Probability of Detecting Band-Tailed Pigeons During Call-Broadcast Versus Auditory Surveys

CHRIS KIRKPATRICK,[1] *School of Natural Resources, 104 Biological Sciences East, University of Arizona, Tucson, AZ 85721, USA*

COURTNEY J. CONWAY, *United States Geological Survey Arizona Cooperative Fish and Wildlife Research Unit, School of Natural Resources, 104 Biological Sciences East, University of Arizona, Tucson, AZ 85721, USA*

KATIE M. HUGHES, *School of Natural Resources, 104 Biological Sciences East, University of Arizona, Tucson, AZ 85721, USA*

JAMES C. DEVOS, JR., *Arizona Game and Fish Department, Research Branch, 2221 West Greenway Road, Phoenix, AZ 85023, USA*

ABSTRACT Estimates of population trend for the interior subspecies of band-tailed pigeon (*Patagioenas fasciata fasciata*) are not available because no standardized survey method exists for monitoring the interior subspecies. We evaluated 2 potential band-tailed pigeon survey methods (auditory and call-broadcast surveys) from 2002 to 2004 in 5 mountain ranges in southern Arizona, USA, and in mixed-conifer forest throughout the state. Both auditory and call-broadcast surveys produced low numbers of cooing pigeons detected per survey route ($\bar{x} \leq 0.67$) and had relatively high temporal variance in average number of cooing pigeons detected during replicate surveys (CV $\geq$ 161%). However, compared to auditory surveys, use of call-broadcast increased 1) the percentage of replicate surveys on which $\geq$1 cooing pigeon was detected by an average of 16%, and 2) the number of cooing pigeons detected per survey route by an average of 29%, with this difference being greatest during the first 45 minutes of the morning survey period. Moreover, probability of detecting a cooing pigeon was 27% greater during call-broadcast (0.80) versus auditory (0.63) surveys. We found that cooing pigeons were most common in mixed-conifer forest in southern Arizona and density of male pigeons in mixed-conifer forest throughout the state averaged 0.004 (SE = 0.001) pigeons/ha. Our results are the first to show that call-broadcast increases the probability of detecting band-tailed pigeons (or any species of Columbidae) during surveys. Call-broadcast surveys may provide a useful method for monitoring populations of the interior subspecies of band-tailed pigeon in areas where other survey methods are inappropriate. (JOURNAL OF WILDLIFE MANAGEMENT 71(1):231–237; 2007)

DOI: 10.2193.2005-493

KEY WORDS Arizona, band-tailed pigeon, call-broadcast, Columbidae, detection probability, *Patagioenas fasciata*, survey methodology.

The band-tailed pigeon (*Patagioenas fasciata*) is a migratory game bird that inhabits forests and woodlands of western North America. A coastal subspecies (*P. fasciata monilis*) breeds in California, Oregon, Washington, USA, and British Columbia, Canada, and an interior subspecies (*P. fasciata fasciata*) breeds in Mexico, Colorado, Utah, New Mexico, and Arizona, USA (Braun 1994). Populations of the coastal subspecies have declined in recent decades (Keppie and Braun 2000). Estimates of population trend for the interior subspecies are not available because few surveys have been conducted in the interior region. However, overall population size for the interior subspecies is substantially smaller than that of the coastal subspecies (Braun 1994), and declines in annual harvest of band-tailed pigeons in Arizona, Colorado, New Mexico, and Utah suggest the interior subspecies has also experienced substantial population declines in recent decades (Pacific Flyway Study Committee and Central Flyway Webless Migratory Game Bird Technical Committee 2001). Consequently, the band-tailed pigeon is considered to be a priority species of conservation concern on the Partners in Flight continental watchlist (Rich et al. 2004).

Management of the interior subspecies of band-tailed pigeon requires better knowledge of its distribution, abundance, habitat associations, and population trajectory (Pacific Flyway Study Committee and Central Flyway Webless Migratory Game Bird Technical Committee 2001), and the development of a reliable population monitoring method is considered a top management priority (Braun 1994, Casazza et al. 2000, Keppie and Braun 2000). Current monitoring programs designed to estimate population trends of all birds in North America (e.g., the North American Breeding Bird Survey; U.S. Geological Survey 2006) do not effectively sample band-tailed pigeons in the interior region (Keppie and Braun 2000, Pacific Flyway Study Committee and Central Flyway Webless Migratory Game Bird Technical Committee 2001). Survey methods used to monitor band-tailed pigeons in the coastal region (e.g., auditory surveys, mineral-site counts) have either not been tested or have had limited success in the interior region (Pacific Flyway Study Committee and Central Flyway Webless Migratory Game Bird Technical Committee 2001). Other potential survey methods (e.g., call-broadcast surveys) have yet to be evaluated in either region.

From 2002 to 2004, we evaluated 2 potential survey methods for monitoring interior populations of band-tailed pigeons by comparing the number of cooing pigeons detected during auditory and call-broadcast surveys conducted along survey routes in Arizona. One of the most important factors affecting the accuracy and precision of any survey method is detection probability (P_{detect}; the probability that an observer will record a bird that is present during a survey; Pendleton 1995). An effective survey method should be accurate (i.e., high detection probability), but more importantly, it should be precise (i.e., low temporal variance in detection probability; Johnson 1995, Thompson

[1] *E-mail: kirkpatr@email.arizona.edu*

2002). Therefore, we estimated detection probability and variance in detection probability associated with our auditory and call-broadcast surveys and used these estimates to 1) further evaluate the efficacy of these 2 survey methods, and 2) adjust estimates of band-tailed pigeon relative abundance (generated during an Arizona statewide band-tailed pigeon survey in 2003) into estimates of band-tailed pigeon density and population size.

