Research Article

Band-Tailed Pigeon Use of Supplemental Mineral

TODD A. SANDERS,[1] *United States Fish and Wildlife Service, Division of Migratory Bird Management, 1211 SE Cardinal Court, Suite 100, Vancouver, WA 98683, USA*

RYAN C. KOCH, *United States Fish and Wildlife Service, Columbia River Fish and Wildlife Conservation Office, 1211 SE Cardinal Court, Suite 100, Vancouver, WA 98683, USA*

ABSTRACT Band-tailed pigeons (*Patagioenas fasciata*) congregate at and use mineral sites (mineralized water or soil) throughout their range; however, information needed to interpret counts of pigeons at these sites and make inference to population abundance and distribution is lacking despite current monitoring efforts. Our objectives were to determine if we could create a mineral site used by band-tailed pigeons; test whether pigeons seek supplemental sodium, calcium, or both; describe the pattern of pigeon use of mineral sites seasonally and within days by individual birds; and evaluate implications of precipitation, fog, temperature, and mineral concentration on pigeon visitation patterns. We attracted hundreds of pigeons/day to a created mineral site that offered sodium, calcium, or both in a forested area in southwestern Washington, USA where we captured and applied passive integrated transponder (PIT) tags to 771 pigeons and monitored mineral use during 2010–2014. When offered paired sodium and calcium stations, pigeons near exclusively consumed sodium, and pigeons continued to use the created mineral site for 3 years when calcium was not available. Pigeons visited sodium stations on average once every 12 days during June through early October; reducing available sodium concentration from 3,500 ppm to 1,000 ppm had no significant effect on visitation rates. Counts of pigeons at mineral sites varied with precipitation, sex, and time of season; consequently, comparison of pigeon counts among mineral sites can be biased if not accounting for these factors. Our results show that pigeons can be attracted to mineral stations, and that counts at mineral sites and stations allow opportunities for population monitoring.

KEY WORDS band-tailed pigeon, calcium, mineral site, *Patagioenas fasciata*, PIT tag, passive integrated transponder, salt, sodium, supplemental mineral use, Washington.

Band-tailed pigeons (*Patagioenas fasciata*) congregate at and use mineral sites (mineralized water or soil) throughout their range, especially in the breeding range of the Pacific Coast band-tailed pigeon (*P. f. monilis*) in western British Columbia, Canada, and in Washington, Oregon, and northern California, USA (Smith 1968, Jarvis and Passmore 2000, 1992; Sanders and Jarvis 2000). Use of mineral sites by band-tailed pigeons is well-documented; pigeons have been counted annually by state and federal wildlife agencies to monitor relative abundance and distribution (Jarvis and Passmore 1992, Casazza et al. 2005, Sanders 2015). Most band-tailed pigeons harvested in the Pacific Northwest are shot at mineral sites (Morse 1950, 1957; Einarsen 1953, March and Sadleir 1972). Aggregation at mineral sites, despite risks from hunters or predators (Jarvis and Passmore 1992), suggests that minerals provide an important resource, possibly even limiting the distribution or abundance of band-tailed pigeons (Jarvis and Passmore 1992, Braun 1994, Bottorff 2009).

Sodium and calcium have been associated with mineral sites used by band-tailed pigeons, but the specific minerals sought and physiological need for supplemental mineral has not been determined. Early observations indicate that band-tailed pigeons frequented sites containing sodium (sea water, saline soils on a cliff face, and salt springs; Prill 1893, Neff 1947) or sodium and calcium (Smith 1968). Later authors speculated that mineral sites were used to supplement a calcium-deficient diet during the nesting season when pigeons in British Columbia, Washington, and Oregon feed almost exclusively on red elderberry (*Sambucus racemosa* var. *arborescens*) and cascara (*Rhamnus purshiana*) berries (March and Sadleir 1972, 1975; Jarvis and Passmore 1992, Braun 1994, Bottorff 2009). Sanders and Jarvis (2000) reported evidence that sodium, not calcium, was sought by band-tailed pigeons in Oregon. Sampled mineral sites were consistently high in sodium but variable in calcium concentrations. Berry food items were especially low in sodium, moderate in calcium, and high in potassium and moisture content, which may increase the need for dietary sodium.

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[1]*E-mail: todd_sanders@fws.gov*

The North American Breeding Bird Survey indicates band-tailed pigeon abundance has decreased significantly during 1968–2014 (−1.8%/year, credible interval = −3.2 to −0.6; Sanders 2015). Understanding the specific resources sought by band-tailed pigeons at mineral sites has implications for conservation and management. Mineral sites are relatively scarce (1/3,846 km^2 in western Oregon), and most (86% in western Oregon) of the known mineral sites used by band-tailed pigeons are on private land (Sanders and Jarvis 2000). Although it is unclear how mineral sites affect population processes, decisions on protection of sites should be informed by identifying the mineral sought by band-tailed pigeons. Further, if birds can be induced to use created sites, this could help alleviate possible limitations of mineral availability.

Furthermore, managers use counts of band-tailed pigeons at mineral sites to assess relative population status and establish harvest regulations. These data would be more meaningful, and sampling protocols could be improved, if it were understood how individual pigeons used mineral sites on a seasonal and daily basis, and in the face of the birds' seasonal cycle, erratic weather (Passmore 1977, Overton et al. 2005), and varying mineral concentrations at mineral sites (Sanders and Jarvis 2000). Information on band-tailed pigeon use of mineral sites also may help direct future research on pigeons' physiological need for supplemental minerals.

We created mineral sites where we monitored a sample of free-living individually marked band-tailed pigeons. Our objectives were to determine if we could create a mineral site used by band-tailed pigeons; test whether pigeons seek supplemental sodium, calcium, or both; describe the pattern of pigeon use of mineral sites seasonally and within days by individual birds; and evaluate implications of precipitation, fog, temperature, and mineral ion concentration on pigeon visitation patterns. Also, we located and sampled mineral sites we knew to be used by pigeons throughout the range of this population to determine mineral concentrations and associated pigeon abundance.

STUDY AREA

Our study area included a privately owned forest (3.0 ha) in southwestern Washington, approximately 8 km east south-east of Battle Ground at 150 m elevation in the mountainous foothills of the western Cascade Range (24 km north of the Oregon and Washington state border). The study area occurred near the center of the breeding range of Pacific Coast band-tailed pigeons and the distribution of mineral sites used by these birds (T. A. Sanders, U.S. Fish and Wildlife Service, unpublished data). The landscape was dominated by forested, private-owned residential lots approximately 1–4 ha in size, with state-owned forest lands 4 km to the east. Climate was marine west coast, characterized by wet, mild winters (Oct–Jun), and cool, dry summers (Jul–Sep) with abundant rainfall (100–200 cm), 75–85% of which occurred between 1 October and 31 March in the form of rain (Franklin and Dyrness 1973, Loy et al. 1976). Most areas were managed for timber production or as forest reserves, and were dominated by dense stands of Douglas-fir (*Pseudotsuga menziesii*) with other overstory species intermixed including grand fir (*Abies grandis*), western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*), and red alder (*Alnus rubra*; Franklin and Dyrness 1973). The nearest known mineral sites used by band-tailed pigeons relative to our study site were 17 km and 33 km north (T. A. Sanders, unpublished data).

METHODS

Mineral Stations

We conducted a pilot study during 2008 and 2009, during which we successfully attracted band-tailed pigeons to a site where we provided whole or cracked shelled corn and sodium- and calcium-enriched tap water and locally collected and sifted soil in individual plastic trays *ad libitum* (i.e., mineral station). Band-tailed pigeons were rarely seen in the vicinity prior to 2008.

