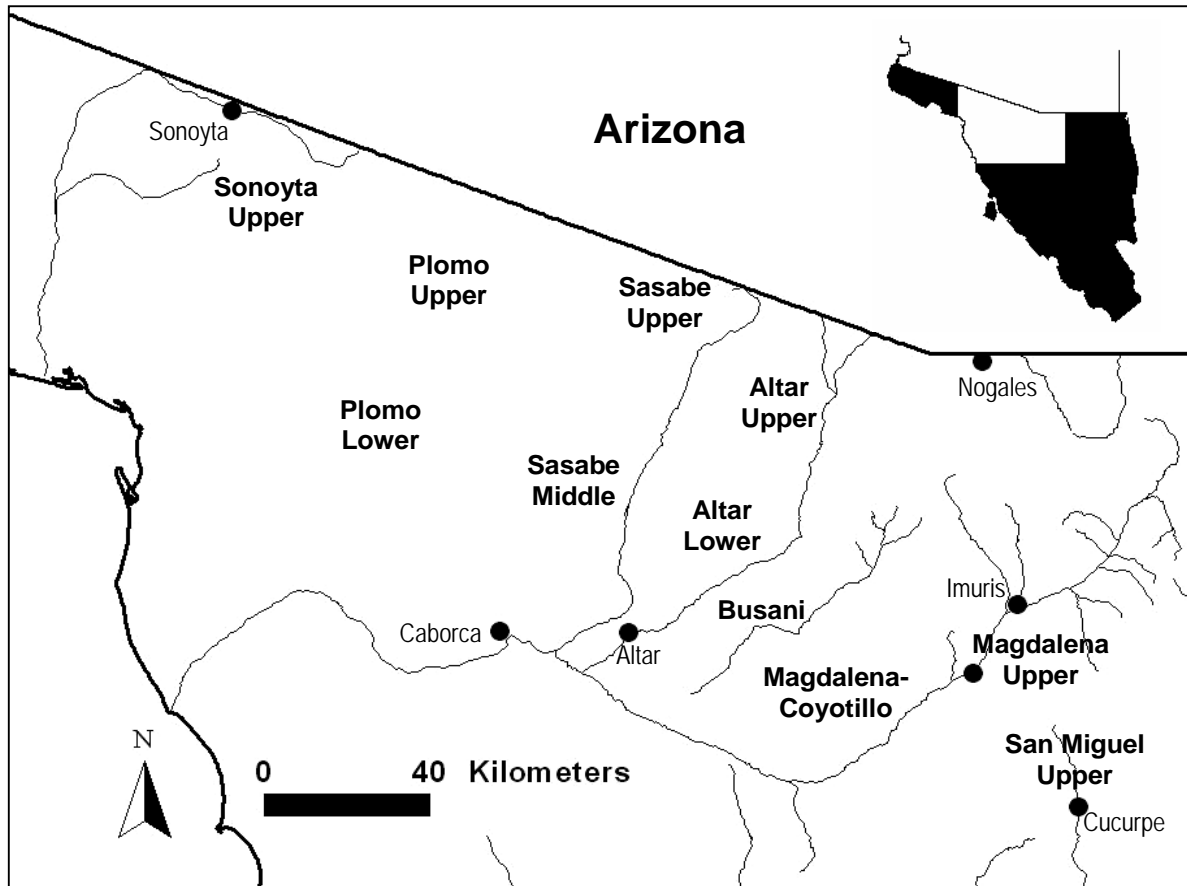
Figure 1. Map of study area in northern Sonora, Mexico illustrating 11 geographic regions in which I monitored pygmy-owls and major cities and drainages. I estimated abundance in the Sasabe Upper, Sasabe Middle, Altar Upper, and Plomo Upper regions and estimated occupancy and demographic parameters in all 11 regions.