STUDY AREA

We surveyed band-tailed pigeons in 2 study areas in Arizona. In southern Arizona (our primary study area), we conducted surveys in 5 Sky Island mountain ranges: the Santa Catalina (Pima County), Pinaleno (Graham County), Santa Rita (Santa Cruz County), Chiricahua, and Huachuca (Cochise County) mountains. The Sky Islands are a group of approximately 40 high-elevation mountain ranges scattered throughout the southwestern United States and northern Mexico that are separated from one another by low-elevation desert basins (Warshall 1995). Climate throughout much of the region was arid or semi-arid but high-elevation forests in the Sky Islands were substantially cooler and wetter than surrounding deserts.

Within the 5 Sky Island mountain ranges in southern Arizona, we surveyed band-tailed pigeons between approximately 1,500-m and 3,000-m elevation in mixed-conifer forest, ponderosa pine (*Pinus ponderosa*) forest, pine-oak woodland, and oak (*Quercus* spp.)–juniper (*Juniperus deppeana*)–pinyon (*Pinus* spp.) woodland on the Coronado National Forest. Other common trees found within these forest types included white fir (*Abies concolor*), Douglas fir (*Pseudotsuga menziessi*), quaking aspen (*Populus tremuloides*), Apache pine (*Pinus engelmannii*), Chihuahua pine (*P. leiophyllus*), and southwestern white pine (*P. strobiformis*).

We also surveyed band-tailed pigeons along survey routes that we randomly situated between approximately 2,000-m and 2,900-m elevation in mixed-conifer forest throughout Arizona (our secondary study area; henceforth, statewide survey). This statewide survey took place on the Apache-Sitgreaves (Apache County), Coronado (Pima and Cochise counties), Kaibab (Coconino County), and Prescott (Yavapai County) National Forests.

METHODS

Establishing Survey Routes

We established a total of 101 band-tailed pigeon survey routes (with a total of 597 survey points) within our 2 study areas. The majority of our survey routes were 2 km in length with 6 survey points located 400 m apart along the route. We used a handheld Global Positioning System receiver to measure the distance between survey points and record the location of each survey point. We also documented the dominant forest type at each survey point (mixed-conifer forest, ponderosa pine forest, pine–oak woodland, or oak–juniper–pinyon woodland).

For the southern Arizona survey, we located 10 survey routes in the Chiricahua Mountains, 12 in the Huachuca Mountains, 10 in the Pinaleno Mountains, 18 in the Santa Catalina Mountains, and 3 in the Santa Rita Mountains. We established survey routes by walking along trails, drainages, ridges, and roads (where available) in areas that had known populations of band-tailed pigeons based on knowledge from local resource managers and results from an extensive bird survey of this region in 2000 (Conway and Kirkpatrick 2001). To help identify habitat associations of the interior subspecies, we stratified survey routes in the Chiricahua, Huachuca, and Santa Catalina mountains by forest type so that approximately 1/3 of survey routes were in mixed-conifer forest, 1/3 were in ponderosa pine forest or pine–oak woodland, and 1/3 were in oak–juniper–pinyon woodland.

For the statewide survey, we employed a Geographic Information System (GIS) to first select 24 random point locations using the following 5 constraints: 1) points were in 1 of 3 Arizona Gap Analysis Program vegetation data mixed-conifer forest types: Douglas fir–mixed conifer, Douglas fir-mixed conifer (Madrean), or Engleman spruce (*Picea engelmannii*), 2) points were within 500 m of a passable road (i.e., no jeep trails), 3) points were in areas with slopes $<35°$, 4) points were >5 km from one another, and 5) points were not located on private land, the Navajo Reservation, the White Mountain Apache Reservation, or in Grand Canyon National Park (due to a lack of permits to conduct surveys in these areas). At each of the 24 random points, we established 2 survey routes starting 500 m apart in opposite directions from one another. For this statewide survey effort, we sampled an area of mixed-conifer forest estimated to be 109,548 ha.

Band-Tailed Pigeon Surveys

From 2002 to 2004, we surveyed band-tailed pigeons within our 2 study areas beginning in late-April and continuing through mid-August (the breeding season for most band-tailed pigeons in southern Arizona; Fitzhugh 1974). We conducted replicate surveys (approx. 1 every 3 weeks) along each of the 40 survey routes in the Chiricahua, Huachuca, and Santa Catalina mountains in 2002 and 2003. We conducted single surveys along each of the 3 survey routes in the Santa Rita Mountains in 2002 and single surveys along the 10 survey routes in the Pinaleno Mountains and our 48 statewide survey routes in 2003 (we conducted these single surveys primarily in Jul and early Aug). We also conducted 1–2 replicate surveys along 15 of 18 survey routes in the Santa Catalina Mountains in 2004. We surveyed points along each route in the same order during each replicate survey. Wildfires interrupted surveys on many routes in the Santa Catalina Mountains for a large part of the 2002 and 2003 field seasons.