We refined the mineral station for the experimental phase of the study during 2010–2014 (Fig. 1). We used one station in 2010. In 2011 we added a second, identical station 50 m away. Each station was constructed of a 1.2 × 1.8-m plywood platform 1.2 m above ground with a 1.2 × 2.4-m sloped plywood roof ≤1.8 m above the platform; both platform and roof were supported by 4, 3.0-m long 5.1 × 7.6-cm boards attached to their outside edge. We fit 2, 2.5 × 5.1-cm wood rails around the station attached to the inside edge of roof supports: one 20 cm above the platform for a perch and the other in support of the roof. We used the roof to prevent dilution of mineral provisions from precipitation but removed it in early July each year (roof supports remained in place and served as an additional perch) to avoid any potential effect of limiting pigeon visibility of mineral provisions and predators. We placed 3 plastic trays (6 cm tall × 60 cm in diameter, 11 L capacity) in a row lengthwise, centered on each mineral station platform and perch rail, leaving 10–30 cm between trays and the edge of the platform for pigeons to stand when accessing the trays.

We applied passive integrated transponder (PIT) technology to monitor pigeon use of each mineral station 24 hours a day from late March through early October each year. Each mineral station had its own antenna, stationary transceiver

Figure 1. Mineral station construction and use by band-tailed pigeons (~115) in mid-June in southwestern Washington, USA.

(FS1001A, Destron Fearing, South St. Paul, MN, USA), and laptop computer housed in a cabinet 3 m from the mineral station. We housed the antenna in a 3.8-cm diameter, white polyvinyl chloride (PVC) pipe surrounding the platform attached to the underside of the mineral station perch rail. The computer collected information about system diagnostics and PIT tag detections from the transceiver via program MiniMon (ver. 1.4.16, Pacific States Marine Fisheries Commission, Portland, OR, USA). We set the transceiver on a 1-minute unique delay to reduce data volume (i.e., each individual tag was recorded only once/min unless time was reset by identification of a different tag).

We evaluated PIT tag antennas and transceivers throughout all monitoring to ensure performance using 3 approaches. First, we initially tuned each antenna for optimal current (4.5 amps), exciter phase (2%), background noise (<12%), and its sensitivity to PIT tag detection, and we manually passed a PIT tag through each antenna near the center and edges to verify sensitivity to PIT tag detection. We periodically checked antenna tuning and sensitivity to PIT tag detection during monitoring. Second, we set the computer at each station to record system diagnostics 4 times/day to verify system tuning and function. Third, we set each transceiver to issue a self-generated test tag every hour to verify reader integrity. Successful test tags were recorded to the daily files and reviewed to identify potential lapses in system function.

Pigeon Trapping and Marking

We captured and marked a sample of band-tailed pigeons during mid-April through May in 2010–2013 using a box trap baited with whole corn 50–100 m from mineral stations. We augmented the marked-pigeon sample in 2010 (24 Jun–2 Jul and 19 Sep–11 Oct) and in 2011 (3–10 Jun) approximately 300 m from the mineral stations when ripe, wild-growing fruits were apparently not readily available and pigeons showed strong interest in bird feeders on adjacent properties. We only used bait away from mineral stations when actively trapping.

We immediately processed band-tailed pigeons, approximately 2 minutes/pigeon, and released them after trapping. We assigned age class (hatching year [HY] or after hatching year [AHY]) and sex for each pigeon based on plumage characteristics (Braun 1976, Sanders and Braun 2013) and banded each pigeon with a uniquely numbered aluminum leg band from the United States Geological Survey's Bird Banding Laboratory (BBL). We marked each pigeon with a PIT tag for passive radio frequency identification (RFID). Tags were 12 mm, 134.2 kHz Super Tag II (TX1411SST) from Biomark (Boise, ID, USA). We implanted PIT tags subcutaneously along the dorso-vertical line of the hind neck of each pigeon using a syringe-style implanter with a 3.2-cm, 12-gauge hypodermic needle (MK7, Biomark) following the recommendations of the Columbia Basin Fish and Wildlife Authority (1999) and in consultation with a local veterinarian. We sterilized each PIT tag and injector (between pigeons) and pigeon hind neck. We verified successful PIT tag implantation by visual inspection of the hind neck area and implanter and by scanning for the tag with a handheld PIT tag reader (134.2 kHz Pocket Reader, Destron Fearing) prior to release of each pigeon.

We evaluated PIT tag retention and complications by marking 60 rock pigeons (*Columba livia*) and 48 band-tailed pigeons wild caught in 2010 and held in captivity. We marked all captive pigeons in April using the same techniques we used for marking wild-living pigeons and monitored captive pigeons through August 2010 (6 months). We weighed and scanned each pigeon for PIT tag retention using our handheld PIT tag reader weekly for the first 2 weeks and then every other week thereafter. The study adhered to relevant regulations and guidelines regarding the ethics of animal welfare, and research protocols followed taxon-specific guidelines (Fair et al. 2010).

Study Design

We evaluated band-tailed pigeon use of supplemental minerals by varying the minerals offered (treatments) at 1–2 mineral stations annually, and between stations within 1 year, over a 5-year period (2010–2014; Figs. 1 and 2). We considered each uniquely marked pigeon as the experimental and sampling unit (i.e., subject exposed to the mineral provision treatment independent of other subjects; Kuehl 1994), and summarized and compared pigeon use of mineral within and among years according to treatments.

We provided only minerals in stations during June–early October each year (except in 2010 where we started 12 Jun), consistent with the period that pigeons typically use mineral sites (March and Sadleir 1972, Jarvis and Passmore 1992). However, we offered whole corn in the center tray and minerals in the 2 outer trays in stations during March–May in 2010–2013 when pigeons arrive in the area and fruit and mast food items are generally scarce. We provided corn to attract pigeons to the area for marking (PIT tag) and to identify marked pigeons known to be in the area. Corn and sodium were at separate stations in 2013 during the period we provided corn. We did not provide corn in 2014.

Treatments during each of the 5 years were sodium and calcium mixed together in soil and water at 1 station (2010), sodium water and calcium water at separate stations and rotated systematically (2011), sodium water at both stations (2012 and 2014), and sodium water at both stations at reduced ion concentration (2013). We discontinued soil provisions after 2010 because pigeons generally did not consume mineral soil when mineral water was available, consistent with pilot study observations. In 2011, the year we rotated minerals between stations, we offered calcium water at the original station and sodium water at the newly added station. We rotated minerals 3 times between stations resulting in 4 intervals: 25 March–31 May (68 days), 1 June–8 July (38 days), 9 July–15 August (38 days), and 16 August–10 October (56 days).