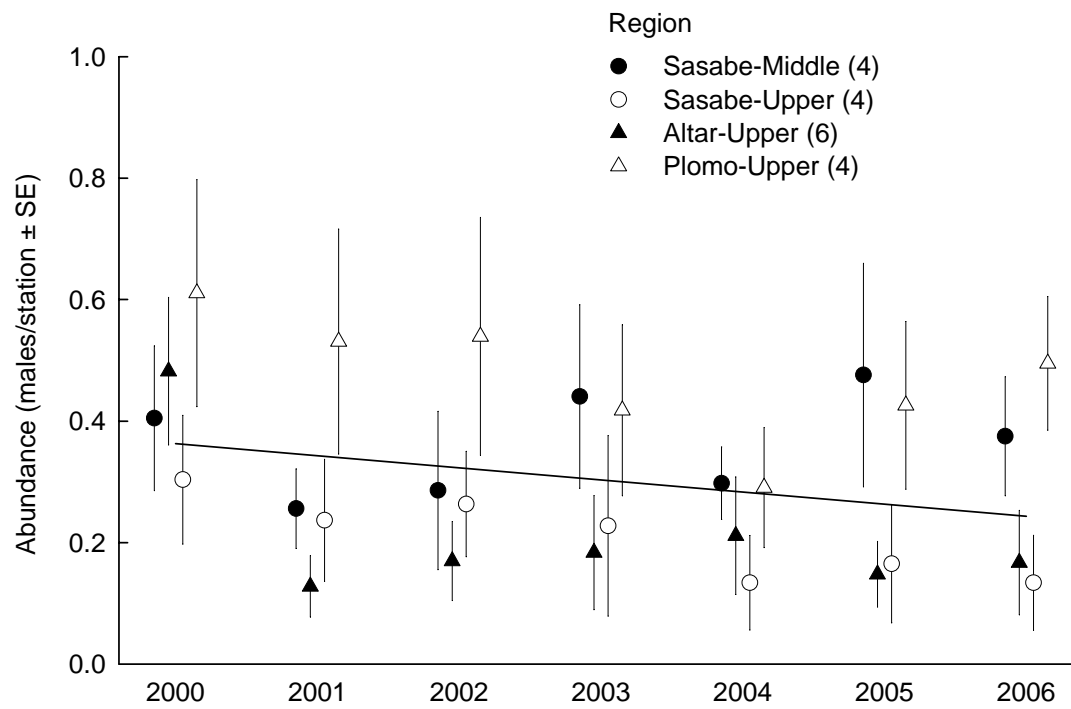
Figure 2. Abundance of male pygmy-owls (males/station) along fixed transects (*n* = 18) in 4 geographic regions between 2000 and 2005 in northern, Sonora, Mexico. Point and error bars equal mean ±1 standard error and parenthetical numbers are number of transects sampled in each region. Regression line is for all transects combined.
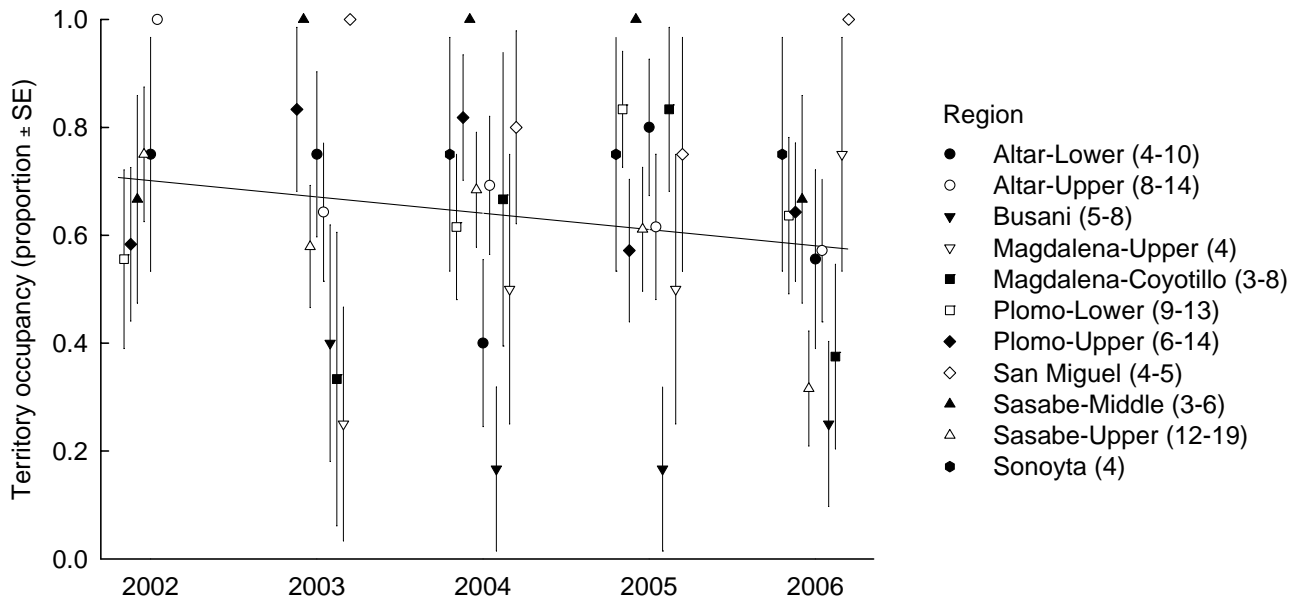
Figure 3. Proportion of territories occupied by ferruginous pygmy-owls in 11 geographic regions between 2002 and 2006, northern Sonora, Mexico. Point and error bars equal the mean proportion and 1 binomial standard error within each region in each year and parenthetical numbers are number of territories surveyed in each region among years. Between 52 and 102 territories were surveyed each year and territories were considered only after the first year they were found to be occupied. Regression line estimates change in the mean proportion of territories occupied across years.