At the start of the field season, we trained all surveyors in the identification (both visual and aural) of band-tailed pigeons and the estimation of distances (m) to broadcasts of recorded band-tailed pigeon calls during practice surveys. Surveyors also took a hearing test before the start of the field season in 2003 and 2004 to ensure their hearing was within an acceptable range. During the field season, we conducted surveys beginning 15 minutes before sunrise and ending

≤120 minutes after sunrise (the time period in which band-tailed pigeons vocalize most frequently; Keppie et al. 1970, Fitzhugh 1974) on days without rain and when average wind speed did not exceed 11 km/hour (Keppie et al. 1970, Pacific Flyway Study Committee and Central Flyway Webless Migratory Game Bird Technical Committee 2001). We measured wind speed at each survey point using a handheld anemometer.

At each survey point, we conducted a 6-minute auditory survey followed immediately by a 6-minute call-broadcast survey (12 min total at each survey point) to test the efficacy of call-broadcast surveys relative to auditory surveys. This paired survey design increased the power of statistical tests and increased our ability to detect differences between the 2 survey methods. During the paired auditory and call-broadcast survey at each survey point, we recorded each band-tailed pigeon detected on a separate line of our data sheet and recorded the type and frequency of the detection(s): visual flying, visual perched, coo-call, chirp, grunt, or wing-clap (Keppie and Braun 2000) during discrete time intervals within the 12-minute survey period. We divided the 6-minute auditory survey into 6 1-minute intervals and the 6-minute call-broadcast survey into 4 1.5-minute intervals (a 15–30-sec broadcast interval followed by a 60–75-sec silent interval with this pattern repeated 4 times). We also estimated the distance (m) to each pigeon and recorded whether each pigeon was a repeat detection (i.e., a pigeon that was also detected earlier during the survey at a previous survey point) so that we could eliminate repeat detections from our analyses.

For the call-broadcast sequences, we created 4 broadcast tracks using vocalizations from 4 different band-tailed pigeons recorded in Oregon (T. A. Sanders, Colorado Division of Wildlife, personal communication). We did not use recordings of band-tailed pigeons from the interior region because the quality of available recordings was poor. In the first year of the study (2002), we used 4 30-second broadcast tracks consisting of 2 coo-calls followed by several chirps and a grunt. We used a portable compact disc player (Model no. AX5111/17; Philips Electronics, Amsterdam, The Netherlands) and a musical power horn (Model no. 32-2037; RadioShack Corp., Fort Worth, TX) to broadcast the calls at 80–90 decibels (measured 1 m from the speaker). We placed the power horn approximately 1 m off the ground (e.g., on a stump, rock, or backpack) and rotated the power horn 90° between each of the 4 broadcast intervals to provide maximum coverage at the survey point. We stood approximately 5 m from the power horn during the survey to reduce the potential of the call-broadcast to hinder the observer's ability to hear vocalizing pigeons. We alternated use of the 4 broadcast tracks during surveys so a different track was played on each replicate survey to minimize the chance that our results were are a function of one particular dialect or of one particular recording (Kroodsma 1989).

We modified our call-broadcast protocol slightly during the second (2003) and third (2004) years of the study by dropping 1 of the 2 coo-calls from all 4 of the broadcast tracks to better simulate the normal rate of cooing by band-tailed pigeons (approx. 0.5 coo-calls/min), eliminating grunts from all tracks, and removing chirps from 2 of the 4 tracks. Consequently, the length of the broadcasts was approximately 15 seconds shorter for each broadcast track in 2003 and 2004. We used amplified computer speakers (RadioShack 40-1404 and 40-1432) in 2003 and 2004 instead of musical power horns to improve the sound quality of our call-broadcast. We conducted all band-tailed pigeon surveys under the University of Arizona's animal protocol control no. 02-010, *An evaluation of survey methods for monitoring interior populations of band-tailed pigeons in Arizona.*

Estimating Detection Probability

The probability of detecting birds aurally during surveys (P_{detect}) is the product of 2 components: 1) the probability that a bird within the survey area sings (P_{sings}), and 2) the probability that a bird is heard given that it sings (P_{heard}). We estimated P_{sings} and P_{heard} for both auditory and call-broadcast surveys using the following methods. For each cooing pigeon that we detected during surveys, we created a detection history by recording when the pigeon first cooed during the discrete time intervals (see above) in the auditory survey period and in the call-broadcast survey period. We used these detection histories to estimate P_{sings} (sensu Farnsworth et al. 2002). We also conducted 17 double-observer trials in which pairs of observers independently recorded cooing pigeons during auditory and call-broadcast surveys along survey routes. We used data from these double-observer trials (using only those surveys where ≥1 pigeon was detected by at least one observer) to estimate P_{heard} (sensu Nichols et al. 2000, Conway and Simon 2003).

Data Analysis

We restricted our analyses to data on band-tailed pigeons detected by coo-calls because: 1) we detected 63% of pigeons during surveys by coo-calls (an additional 10% were detected by other aural cues); 2) pigeons observed solely as flyovers were not associated directly with survey routes; 3) we observed pigeons solely as perching, nonvocalizing birds at only 17 survey points; and 4) other monitoring efforts (e.g., Keppie et al. 1970, Fitzhugh 1974) have recorded only coo-call detections during surveys.