We provided sodium and calcium in water (or soil) at ion concentrations of 3,500 ppm and 1,500 ppm, respectively. We selected mineral concentrations based on the mean sodium (3,480) and calcium (1,662) ion concentrations reported by Sanders and Jarvis (2000) for 33 sites (springs)

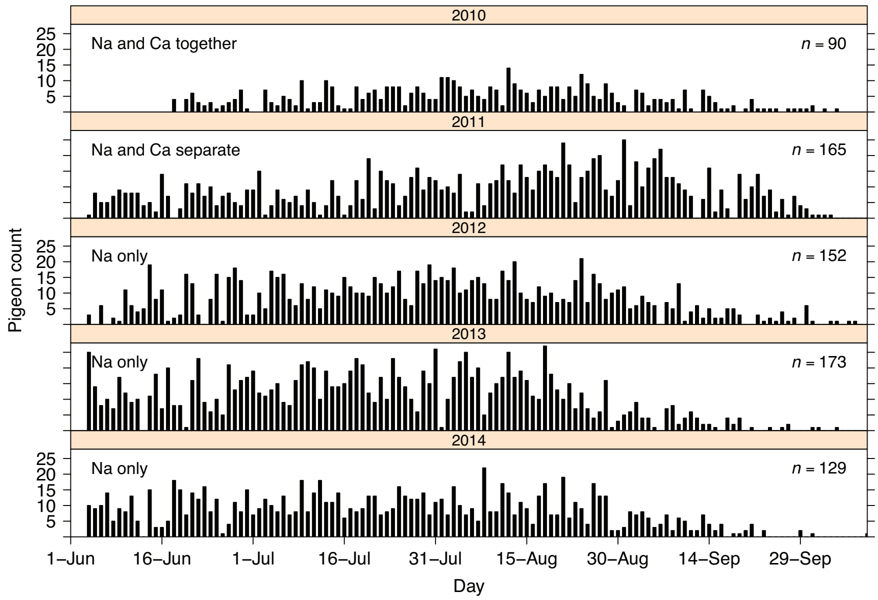

Figure 2. Daily frequency of uniquely marked band-tailed pigeons visiting mineral stations during 4 June–10 October in 2010–2014 in southwestern Washington, USA. Sodium (Na) ion concentration was 3,500 ppm each year except in 2013 when we reduced it to 1,000 ppm, and calcium (Ca) ion concentration was 1,500 ppm. The annual sample size is the number of uniquely marked pigeons visiting the mineral stations each year.

used by pigeons in western Oregon. In 2013 we reduced sodium concentration to 1,000 ppm, approximately the minimum level at natural springs (Sanders and Jarvis 2003). We created mineral provisions by mixing tap water with >99% pure sodium chloride and calcium chloride (dihydrate), and fine-sifted soil from the study area with >99% pure sodium chloride and calcium carbonate, to achieve desired concentrations. Mineral concentrations were verified by Oregon State University's Central Analytical Laboratory by induction coupled plasma (ICP) spectrometer scan. We maintained mineral solutions within 2 L of tray capacity on a daily basis, and cleaned trays and replaced mineral solutions and soil at least once every 1–2 weeks to maintain concentrations and sanitary conditions. We measured mineral water consumption daily in the late evening during 1 June through 10 October in 2013 and 2014 to the nearest 0.5 L. We measured evaporation adjacent to mineral stations in the same type of trays that we offered mineral provisions at stations, but we enclosed these trays with a 2.5-cm wire mesh to prevent vertebrate use.

Mineral Station Observations

We observed band-tailed pigeons opportunistically at the mineral stations with a spotting scope from a nearby residence. We recorded the time that a flock of pigeons entered and departed a mineral station, total number of pigeons that entered the station during that period, age (HY or AHY) of each pigeon, and the ratio of PIT tagged (banded):untagged pigeons in 2010–2013 (we had no onsite observer in 2014). We later evaluated PIT tag detection data from mineral stations to ascertain the number of marked pigeons detected at the station during the time that each group occupied the station. We corrected the observed ratio of PIT tagged:untagged pigeons for each flock with station data if necessary. We visually counted all band-tailed pigeons passing through the antenna from daylight to noon during 1 day in mid-to-late July in 2010–2014 at each mineral station following established protocols of the Mineral Site Survey currently used to monitor abundance of this population (Sanders 2015).

Mineral Site Sampling

We attempted during June and July in 2009 and 2010 to locate and verify band-tailed pigeon use at all mineral sites reportedly used by pigeons. We sampled mineral ion concentration at all confirmed use sites where we received permission for access. We collected a 0.5-L water sample (or soil sample for dry sites) from each site after observing the general location that pigeons used and identifying the area with the greatest mineral concentration evaluated with a conductivity meter. We submitted water and soil samples to Oregon State University's Central Analytical Laboratory for analysis of cation composition by ICP spectrometer scan.

Data Analyses

We evaluated band-tailed pigeon use of minerals at stations during the period when we provided only mineral provisions (beginning 3 days after we removed corn from the stations each year: 15 Jun–10 Oct in 2010, 4 Jun–10 Oct in 2011–2013, 22 Mar–10 Oct in 2014). We analyzed PIT tag detection data in 2 different formats to evaluate band-tailed pigeon visitation patterns: raw and reduced (only the first detection for each uniquely marked pigeon each day). From the raw data, we calculated the number of detections and time between the first and last detection for each uniquely marked pigeon detected/day. From the reduced data, we calculated the mean days between visits for each pigeon with $\geq$2 detections/year during dates when we provided only minerals. We calculated the annual mean days between visits from the mean for each pigeon, and the mean days between visits across multiple years from the annual means weighted by individual pigeon sample size each year.

We calculated the number of uniquely marked pigeons detected seasonally and daily, the time of the first and last uniquely marked pigeon visiting mineral stations each day, and the sex ratio (M:F) pooled over half-month intervals. We calculated the daily number of uniquely marked pigeons separately for each station in 2011 when sodium and calcium were offered at different stations and in 2013 when corn and sodium were at different stations; otherwise, we combined detection data for both stations because provisions were the same. We excluded pigeons marked in late September–early October 2010 from all mineral station analyses until 2011 to avoid any potential bias in mineral station use associated with marking birds late in the data collection period.

We determined the first and last day of visitation annually for each uniquely marked pigeon during all monitoring (late Mar—early Oct) each year from the reduced detection data as an indication of arrival and departure. During 2013, we used only data from the station that offered minerals when we also provided corn before June. We excluded pigeons banded during the same year for arrival analysis because they may have been present at the mineral stations before they were captured.

We estimated the number (marked and unmarked) of pigeons visiting the mineral stations during the dates when we provided only minerals by expanding the annual mean and maximum daily number of marked pigeons visiting the stations by the ratio of total to marked pigeons using the stations each year using equations 1–4 in Sanders and Trost (2013).

We obtained daily climate data (Menne et al. 2012*a*, *b*) for the Portland International Airport station (25 km southwest of the study site, Station ID = USW00024229) from the National Climatic Data Center of the National Oceanic and Atmospheric Administration and local sunrise and sunset data from the Astronomical Applications Department of the United States Naval Observatory. We used Poisson (negative binomial to account for overdispersion) regression analysis to evaluate relationships between precipitation, fog, and maximum temperature (in °C) explanatory variables and 2 response variables, including the number of uniquely marked pigeons at mineral stations and the time of the first uniquely marked pigeon detected each day. All models included a quadratic term for day of the observation period and a year categorical variable with 5 levels to account for seasonal and year effects. We compared models with all combinations of explanatory variable main effects and based model selection on model fit and parsimony using Akaike's Information Criterion (AIC_c) corrected for sample size (Burnham and Anderson 2002). We selected models with the lowest AIC_c. Values for response variables are reported as mean (± SE).

We used Poison regression to evaluate the relationship between sodium ion concentration and 5-year (2008–2012) mean pigeon counts at mineral sites obtained from the Mineral Site Survey (Sanders 2015). We included site latitude as a quadratic term to account for possible abundance effects across the breeding range.

RESULTS

We marked 771 band-tailed pigeons with a PIT tag and aluminum leg band (2010–2013; $n = 351$, 221, 114, and 85, respectively). Most (679) were marked before June each year (except 30 in spring 2010, 33 in fall 2010, and 29 in Jun 2011). The marked pigeon sample included 438 AHY males, 320 AHY females, and 13 HY pigeons (6 marked in May and 7 in Jun). Only 5 tagged HY pigeons visited the mineral stations when we provided only minerals; thus, we excluded the small sample of HY birds from all analyses. Of the marked adult pigeons, 58.6% visited the mineral stations at least once during all monitoring, and 38.4% when we provided only minerals (30.0% the year of marking). Pigeons that used mineral stations when we provided only minerals had a high probability (70.2%, weighted mean over 4 years) of returning in the subsequent year during the same period.