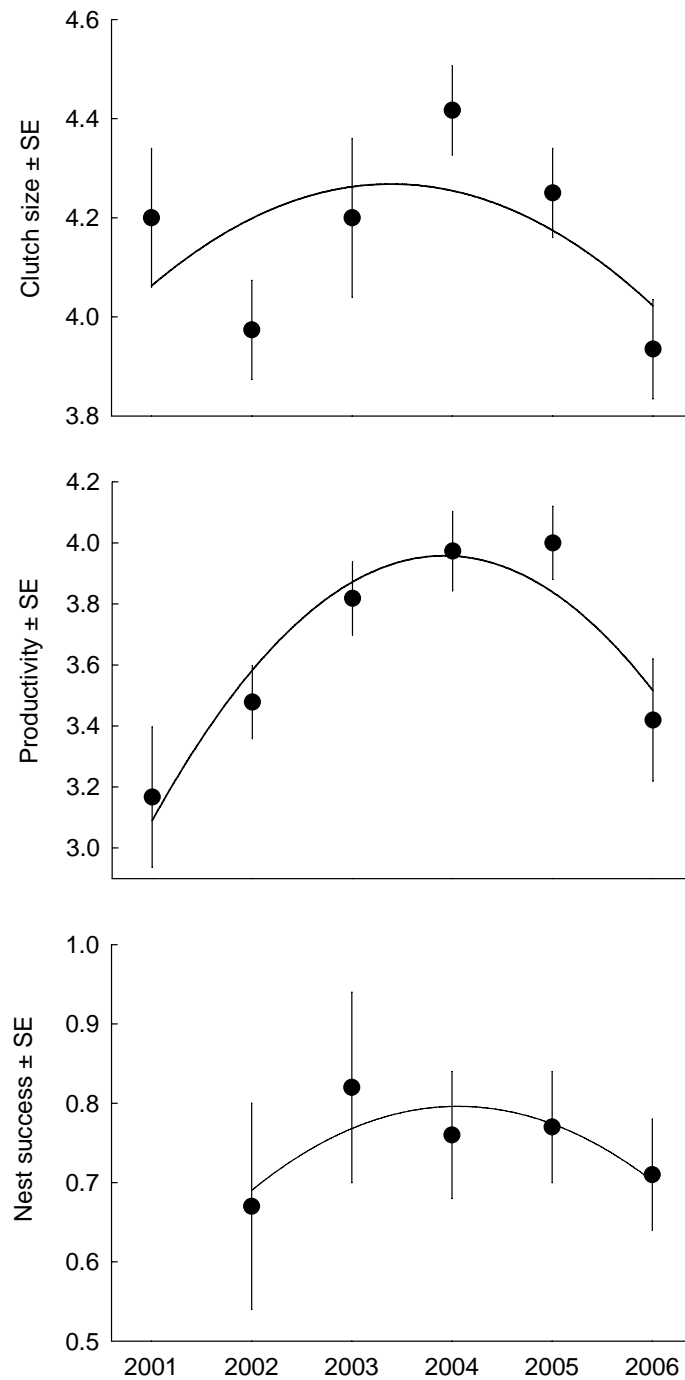
Figure 4. Trends in demographic parameters of ferruginous pygmy-owls between 2001 and 2006 in northern Sonora, Mexico. Each point and error bar represents the mean ± 1 standard error for each year. Lines are quadratic terms from least squares regression adjusted for site effects for clutch size ($P = 0.0087$), productivity ($P = 0.0002$), and nest success ($P = 0.15$). For nest success only nests that were initially detected within 14 days of clutch completion were considered; year 2001 was not considered because few nests were detected.