We used 1-tailed paired *t*-tests to compare 1) the average number of cooing band-tailed pigeons detected across survey routes ($n = 101$) during auditory and call-broadcast surveys, and 2) the percentage of replicate surveys ($n = 345$) on which we detected ≥1 cooing pigeon during auditory and call-broadcast surveys. We used 1-tailed tests because call-broadcast should increase bird detections (Marion et al. 1981). We compared temporal variances in average number of cooing pigeons detected during auditory and call-broadcast surveys by first calculating coefficients of variation (percent CV) for each survey route using a subset of routes ($n = 26$) in southern Arizona on which we conducted multiple (>5) replicate surveys and then calculating an average percent coefficient of variation across these 26 routes.

To estimate band-tailed pigeon density and population

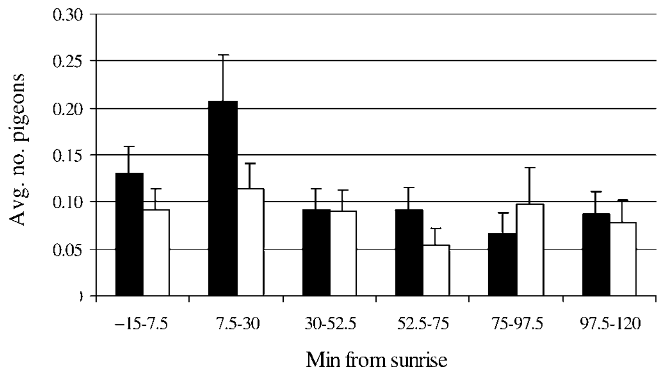

Figure 1. Number of cooing band-tailed pigeons detected per survey route ($\bar{x} \pm$ SE) as a function of the number of minutes before and after sunrise during call-broadcast (dark bars) and auditory (light bars) surveys in Arizona, USA, 2002–2004.

size for the statewide survey, we first adjusted the average number of cooing band-tailed pigeons detected during the 6-minute call-broadcast portion of the survey at our 281 statewide survey points by the estimated detection probability for call-broadcast surveys. We assumed a 200-m effective survey radius at each survey point because we found that this was the distance from the surveyor at which pigeon detections began to decline sharply. Hence, we surveyed 3,544 ha of the 109,548 ha of mixed-conifer forest in Arizona. We extrapolated our population estimate to the entire 109,548 ha of mixed-conifer forest because we located the statewide survey routes at random.

We used detection histories of pigeons detected cooing during surveys and removal models in Program MARK (White 1998) to estimate the probability of a band-tailed pigeon vocalizing (P_{sings}) during auditory and call-broadcast surveys. We calculated percent coefficient of variation to compare temporal variance in P_{sings} for each survey method. We also compared estimates of P_{sings} calculated separately for each month of the breeding season (May, Jun, Jul, and Aug). We standardized descriptive statistics (means and confidence intervals) generated for P_{sings} for call-broadcast surveys (calculated for a 1.5-min interval) so we could compare them to estimates of P_{sings} for auditory surveys (calculated for a 1-min interval) using the equation: $P_{1\text{-}min} = 1 - \sqrt[1.5]{1 - P_{1.5\text{-}min}}$. We also transformed our 1-minute estimates of P_{sings} into 6-minute estimates of P_{sings} for both auditory and call-broadcast surveys using the equation: $P_{6\text{-}min} = 1 - (1 - P_{1\text{-}min})^6$.

To estimate P_{heard} during double-observer trials, we estimated the proportion of cooing pigeons that each primary observer ($n = 7$ observers) detected as: (no. pigeons detected by primary observer)/[(no. pigeons detected by primary observer) + (no. pigeons detected only by secondary observer)]. We averaged estimates of P_{heard} across our 7 primary observers to generate an overall estimate of P_{heard} for both the 6-minute auditory portion and the 6-minute call-broadcast portion of the survey. To generate an estimate of detection probability (P_{detect}) for each survey method, we multiplied our estimates of P_{heard} from double-observer trials with our estimates of P_{sings} from modeling detection histories for each survey method.

We used a chi-square test of independence to examine if band-tailed pigeons were associated with a particular forest type. We compared the frequency of survey points where we detected cooing pigeons across 4 forest types (mixed-conifer, ponderosa pine, pine–oak, and oak–juniper–pinyon) in the Chiricahua, Huachuca, and Santa Catalina mountains of southern Arizona.

RESULTS

Band-Tailed Pigeon Surveys

We conducted 345 replicate auditory and call-broadcast surveys along 101 survey routes (597 survey points) throughout Arizona from 2002 to 2004. We detected 470 band-tailed pigeons during surveys and 78% of pigeons were detected by only one detection type (e.g., coo-call), 17% were detected by 2 detection types (e.g., coo-call and chirp), and 5% were detected by 3 to 5 detection types. Seventy-one percent of pigeons were initially detected via an aural cue (62.1% coo-calls, 7.4% wing claps, 0.6% chirps, and 0.4% by grunts) and 29% were initially detected by a visual cue (22.9% flyovers and 6.4% perched). Eight percent of the pigeons first detected visually were subsequently detected aurally (4% by coo-calls alone). Hence, we detected 73% of the 470 band-tailed pigeons aurally and 63% by coo-calls alone.