PIT Tag Retention and Detection

Of the 108 captive pigeons implanted with a PIT tag, all retained their tag during monitoring ($\geq$153 days). We examined all captive pigeons the day after marking and found little sign of PIT tag implantation and no apparent behavioral changes. Birds maintained their mass through the week after marking ($t_{107} = 1.66$, $P = 0.44$; paired *t*-test), and no pigeon perished. We recaptured 8 free-living band-tailed pigeons; all had retained their PIT tag.

We verified that PIT tag systems (antennas and transceivers) functioned continuously 24 hours a day; the only exception occurred during 2 electrical outages lasting a total of 13 hours. Only 1 hour was during the period when we provided just minerals, and we believe that no pigeons used the stations at this time because of technician presence to restore power (i.e., pigeon use was delayed).

Pigeons were often detected multiple times at the mineral stations during a single visit. When we provided only minerals, the mean number of detections for each pigeon within a visit/day was 3.7 ± 0.2 in 2010, 2.8 ± 0.1 in 2011, 3.1 ± 0.1 in 2012, 2.4 ± 0.1 in 2013, and 2.3 ± 0.1 in 2014 ($n = 464$, 1,082, 1,022, 1,281, and 985, respectively). At no time did we observe a marked pigeon at a mineral station that we did not also detect a pigeon via PIT tag at the same time during 43, 37, 29, and 34 observations in 2010–2013, suggesting that our PIT tag systems did not fail to detect each marked pigeon at least once within the day of visit at mineral stations (i.e., 100% detection probability for individual pigeon daily use).

Mineral Site Creation

We successfully attracted band-tailed pigeons to stations when providing only minerals (Fig. 2). The daily mean number of uniquely marked pigeons visiting mineral-only stations ranged from 4.1 ± 0.3 to 9.9 ± 0.7, and the maximum ranged from 14 to 27 (Table 1). Hundreds of pigeons (marked and unmarked) could easily be observed using the mineral stations during most days, particularly in late July and early August. Only approximately 5% of birds were marked (PIT tag and leg band). The estimated daily mean number (marked and unmarked) of adult pigeons visiting the mineral stations each year during 2010–2013

Table 1. Number of band-tailed pigeons using mineral stations/day in southwestern Washington, USA during 4 June–10 October 2010–2014. Variables are mean and maximum uniquely marked pigeons/day (marked $\bar{x}$ and max.), total pigeons/marked pigeon (ratio), and mean and maximum total pigeons/day (total $\bar{x}$ and max.).

	Marked			Ratio[a]		Total			
	$\bar{x}$					$\bar{x}$		Max.	
Year	Estimate	SE	Max.	Estimate	SE	Estimate	SE	Estimate	SE
2010	4.1	0.3	14	21.2	3.4	86.4	15.3	297.1	47.9
2011	8.4	0.5	25	15.6	2.5	130.8	22.4	390.0	62.5
2012	8.0	0.5	21	19.4	2.7	156.1	23.8	407.4	56.7
2013	9.9	0.7	27	17.3	2.2	171.4	24.9	466.1	59.8
2014	7.6	0.5	22						

[a] We did not collect total/marked pigeon data in 2014, and consequently there are no estimates for mean and maximum total pigeons in 2014.

ranged from 86.4 ± 15.3 to 171.4 ± 24.9, and the maximum ranged from 297.1 ± 47.9 to 466.1 ± 59.8 (Table 1). These total abundance estimates were consistent with our counts of pigeons using the mineral stations between daylight and noon during a single day in July each year, which were 103, 217, 253, and 294 pigeons, respectively (346 in 2014).

Sodium Versus Calcium

In 2011, when we offered sodium and calcium at separate stations and rotated minerals systematically, band-tailed pigeons moved between mineral stations to follow the availability of sodium and generally abandoned the station with calcium within 1–2 days unless corn was also available (Fig. 3). However, when pigeons first arrived in the area and corn was available at both stations, pigeons used the calcium station to a greater extent, perhaps because it was located where the single station had been in 2010. Visitation dropped and station preference shifted in early May (Fig. 3), which coincided with the expected loss of interest in corn in favor of berry food items (Braun 1994), a pattern we also observed during our pilot study. As stations were rotated during the season, birds generally abandoned the calcium station within 2 days, and especially during rotations subsequent to the first rotation (Fig. 3).

We located 86 mineral sites used by band-tailed pigeons (9 sites in British Columbia, 21 in Washington, 41 in Oregon, and 15 in California), excluding piles of road salt and our created sites. Of the mineral sites, 48 were springs, 29 were tidal, 6 were soil, and 3 were wastewater associated with pulp mills. Mean maximum mineral ion concentrations at wet, non-tidal sites ($n = 45$) were 4,140 ± 651 (range = 300–18,500) ppm sodium and 2,717 ± 563 (range = 22–15,610) ppm calcium; excluding the 2 highest concentration sites (possible outliers) resulted in 3,535 ± 516 ppm sodium (max. = 13,220) and 2,166 ± 429 ppm calcium (max. = 9,751). Concentrations for each site were not normally distributed; 80% of the sites had ≤8,414 ppm sodium and ≤6,654 ppm calcium. Mineral concentration at tidal sites was highly variable depending on tide cycles and fresh water mixing, but maximum concentration was

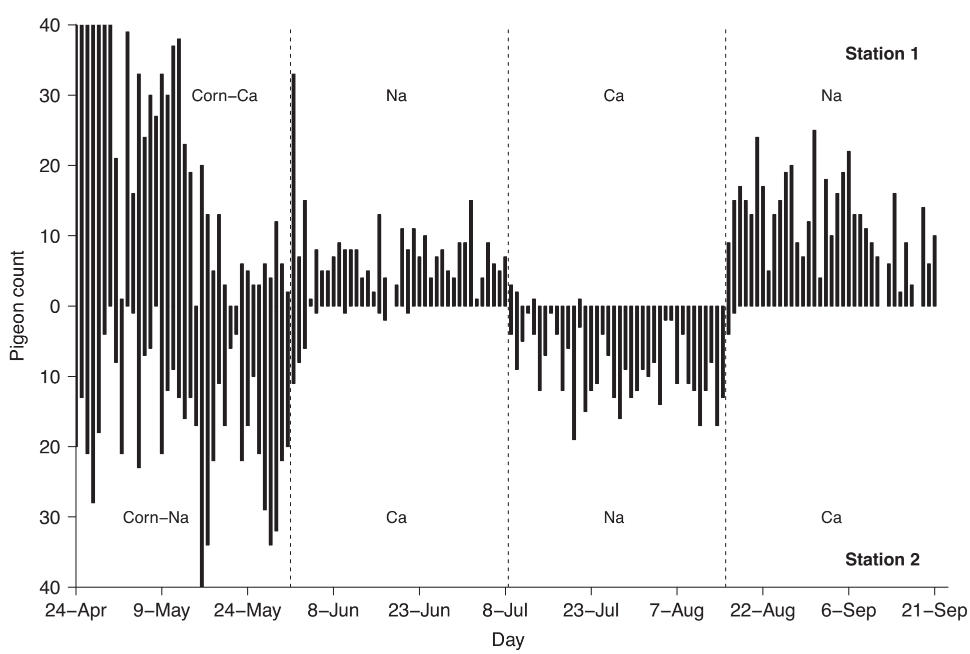

Figure 3. Daily frequency of uniquely marked band-tailed pigeons visiting paired mineral stations with either sodium (Na) or calcium (Ca) each day during 24 April to 22 September 2011 in southwestern Washington, USA. We rotated sodium and calcium provisions systematically between the 2 mineral stations every 38 days, and provided corn at both stations only during the first period.

equivalent to seawater. Mean ion concentrations in seawater ($n = 2$) were $9,010 \pm 590$ ppm sodium and 331 ± 6 ppm calcium. Sampled soil sites ($n = 4$) had mean ion concentrations of $1,860 \pm 405$ (range = 1,082–2,970) ppm sodium and $1,083 \pm 232$ (range = 752–1,762) ppm calcium. None of the 45 sampled, wet, non-tidal sites had <300 ppm sodium, whereas 13 (29%) sites had <330 ppm calcium, and all seawater sites were high in sodium but low in calcium.