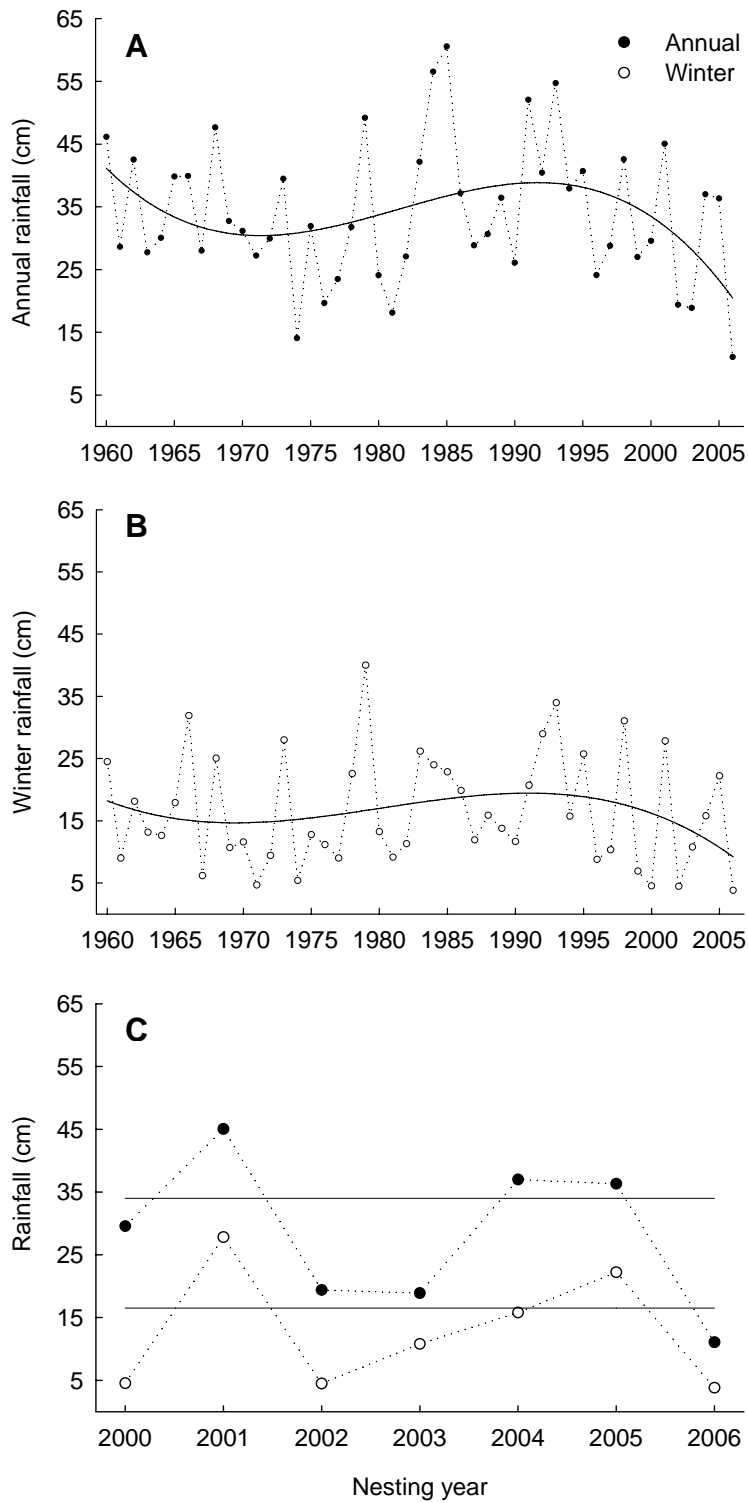
Figure 5. Trends in annual (A) and winter (B) rainfall averaged between the Sasabe and Organ Pipe Cactus National Monument weather stations on the U.S.-Mexico border 1960-2006 with detail (C) for 2000-2006.   Horizontal lines (C) represent mean annual and winter rainfall since 1960. Annual rainfall is for the 12-month period from 1 June to 31 May and winter rainfall is from 1 October to 30 April.