We estimated distances to 291 cooing pigeons detected during replicate surveys. The average distance from the surveyor to a cooing pigeon was 182 m (SE = 7). Seventy-one percent of cooing pigeons were detected within 200 m of the surveyor and 94% were detected within 300 m of the surveyor. We detected cooing pigeons most frequently at survey points located in mixed-conifer forest compared to other forest types in southern Arizona ($\chi^2 = 12.3$, df = 3, $P < 0.001$). We detected $\geq$1 cooing pigeon on $\geq$1 replicate survey at 76% of the 46 survey points in mixed-conifer forest, at 51% of the 68 survey points in oak–juniper–pinyon woodland, at 44% of the 39 survey points in pine–oak woodland, and at 36% of the 11 survey points in ponderosa pine forest.

Of the 470 band-tailed pigeons detected during surveys, we detected 185 cooing pigeons during the 6-minute auditory survey segment and 224 cooing pigeons during the 6-minute call-broadcast survey segment. The rate of coo-calls given by pigeons averaged 0.45 coo-calls/min (SE = 0.028) during auditory surveys and 0.46 coo-calls/min (SE = 0.022) during call-broadcast surveys. Compared to auditory surveys, the use of call-broadcast increased the number of cooing pigeons detected per survey route by an average of 29% (0.67 $\pm$ 0.100 vs. 0.52 $\pm$ 0.080, $t = 2.7$, df = 100, $P = 0.004$), with this difference being greatest during the first 45 minutes (approx. 15 min before sunrise to 30 min after sunrise) of the 135-minute morning survey period (Fig. 1).

The pattern of increased pigeon detection during call-broadcast surveys was consistent when we examined our data separately from each of the 5 Sky Island mountain ranges in our study area in southern Arizona and from our statewide

Table 1. Number of cooing band-tailed pigeons detected during auditory and call-broadcast surveys during 345 replicate surveys[a] along 101 survey routes in Arizona, USA, 2002–2004.

Location	No. detected during surveys		
	Auditory	Call-broadcast	% increase[b]
Chiricahua Mountains	62	68	10
Huachuca Mountains	39	44	13
Pinaleno Mountains	12	17	42
Santa Catalina Mountains	61	80	31
Santa Rita Mountains	1	2	100
Statewide (mixed-conifer)	10	13	30

[a] Replicate surveys were conducted along survey routes in the Chiricahua, Huachuca, and Santa Catalina mountains but only a single survey was conducted along routes in the Pinaleno and Santa Rita mountains and in mixed-conifer forest throughout Arizona.

[b] Percentage increase = 100 × [(no. pigeons detected during call-broadcast survey) − (no. pigeons detected during auditory survey)]/(no. pigeons detected during auditory survey).

survey in mixed-conifer forests throughout the state (Table 1). The use of call-broadcast also increased the percentage of replicate surveys on which we detected ≥1 cooing pigeon by an average of 16% (36% vs. 31%, $t = 2.4$, df = 344, $P = 0.007$). We were unable to detect a difference in the temporal variance in the average number of cooing pigeons detected during replicate call-broadcast and auditory surveys ($CV_{call\text{-}broadcast} = 161\%$ and $CV_{auditory} = 169\%$, $t = 0.7$, df = 25, $P = 0.492$).

Despite using a GIS to locate our statewide survey routes in mixed-conifer forest, only 67% of the survey points were actually in mixed-conifer forest, whereas 26% were in ponderosa pine forest, and 7% were in other forest types (e.g., spruce [*Picea* spp.] forest, pine–oak woodland). We detected cooing band-tailed pigeons on 17% of our 48 statewide survey routes (5% of 281 statewide survey points) and in all of the national forests we surveyed. We detected an average of 0.046 ± 0.013 cooing pigeons per survey point during the call-broadcast portion of our statewide surveys. Thus, density of male band-tailed pigeons averaged 0.004 ± 0.001 pigeons/ha and estimated population size was 483 ± 131 in mixed-conifer forest in Arizona. We probably underestimated population density and size because: 1) we likely detected few mated males (see Discussion), and 2) we conducted our statewide survey in forested areas with slopes <35° that were accessible by roads (not necessarily ideal band-tailed pigeon habitat).

Estimating Detection Probability

Using the most parsimonious closed-capture, removal model (M_b), P_{sings} averaged 0.20 (95% CI = 0.14–0.28) per minute during auditory surveys and 0.31 (95% CI = 0.26–0.38) per minute during call-broadcast surveys. P_{sings} for a complete 6-minute survey period was 0.74 (95% CI = 0.62–0.83) and 0.90 (95% CI = 0.83–0.94) for auditory and call-broadcast surveys, respectively. Although the 2 estimates of P_{sings} were not statistically different (at the $P < 0.05$ level), the relatively large difference (22%) between the 2 estimates suggests that call-broadcast increased the probability of a pigeon cooing during our surveys. Variance in P_{sings} was

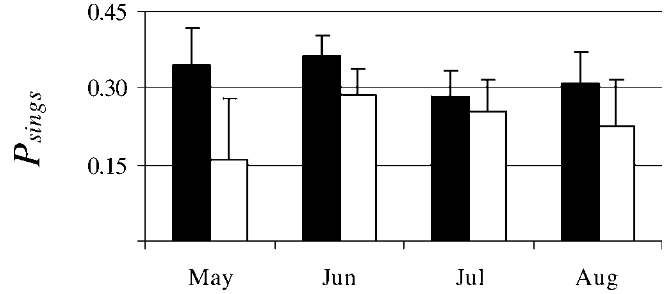

Figure 2. Probability ($\bar{x}$ ± SE) that a band-tailed pigeon would give a coo-call (P_{sings}) during each 1-minute interval of the survey period for call-broadcast (dark bars) and auditory (light bars) surveys during 4 months of the breeding season in Arizona, USA, 2002–2004. We transformed estimates of P_{sings} for call-broadcast surveys (initially calculated for a 1.5-min interval) to a 1-minute interval for comparison.