Daily Mineral Station Visitation Patterns

Band-tailed pigeons visited mineral stations once every 11.9 ± 0.5 days (weighted mean during 5 year; Fig. 4). The mean visitation rate was similar among years, despite calcium not being available during 3 of 5 years (2012–2014). Detection histories showed individual pigeons had similar intervals between station visits, but intervals generally varied among pigeons from 1–2 weeks. However, some pigeons visited the mineral stations only once (range = 7.5–13.3%), ≤2 times (11.6–25.6%), and ≤3 times (15.5–34.4%) each year ($n = 5$). Single-visits occurred throughout the period when only minerals were provided.

Band-tailed pigeons began visiting the mineral stations as early as 6 minutes after sunrise, continuing through the day to as late as 34 minutes before sunset. Band-tailed pigeons primarily visited mineral stations in the morning with 75.4% of the uniquely marked pigeons visiting by 6 hours after sunrise and <4.3% new visits after 9 hours after sunrise (sunrise in mid-Jul was ~0537 hours and sunset ~2055 hours; Fig. 5). Male and female pigeons visited mineral stations at different times of the day: males primarily in early morning and females primarily in late morning (Fig. 6). The mean sex ratio (M:F) of uniquely marked band-tailed pigeons visiting mineral stations during 2010–2014 was approximately 1 (1.05:1; 1.37:1 at marking); however, the ratio was female biased (0.72:1) before mid-July, near 1 (0.95:1) mid-July through August, and strongly male biased (1.58:1) in September (Fig. 7).

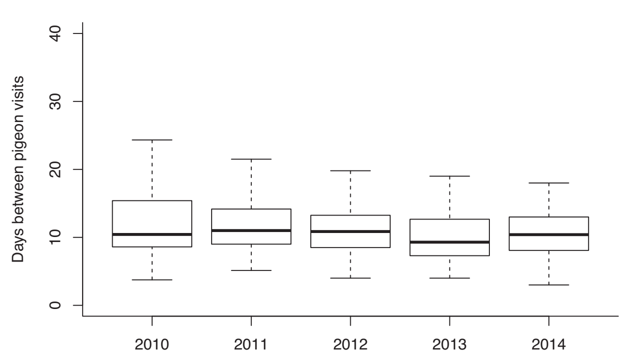

Figure 4. Mean span in days between visits to mineral stations for each uniquely marked band-tailed pigeon ($n = 81$, 143, 133, 160, 119) using the stations during 4 June–10 October in 2010–2014 in southwestern Washington, USA. Sodium ion concentration was 3,500 ppm each year except in 2013 when we reduced it to 1,000 ppm. Boxes represent the 25th and 75th percentiles, bold horizontal lines indicate means, capped bars signify the 10th and 90th percentiles, and open circles mark all data points outside the 10th and 90th percentiles.

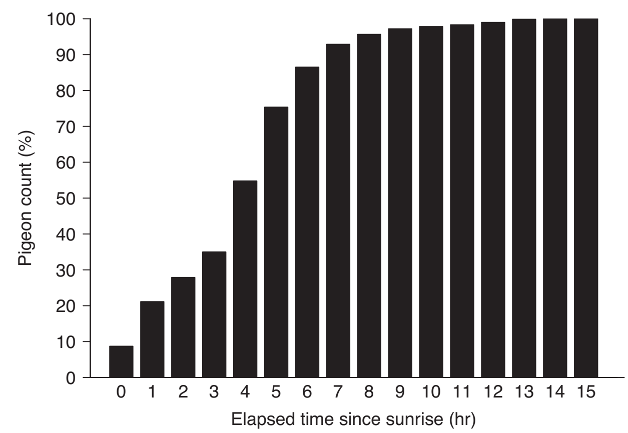

Figure 5. Cumulative percentage of all uniquely marked band-tailed pigeons detected ($n = 4,833$; considering only first detection for each pigeon and day, data pooled over 5 years) by elapsed hour after sunrise (0 = 0 hr and 0 to 59 min) at mineral stations during 4 June–10 October in 2010–2014 in southwestern Washington, USA. Sunrise in mid-July was approximately 0537 hours and sunset approximately 2055 hours.

Band-tailed pigeons generally visited the mineral stations only once within a day. Detections for each uniquely marked pigeon within a day were within 2 minutes for 80.4% of the pigeons during 5 years. Detections were within 10 minutes for 87.0%; and within 60 minutes for 96.7% of the pigeons. The few pigeons visiting the stations within a day >60 minutes apart were generally males visiting during the early morning and then again in the late afternoon. The span in detection times within a day for each uniquely marked pigeon was somewhat greater when sodium ion concentration was 1,000 ppm versus 3,500 ppm (detections were within 2 min for 71.2% vs. 83.0% of the pigeons, within 10 min for 78.8% vs. 89.3% of the pigeons, within 30 min for 85.4% vs. 93.3% of the pigeons, and within 60 min for 94.5% vs. 97.3% of the pigeons, respectively).

Seasonal Mineral Station Visitation Patterns

Based on data from 2013 and 2014 when we had only sodium water year-long (i.e., no corn or calcium), band-tailed pigeon

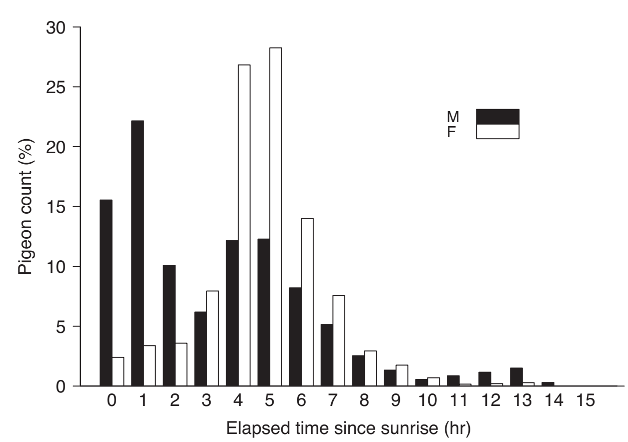

Figure 6. Percentage of all uniquely marked band-tailed pigeons detected ($n = 4,833$; considering only first detection for each pigeon and day, data pooled over 5 years) by sex and elapsed hour after sunrise (0 = 0 hr and 0 to 59 min) at mineral stations during 4 June–10 October in 2010–2014 in southwestern Washington, USA.

use of sodium began when pigeons arrived in the area in late March (pigeons were first observed at nearby feeders during 22–25 Mar 2008–2014), increased to a peak in July and early August, and then decreased in late August and early September (Figs. S1 and S2, available online in Supporting Information). Use of mineral stations was negligible by late September when pigeons appeared to depart the area. The daily consumption of sodium water at mineral stations was consistent with the number of pigeons detected at mineral stations and averaged 7.8 ± 0.5 L/day (total = 1,024 L, max. = 26 L/day) in 2013 and 5.8 ± 0.4 L/day (total = 770 L, max. = 17 L/day) in 2014 (Figs. S1 and S2). Considering our estimated mean of 171.4 pigeons/day at the stations in 2013, pigeons may consume approximately 46 ml of sodium water/mineral station visit.