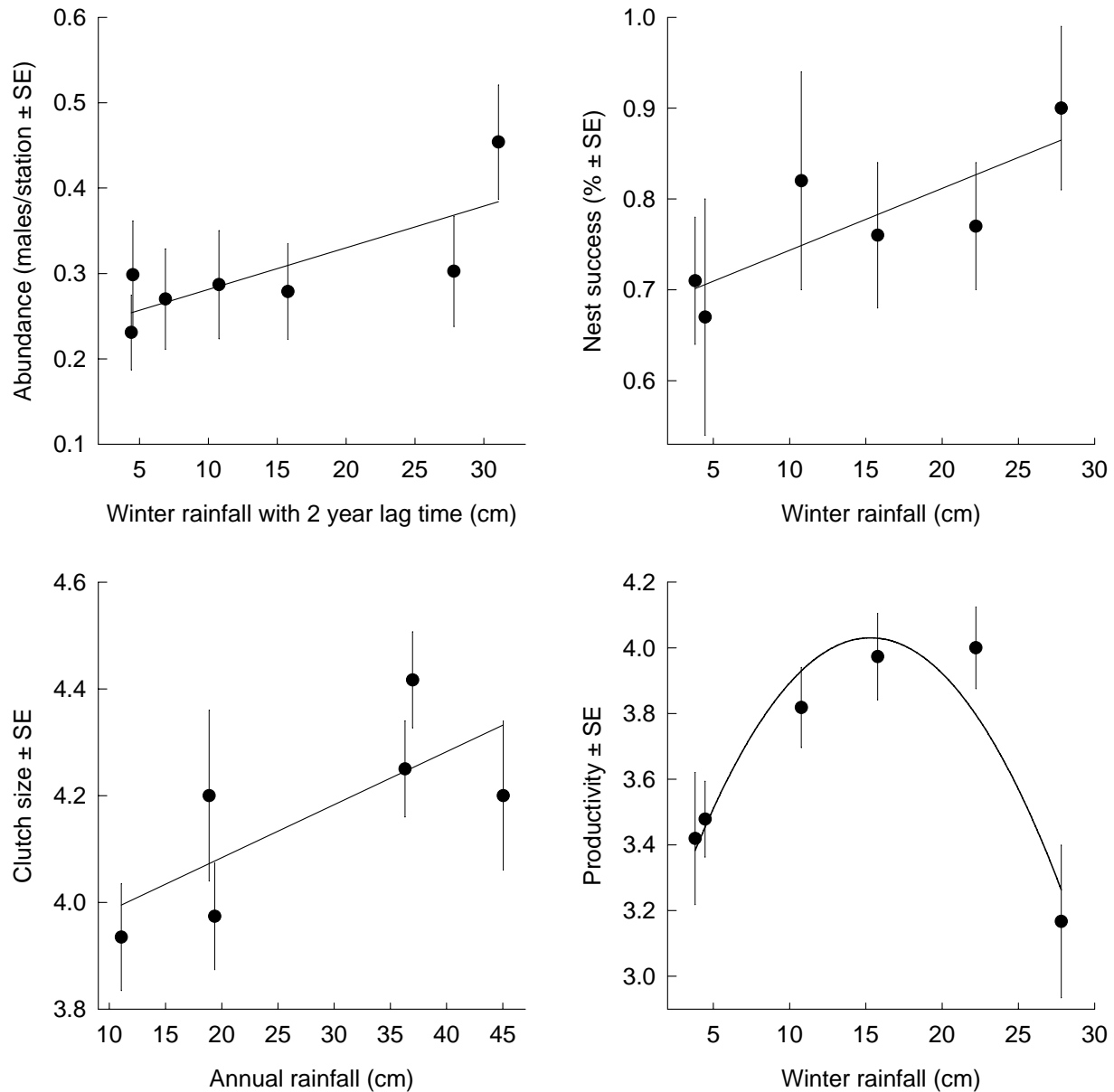
Figure 6. Associations between abundance, nest success, clutch size, and productivity (young/successful attempt) of ferruginous pygmy-owls and quantity of annual or winter rainfall in northern Sonora, Mexico 2000 to 2006. Associations for demographic parameters are with rainfall during each nest year and those with abundance are with rainfall with a lag time of 2 years. Annual rainfall is for the 12-month period from 1 June to 31 May and winter rainfall is from 1 October to 30 April. Rainfall data are from the Sasabe and Organ Pipe weather stations along the northern edge of the study area. Each point and error bar represents the mean and 1 standard error during each year. Lines are from least squares regression for abundance ($P = 0.047$), clutch size ($P = 0.097$), nest success ($P = 0.051$), and productivity ($P = 0.018$ for quadratic term).