32% less for call-broadcast surveys (CV = 134%) compared to auditory surveys (CV = 198%) and P_{sings} was consistently greater for call-broadcast surveys compared to auditory surveys when we calculated P_{sings} separately for May, June, July, and August (Fig. 2).

At least 1 cooing band-tailed pigeon was detected by ≥1 observer during 12 of the 17 double-observer trials (total of 47 cooing pigeons detected). Average P_{heard} calculated for the 7 observers was 0.85 (range 0.50–1) for the auditory survey period and 0.89 (range 0.57–1) for the call-broadcast survey period. After multiplying our estimates of P_{heard} from double-observer trials with our estimates of P_{sings} from modeling detection histories (with 1-min P_{sings} estimates adjusted to 6-min P_{sings} estimates), detection probability was 27% greater for call-broadcast surveys compared to auditory surveys. Thus, given that a band-tailed pigeon was present in the survey area, an average observer had an 80% chance of detecting the bird during a 6-minute call-broadcast survey and a 63% chance of detecting the bird during a 6-minute auditory survey.

DISCUSSION

Our evaluation of auditory and call-broadcast surveys for monitoring the interior subspecies of band-tailed pigeon revealed that both survey methods shared several characteristics. The average number of cooing pigeons detected during surveys was low (≤0.67 pigeons/survey), the percentage of replicate surveys with ≥1 cooing pigeon detected was low (≤36%), and temporal variance was relatively high for the average number of cooing pigeons detected per survey route (CV ≥ 161%). These findings reflect the difficulties of surveying a species that is uncommon, patchily distributed, and highly mobile. However, compared to a strictly auditory survey method, the use of call-broadcast helped alleviate some of these potential shortcomings by improving the accuracy of band-tailed pigeon counts during surveys.

Call-broadcast improved the accuracy of counts during surveys by increasing the average number of cooing pigeons detected, with this difference being greatest during the first 45 minutes of the morning survey period. Use of call-broadcast also increased the percentage of replicate surveys on which ≥1 cooing pigeon was detected, thus reducing the number of surveys on which no pigeon was detected. More importantly, the use of call-broadcast did not increase temporal variance in the average number of cooing pigeons detected relative to auditory surveys. This is the first time call-broadcast has been shown to increase detections of band-tailed pigeons (or any species of Columbidae) during surveys.

The increased accuracy of call-broadcast surveys likely reflects the underlying influence of the call-broadcast on band-tailed pigeon detection probability. Compared to auditory surveys, call-broadcast not only increased the probability of a band-tailed pigeon cooing during a survey (P_{sings}) but also appeared to reduce temporal variance in P_{sings} across replicate surveys. Based on the double-observer trials, we found that the probability of an observer detecting a pigeon given that it vocalized (P_{heard}) was slightly higher for call-broadcast surveys compared to auditory surveys, despite initial concerns that call-broadcast would hinder the observer's ability to hear cooing pigeons during surveys. Overall, detection probability (P_{detect}) was 27% higher for call-broadcast versus auditory surveys.

Although call-broadcast increased the probability of detecting band-tailed pigeons during surveys, our estimates of P_{sings} for both auditory and call-broadcast surveys may have been biased high. One assumption of the method that we used to estimate P_{sings} (Farnsworth et al. 2002) is that males in a population sing at a similar rate regardless of their breeding status (i.e., no autocorrelation in singing bouts). However, we know that mated male band-tailed pigeons are either absent from nests (Keppie and Braun 2000, Kirkpatrick et al. 2005) or present near nests but generally quiet (Kirkpatrick et al. 2005) during early morning hours throughout much of the incubation and nestling stages. We conducted our band-tailed pigeon surveys from 15 minutes before sunrise to 2 hours after sunrise. Hence, we probably failed to detect many breeding male pigeons while conducting surveys during a sizeable portion of the breeding season because the combined length of the incubation and nestling stages averages almost 50 days (Braun 1994).

In a previous study of captive band-tailed pigeons (Sisson 1968), unmated males were 8 times more likely than mated males to give coo-calls, and unmated males gave an average of 0.42 coo-calls/minute. Pigeons averaged 0.46 coo-calls/minute during our surveys. Thus, we may have detected primarily unmated males (perhaps even immature males) advertising for females or establishing territories during our surveys. This is a potential problem for any survey method that relies on counts of singing males. Ideally, a survey method effectively samples known breeders so that inferences can be made to the breeding population; this may not be the case with band-tailed pigeons detected during surveys. Nevertheless, if most of the unmated (presumably) males that we detected found mates and reproduced, we may have sampled the eventual breeding population during our surveys. Additional research needs to clarify exactly what fraction of the breeding population is being sampled during surveys and how this fraction varies through time.