The first and last detection of each uniquely marked band-tailed pigeon at the mineral stations year-long indicated pigeons arrived primarily April through May and departed primarily 15 August through 15 September, and may represent prolonged spring (2 months) and fall (1 month) migrations (Fig. 8). This pattern varied little among years (2010–2014), particularly for spring compared to fall migration (Fig. 8). Fall migration was almost 1 month later in 2010 in association with apparent mild ambient conditions and availability of berry food items. Apparent spring arrival and fall departure patterns were consistent with the seasonal use of supplemental sodium at mineral sites in the Pacific Northwest (Figs. 2 and 8). Spring arrivals did not differ for years ($n = 3$) when corn was available compared to years ($n = 2$) when only minerals were available, and indicate no delay in use of supplemental mineral upon arrival in breeding areas (Fig. 8). However, approximately 25% of the pigeons were not detected again after we removed corn from the site 1 June (Fig. 8), indicating either departure from the area or no use of supplemental sodium. Because detection of arrivals did not depend on availability of corn, we combined years with and without corn for assessment of difference between sexes. Male and female pigeons had the same pattern in arrival and departure, except for departures during years when corn was available in that approximately 20% more males than females were not detected again after we removed corn from the site (Fig. 8). There also appears to be early departure of males than females in September consistent with differences in sex ratios at mineral stations during this time (Figs. 6 and 8).

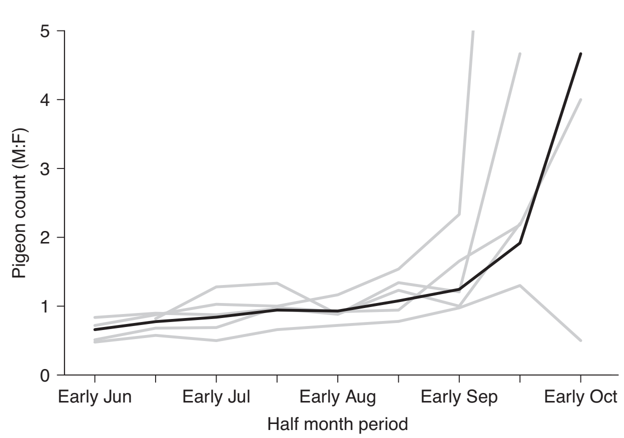

Figure 7. Ratio of male:female uniquely marked band-tailed pigeons during half-month intervals at mineral stations during 4 June–10 October in 2010–2014 in southwestern Washington, USA. Estimates are for each of 5 years (gray lines) and pooled (black line).

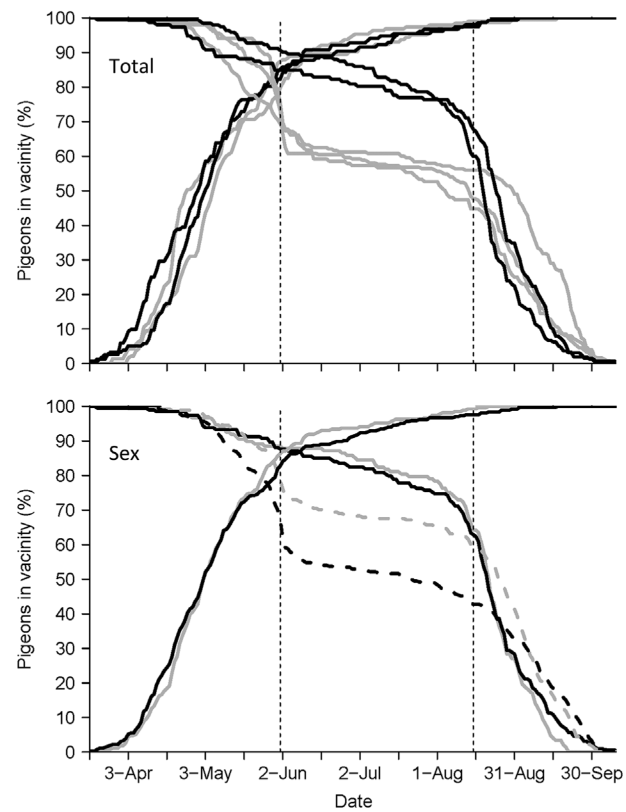

Figure 8. Cumulative percentage of the first (ascending) and last (descending) visit for each uniquely marked band-tailed pigeon at mineral stations during 19 March–10 October in 2010–2014 in southwestern Washington, USA. Top panel is by year when corn was available before June (gray) and when we provided only minerals (black). Bottom panel is by sex for males (black) and females (gray) pooled over years, except that departures are separate for years when corn was available (broken) versus sodium only (solid).

The return rate of pigeons to stations in subsequent years during the period when we provided only minerals was 0.702 without accounting for survival probability, and return rates were 0.065 higher for females than males. Homing rates averaged 0.912 for males and 1.000 for females when accounting for apparent survival probability (0.735 ± 0.019; T. A. Sanders, unpublished data).

Sodium Ion Concentration and Weather Effects on Visitation

The mean days between visits of band-tailed pigeons to mineral stations was similar when sodium ion concentration was 3,500 (2010–2012, 2014) versus 1,000 ppm (2013), and was 12.2 ± 0.01 versus 11.2 ± 0.04 days, respectively (Fig. 4). Also, we found no relationship between sodium ion concentration and 5-year mean pigeon counts at 39 non-tidal mineral sites with pigeon count data ($n = 39$, deviance = 42, sodium factor $X_{35}^{2} = 1.0$, $P = 0.32$).

Our best fitting models relating weather variables to daily individual pigeon counts and time of first use included precipitation and temperature effects (Table 2). The next best fitting model for each response variable also included fog effects, and dropped in weight by <0.02, but estimates for fog effects were not significant ($P > 0.157$). Estimates for precipitation and temperature were similar between the 2 best fitting models for each response variable; therefore, we report parameter estimates only from the best fitting model (Table 3). Mean daily individual pigeon counts were lower by a factor of 0.65 on days with precipitation, and mean first use in minutes since sunrise was later by 1.41 times (Table 3). Mean daily pigeon counts increased approximately 1.25 times (but depended on temperature) with each 1°C in daily maximum temperature, and mean first use in minutes since sunrise was earlier by 0.96 times.

DISCUSSION

Mineral Site Creation and Sodium Versus Calcium

We successfully created a mineral site used by band-tailed pigeons by providing only sodium water in a forested area. We attracted pigeons with only sodium water during late March through early October in numbers that exceeded counts at most natural mineral sites across the species' range. Our experimental study shows that band-tailed pigeons visit mineral sites during the breeding season to supplement dietary sodium and not calcium (Fig. 3).

Band-tailed pigeons did not consume calcium water unless it also contained sodium. There was no indication that pigeons sought water; we did not observe pigeons using pure tap water provided during the 2-year pilot study or using water naturally available around stations during the 5-year experiment. Water is readily available throughout Pacific Northwest forests, and we are aware of no observations of pigeons congregating to drink non-mineralized water in the published literature. Pigeons consumed sodium soil at our mineral station when sodium water was not available. Data collected at mineral sites used by band-tailed pigeons across the population's range also indicate pigeons seek sodium, as these sites were consistently high in sodium (≥300 ppm), but many (57%, 42 of 74) wet sites had low calcium (≤331 ppm).