Previous attempts to use counts along survey routes for monitoring the interior subspecies have been criticized because 1) observers did not penetrate band-tailed pigeon habitat effectively (i.e., most surveys were conducted only along roadsides), and 2) band-tailed pigeons are uncommon and patchily distributed in the interior region (Pacific Flyway Study Committee and Central Flyway Webless Migratory Game Bird Technical Committee 2001). Our results suggest that counts along survey routes can potentially be used to estimate band-tailed pigeon population trend and density in rugged terrain in Arizona when observers travel beyond roadways and enter band-tailed pigeon habitat on foot. Moreover, we found that call-broadcast helps to alleviate problems associated with infrequent detections by increasing the probability of detecting cooing band-tailed pigeons; call-broadcast not only increased the number of pigeons detected during surveys (without increasing temporal variance) but also reduced the number of replicate surveys on which no pigeon was detected.

We believe that additional research is required to identify the most appropriate survey method for monitoring band-tailed pigeons throughout the interior region. For example, capture–recapture of marked pigeons or counts of pigeons at bait sites or mineral springs (Curtis and Braun 1983, Cassaza et al. 2000) may provide a more effective and reliable monitoring method in areas where large flocks of pigeons congregate regularly in agricultural fields or at mineral springs. However, a preliminary evaluation of these 2 methods in southern Arizona suggests that they are less effective than auditory and call-broadcast survey methods (Kirkpatrick et al. 2005), in part, because breeding pigeons in this region do not aggregate at mineral springs or grain fields. We suspect that call-broadcast surveys may provide a useful method with which to estimate population trend or density of pigeons in other areas that lack these attributes (a potentially sizeable portion of the rugged mountainous region within AZ, NM, and UT). Ultimately, the use of several different methods may be required to effectively monitor band-tailed pigeons throughout the interior region.

MANAGEMENT IMPLICATIONS

Managers should initiate regular surveys to monitor the interior subspecies of band-tailed pigeon in Arizona given that the Arizona population appears to be declining (Pacific Flyway Study Committee and Central Flyway Webless Migratory Game Bird Technical Committee 2001, Kirkpatrick et al. 2005) and population density is relatively low in mixed-conifer forest throughout the state (as measured during our study). Estimates of population trend generated from such an effort will facilitate managers in setting future harvest regulations. Should managers use call-broadcast surveys to monitor the Arizona population, we suggest that surveys be conducted primarily in mixed-conifer forest in southern Arizona where cooing pigeons are detected most frequently and where pigeons are known to nest regularly (Fitzhugh 1974, Kirkpatrick et al. 2005). In the central and northern parts of the state, call-broadcast surveys may need to be conducted in additional forest types because the interior subspecies of band-tailed pigeon is also associated with ponderosa pine forest, pine–oak woodland (Braun 1994), and oak–juniper–pinyon woodland (Phillips et al. 1964) in these areas.

We recommend that call-broadcast surveys be conducted in the early morning (approx. 15 min before sunrise to 30 min after sunrise) when band-tailed pigeons appear to be most responsive to call-broadcast; this will maximize detections of cooing pigeons but will also limit the time in which surveys can be conducted each morning. One promising option for monitoring species that are rare or difficult to detect (e.g., the interior subspecies of band-tailed pigeon) is to estimate trends in site occupancy as opposed to trends in numbers of animals detected (MacKenzie et al. 2002). Estimating trends in site occupancy by conducting short-duration, early-morning call-broadcast surveys during $\geq$3 replicate visits to survey points (MacKenzie et al. 2002) may be the most effective method for monitoring band-tailed pigeons in parts of the interior region where other survey methods are inappropriate.

ACKNOWLEDGMENTS

This project was funded by the Webless Migratory Game Bird Research Program, the Arizona Game and Fish Department Heritage Fund (no. I03004), the United States Fish and Wildlife Service, the United States Geological Survey, and the University of Arizona. Surveys were conducted by M. H. Ali, K. J. Bergstrand, S. B. Cariss, D. M. Fox, G. F. Gryniewicz, J. Havelaar, K. M. Hemmelgarn, D. Holstein-Radin, D. LaRoche, E. Martinez-Leyva, E. G. Nolte, C. L. Murray, L. W. Seal, and J. M. Warr. C. E. Braun, N. C. Kline, and T. A. Sanders reviewed a draft of the proposed project and provided comments on the study design. M. Reed helped with GIS and R. J. Steidl assisted with analyses. P. T. Deecken, G. Gonzales, G. Helbing, L. Jones, J. Magehee, B. Stolp, and J. Taiz assisted with access to study areas and provided information on band-tailed pigeon locations in southern Arizona. C. E. Braun, M. L. Casazza, E. L. Fitzhugh, J. P. Leonard, and T. A. Sanders provided insight into working with band-tailed pigeons. R. L. Peterson and the University of Arizona Steward Observatory provided field housing. We thank D. D. Dolton and C. E. Braun for project support.

LITERATURE CITED

Braun, C. E. 1994. Band-tailed pigeon. Pages 61–74 *in* C. Tacha and C. E. Braun, editors. Management of migratory shore and upland game birds in North America. Allen Press, Lawrence, Kansas, USA.

Casazza, M. L., J. L. Yee, M. R. Miller, and D. L. Orthmeyer. 2000. Development of reliable population indices for band-tailed pigeons. U.S. Geological Survey, Western Ecological Research Center, Dixon, California, USA.

Conway, C. J., and C. Kirkpatrick. 2001. Population status, detection probability, and effects of fire on buff-breasted flycatchers. Arizona Game and Fish Department, Phoenix, USA.

Conway, C. J., and J. C. Simon. 2003. Comparison of detection probability associated with burrowing owl survey methods. Journal of Wildlife Management 67:501–511.

Curtis, P. D., and C. E. Braun. 1983. Recommendations for establishment and placement of bait sites for counting band-tailed pigeons. Wildlife Society Bulletin 11:364–366.

Farnsworth, G. L., K. H. Pollack, J. D. Nichols, T. S. Simons, J. E. Hines, and J. R. Sauer. 2002. A removal model for estimating detection probabilities from point count surveys. Auk 119:414–425.

Fitzhugh, E. L. 1974. Chronology of calling, egg laying, crop gland activity, and breeding among wild band-tailed pigeons in Arizona. Dissertation, University of Arizona, Tucson, USA.

Johnson, D. H. 1995. Point counts of birds: what are we estimating? Pages 117–123 *in* C. J. Ralph, J. R. Sauer, and S. Droege, technical coordinators. Monitoring bird populations by point counts. U.S. Forest Service General Technical Report PSW-GTR-149, Pacific Southwest Research Station, Berkeley, California, USA.

Keppie, D. M., and C. E. Braun. 2000. Band-tailed pigeon (*Columba fasciata*). Account 530 *in* A. Poole and F. Gill, editors. The birds of North America. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and The American Ornithologists' Union, Washington, D.C., USA.

Keppie, D. M., H. M. Wright, and W. S. Overton. 1970. A proposed band-tailed pigeon census—a management need. Transactions of the North American Wildlife and Natural Resources Conference 35:157–171.

Kirkpatrick, C., C. J. Conway, K. M. Hughes, and J. C. deVos, Jr. 2005. An evaluation of survey methods for monitoring interior populations of band-tailed pigeons. Wildlife Report #2005-03, U.S. Geological Survey Arizona Cooperative Fish and Wildlife Research Unit, Tucson, USA.

Kroodsma, D. E. 1989. Suggested experimental designs for song playbacks. Animal Behavior 37:600–609.

MacKenzie, D. I., J. D. Nichols, G. D. Lachman, S. Droege, J. A. Royle, and C. A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248–2255.

Marion, W. R., T. E. O'Meara, and D. S. Maehr. 1981. Use of playback recordings in sampling elusive or secretive birds. Studies in Avian Biology 6:81–85.

Nichols, J. D., J. E. Hines, J. R. Sauer, F. W. Fallon, J. E. Fallon, and P. J. Heglund. 2000. A double-observer approach for estimating detection probability and abundance from point counts. Auk 117:393–408.

Pacific Flyway Study Committee and Central Flyway Webless Migratory Game Bird Technical Committee. 2001. Pacific and central flyways management plan for the Four Corners population of band-tailed pigeons. Pacific Flyway Council, U.S. Fish and Wildlife Service, Portland, Oregon, USA.

Pendleton, G. W. 1995. Effects of sampling strategy, detection probability, and independence of counts on the use of point counts. Pages 131–134 *in* C. J. Ralph, J. R. Sauer, and S. Droege, technical coordinators. Monitoring bird populations by point counts. U.S. Forest Service General Technical Report PSW-GTR-149, Pacific Southwest Research Station, Berkeley, California, USA.

Phillips, A. R., J. Marshall, and G. Monson. 1964. The birds of Arizona. University of Arizona Press, Tucson, USA.

Rich, T. C., C. J. Beardmore, H. Berlanga, P. J. Blancher, M. S. W. Bradstreet, G. S. Butcher, D. W. Demarest, E. H. Dunn, W. C. Hunter, E. E. Inigo-Elias, J. A. Kennedy, A. M. Martell, A. O. Panjabi, D. N. Pashley, K. V. Rosenberg, C. M. Rustay, J. S. Wendt, and T. C. Will. 2004. Partners in Flight North American landbird conservation plan. Cornell Laboratory of Ornithology, Ithaca, New York, USA.

Sisson, L. H. 1968. Calling behavior of band-tailed pigeons in reference to a census technique. Thesis, Oregon State University, Corvallis, USA.

Thompson, W. L. 2002. Towards reliable bird surveys: accounting for individuals present but not detected. Auk 119:18–25.

U.S. Geological Survey. 2006. North American breeding bird survey. <ftp://ftpext.usgs.gov/pub/er/md/laurel/BBS/>. Accessed 15 Aug 2006.

Warshall, P. 1995. The Madrean Sky Island Archipelago: a planetary overview. Pages 6–18 *in* L. F. DeBano, P. F. Ffolliott, A. Ortega-Rubio, G. J. Gottfried, R. H. Hamre, and C. B. Edminster, editors. Biodiversity and management of the Madrean Archipelago: the sky islands of southwestern United States and northwestern Mexico. U.S. Forest Service General Technical Report RM-GTR-264, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, USA.

White, G. 1998. Program MARK software. 1998 version. <http://www.warnercnr.colostate.edu/~gwhite/mark/mark.htm>. Accessed 15 Aug 2006.

Associate Editor: Green.