Sanders and Jarvis (2000) reported that the presence of sodium appeared to be the principal attractant to pigeons at mineral sites in Oregon. Only 1 of 36 mineral sites they sampled had <678 ppm sodium, whereas 64% of sites had <200 ppm calcium. We resampled the 1 mineral site with <678 ppm sodium for this study in 2009 and it exceeded 15,000 ppm at the creekside location of greatest concentration found with a conductivity meter (a technique they did not use). Our results also are consistent with the mineral concentrations reported by earlier investigators who sampled mineral sites used by band-tailed pigeons in California, Oregon, Washington, and British Columbia (Smith 1968, March and Sadleir 1972). Our results do not support the conclusions of March and Sadleir (1972, 1975) and Jarvis and Passmore (1992) that band-tailed pigeons seek calcium at mineral sites. These conclusions were based on observed

Table 2. Fit statistics (number of model parameters [K], change in Akaike's Information Criterion corrected for small sample size [AIC_c], and AIC_c weight) for generalized linear models associating weather explanatory variables with the number of uniquely marked band-tailed pigeons using mineral stations and the timing (elapsed min since official local sunrise) of first use/day in a forested area in southwestern Washington, USA during 4 (except 15 in 2010) June–10 October in 2010–2014.

Model[a]	df	K	Deviance	ΔAIC_c	Weight
Count of marked pigeons					
Precip + temp + temp^2 + day + day^2 + year	624	10	740.7	0.0	0.25
Precip + fog + temp + temp^2 + day + day^2 + year	623	11	740.1	1.7	0.23
Precip + temp + day + day^2 + year	625	9	742.7	11.9	0.14
Precip + fog + temp + day + day^2 + year	624	10	741.4	13.2	0.13
Temp + temp^2 + day + day^2 + year	625	9	737.6	25.5	0.07
Fog + temp + temp^2 + day + day^2 + year	624	10	738.6	26.1	0.07
Precip + day + day^2 + year	626	8	743.8	32.8	0.05
Precip + fog + day + day^2 + year	625	9	741.9	33.8	0.05
Fog + temp + day + day^2 + year	625	9	740.3	53.2	0.02
Temp + day + day^2 + year	626	8	738.0	53.2	0.02
Fog + day + day^2 + year	626	8	742.8	112.2	0.00
Day + day^2 + year	627	7	738.1	115.2	0.00
Time of first visit by a marked pigeon					
Precip + temp + day + day^2 + year	550	11	603.9	0.0	0.14
Precip + fog + temp + day + day^2 + year	551	10	603.8	0.0	0.14
Precip + temp + temp^2 + day + day^2 + year	551	10	603.9	1.7	0.13
Precip + fog + temp + temp^2 + day + day^2 + year	552	9	603.8	1.8	0.13
Fog + temp + day + day^2 + year	552	9	604.4	6.7	0.10
Fog + temp + temp^2 + day + day^2 + year	551	10	604.3	8.5	0.09
Temp + day + day^2 + year	552	9	604.8	12.1	0.08
Temp + temp^2 + day + day^2 + year	552	9	604.8	13.7	0.07
Precip + day + day^2 + year	553	8	605.6	20.5	0.05
Precip + fog + day + day^2 + year	553	8	605.5	20.7	0.05
Fog + day + day^2 + year	553	8	607.5	48.0	0.01
Day + day^2 + year	554	7	608.7	62.1	0.01

[a] Variables: precip = indicator variable for presence of measurable precipitation, temp = maximum temperature in degrees Celsius, fog = indicator variable for presence of fog weather types, day = day of the observation period from 4 June through 10 October, and year = categorical variable with 5 levels for each year of the study.

Table 3. Parameter estimates from negative binomial regression models associating weather explanatory variables with the daily number of uniquely marked band-tailed pigeons using mineral stations and time (elapsed min since official local sunrise) of first use/day in a forested area in southwestern Washington, USA during 4 (except 15 in 2010) June–10 October in 2010–2014. Each parameter had 1 degree of freedom.

Parameter[a]	Estimate	SE	Wald 95% CI		Wald X^2	$P > X^2$
			Lower	Upper		
Count						
Intercept	−1.731	0.693	−3.088	−0.374	6.3	0.012
Precip	−0.431	0.081	−0.589	−0.273	28.5	<0.001
Temp	0.226	0.053	0.123	0.328	18.5	<0.001
$Temp^2$	−0.004	0.001	−0.006	−0.002	14.0	0.000
Day	0.033	0.003	0.026	0.040	96.1	<0.001
Day^2	0.000	0.000	0.000	0.000	169.8	<0.001
Year1	−0.544	0.086	−0.712	−0.377	40.6	<0.001
Year2	0.276	0.074	0.130	0.422	13.8	0.000
Year3	0.094	0.074	−0.050	0.239	1.6	0.202
Year4	0.266	0.072	0.125	0.407	13.7	0.000
Time						
Intercept	5.773	0.228	5.326	6.220	640.7	<0.001
Precip	0.342	0.092	0.161	0.523	13.8	<0.001
Temp	−0.040	0.008	−0.056	−0.024	23.4	<0.001
Day	−0.006	0.004	−0.014	0.002	2.0	0.154
Day^2	0.000	0.000	0.000	0.000	8.3	0.004
Year 1	0.258	0.099	0.064	0.452	6.8	0.009
Year 2	−0.024	0.096	−0.213	0.164	0.1	0.802
Year 3	−0.239	0.097	−0.428	−0.049	6.1	0.014
Year 4	−0.059	0.096	−0.247	0.130	0.4	0.542

[a] Parameters: precip = indicator variable for presence of measurable precipitation, temp = maximum temperature in degrees Celsius, day = day of the observation period from 4 June through 10 October, and year = categorical variable with 5 levels for each year of the study (year 5 is the reference year).

changes in calcium content in serum and bone, elevated calcium demand for egg and crop milk production, seasonal use of mineral sites that were generally high in calcium concentration, and nesting phenology. However, these authors did not determine whether band-tailed pigeons had a diet deficient in calcium, nor did they consider sodium, even though all mineral sites evaluated had high concentrations of sodium.

Mineral Site Visitation Patterns

We are aware of no other reliable empirical data on band-tailed pigeon visitation rates at mineral sites. Leonard (1998) approximated that radio-tagged pigeons in Oregon used mineral sites once/week during the nesting season. Casazza et al. (2001) reported that radio-tagged pigeons visited mineral sites in California once every 21 days on average at one study area, and only once or twice in another study area during June through September, but sample sizes were small, data loggers at mineral sites did not scan continuously or function reliably, and detections were in part a result of pigeons nesting near mineral sites. Passmore (1977) provided data that indicated some pigeons may use sites approximately once/week but did not determine visitation rates. Our results on pigeon visitation rates to mineral sites (once every 11.9 ± 0.5 days) are consistent with these limited observations at natural mineral sites in California and Oregon.

Band-tailed pigeons use mineral sites primarily between sunrise and 1400 hours, with males primarily in early morning and females primarily in late morning. Band-tailed pigeons generally visited the mineral stations only once within a day, and the time span between uses within a day was <2 minutes for most (80.4%) pigeons. Pigeons with spans up to 60 minutes were a result of flocks that temporarily flushed from the stations to tree limbs just above the stations and returned when presumed safe. We observed pigeons loafing in trees adjacent to the mineral stations for up to 2 hours before using mineral stations.

Seasonally, band-tailed pigeons began using the mineral station when they arrived in the area in late March and use continued until they apparently migrated primarily during mid-August through September, although some birds continued to use the mineral stations through early October. There was no evidence of delay in use of mineral stations as pigeons likely used stations with corn immediately upon arrival when corn was available (Braun 1994, Gutiérrez et al. 1975), and use patterns did not differ when compared to stations with only mineral provisions year long. Male and female pigeons had the same pattern in first and last use of mineral sites, except that the mean sex ratio (M:F) visiting mineral stations was somewhat female biased early in the seasons and became strongly male biased in September. Female pigeons stopped using mineral stations or initiated migration earlier in September than did male pigeons.

Band-tailed pigeon daily and seasonal visitation patterns at our created mineral sites were consistent with patterns reported by other researchers investigating this populations' use of naturally occurring mineral sites during the breeding season (March and Sadleir 1972, Passmore 1977, Jarvis and Passmore 1992, Leonard 1998, Overton et al. 2005), with the exception of the ratio of males:female throughout the nesting season. March and Sadleir (1975) reported a preponderance of females at mineral sites from May through August, but their sample is believed to be biased because they collected samples at mineral sites during the late morning when females are expected to be most prevalent (Jarvis and Passmore 1992). Jarvis and Passmore (1992) reported the preponderance of males using mineral sites in September may be because females cease feeding the nestling before it is fledged, leaving the male to finish caring for the young, as do rock pigeons (Whitman 1919). Female pigeons likely have a higher need for supplemental sodium than do males early in the nesting season associated with egg production (Hayslette and Mirarchi 2002).

Sodium Ion Concentration and Weather Effects on Visitation

We found no statistical evidence that sodium ion concentration at mineral sites affected pigeon visitation rates within the range of 1,000 ppm to 3,500 ppm; however, pigeons appeared to visit somewhat more frequently and for longer periods within a day when sodium concentration was reduced. Also, we found no relationship between sodium ion concentration and 5-year mean pigeon counts at 39 non-tidal mineral sites with pigeon count data. All tidal and non-tidal mineral sites used by pigeons that we sampled had a concentration $\geq$300 ppm sodium but most (96%, 75 of 78) had >550 ppm sodium. We sampled the 3 mineral sites (1 each in California, Oregon, and Washington) with low (<400 ppm) sodium concentration multiple times and in different years to confirm results. Thus, pigeons will use mineral sites with concentrations as low as 300 ppm sodium; however, it is unknown whether pigeons that use sites with concentrations <1,000 ppm have more frequent visitation rates than we found.

We found evidence that mean pigeon counts were lower and use delayed during days with measurable precipitation compared to dry days, and counts increased with maximum daily temperature. This pattern was strongly apparent during observations at our mineral stations, whereas our models were developed linking pigeon counts to weather patterns 25 km southwest of the study site. Passmore (1977) and Overton et al. (2005) also reported pigeon counts were lower at mineral sites during days with precipitation (recorded at the mineral site). Overton et al. (2005) reported greater counts $\leq$2 days after rain than during days with rain, and suggested avoiding counts of pigeons at mineral sites during or immediately after days with rain.

Reliability of Results

It is unknown whether band-tailed pigeons that consumed supplemental mineral from our stations during June–October also consumed minerals from other supplemental sources during the same period, which could affect observed visitation rates, but other use seems unlikely. The source of minerals at most mineral sites used by band-tailed pigeons is seawater or connate water (seawater trapped in the pores of marine sedimentary bedrock at the time of deposition), and consequently, inland sodium sources are relatively scarce and new sources are rarely exposed (Caldwell 1993, Sanders and Jarvis 2000). Scarcity of supplemental sodium sources used by band-tailed pigeons is supported by observations that pigeons readily discover and use new sodium sources. Furthermore, mineral sites used by pigeons are assumed to be mostly known because pigeons have high rates of fidelity and homing to mineral sites (Jarvis and Passmore 1992, Leonard 1998), sites are popular among sportsmen and bird enthusiasts (Morse 1950, 1957, Einarsen 1953), and most used mineral sites have been documented by wildlife agencies for >50 years and the rate of new discovery is low (approximately 1/decade and similar to loss rate; T. A. Sanders, unpublished data).

Jarvis and Passmore (1992) reported high rates of homing and no exchange of pigeons between 2 mineral sites 37 km apart but found some exchange between 2 mineral sites 5.6 km apart during the same year. Our study location was 17 km from the nearest known mineral site used by band-tailed pigeons. Leonard (1998) radio-tagged 127 adult band-tailed pigeons and found they traveled an average distance of 5.0 km to feeding areas (but distance decreased with onset of the nesting season and increasing berry availability), and few traveled >20 km during the breeding season in Oregon. Leonard (1998) also reported that all pigeons used the known mineral site nearest to their nest (20 detections of marked pigeons at 3 known mineral sites); distances averaged 8.4 km (range = 3.5–14.0, SE = 0.83). All 138 nests found averaged 10.0 km (range = 2.0–21.3, SE = 0.4) from the nearest known mineral site. We had 1 recovery of a marked pigeon at another known mineral site (17 km distance), which was popular among sportsmen, and that pigeon visited our mineral stations only once in 2 years after capture. Both visits (capture and detection) were $\leq$5 June when native berries were scarce and corn was either available or recently available in or near the stations.

Failure to detect marked band-tailed pigeons at mineral stations could have implications for estimation of visitation rates (i.e., could be more frequent than estimated) but should not have consequences on other visitation patterns unless each marked bird did not have the same probability of detection when present. We found no information to be concerned about either possibility based on visual observations of marked pigeons at mineral stations, system diagnostics, manual system performance testing, automated test tags, detection data, and results of our tag retention study. We maximized the likelihood of detecting each marked band-tailed pigeon by 1) placing the PIT tag along the dorso-vertical line of the hind neck of each pigeon and perpendicular to the mineral station antenna where the tag passed through the antenna $\geq$2 times each visit as pigeons frequently lift their head up and above the antenna to look for predators between drinking or pecking, and 2) leaving only 10–30 cm between food-mineral trays and the platform edge requiring pigeons to stand in close proximity to the antenna. Our data indicate that each marked pigeon detected at mineral stations each day was detected multiple times (2.7 ± 0.1), despite the system being set to register each unique mark once/minute. These detection rates, combined with observations of marked pigeons being consistent with detections at stations, suggest there was a high probability of detecting a marked pigeon at the mineral stations at least once during the day of visit. We believe results from our study have low probability of bias compared to other past studies of band-tailed pigeon mineral site use because our data were computer recorded 24 hours a day season long, whereas other studies are based on observations during part of the day and season and were subject to observation and data recording errors.

Establishing replicate mineral sites (natural or created) to determine variability in our results was challenged by the need for a dependable, 120-volt electricity supply; security of the PIT tag monitoring system; access for regular maintenance; and mineral access limited to 1 or few discrete areas that can be surrounded by an antenna. We did create a replicate mineral station in a privately owned forest in northwestern Oregon (10 km west of Banks) in 2010. The station, provisions, procedures, and monitoring period were the same as that used at the mineral site in southwestern Washington. Only 11 of 98 marked pigeons returned to use the station during the period when we provided only minerals. Six pigeons used the mineral station only 1 day, whereas the other 5 pigeons used the station 2–8 days (2.91 ± 0.88). The span between visits to the mineral station was 9.38 ± 4.60 days (range = 2–27), but sample size was small. Thus, band-tailed pigeon use and visitation patterns appeared similar between replicate mineral station sites. We attributed the small, effective sample size at the Oregon site to its recent creation (i.e., first year of study without adequate time for a tradition of pigeon use to build) and close proximity (<37 km) to other ($n = 8$) mineral sites known to be used by band-tailed pigeons. We discontinued monitoring at the Oregon site because of the logistical challenge of managing sites that required daily service in Oregon and Washington (separated by 66 km). However, the landowner maintained sodium water at the replicate mineral station and pigeons regularly used this site daily (>100 could be seen at one time) during late March through early October in 2011 (S. Hayes, landowner, personal communication).

Use of Supplemental Sodium

The necessity of supplemental sodium sites for band-tailed pigeon survival and productivity has not been determined, although mineral deposits appear to be a key resource during the breeding season and are scarce in the range of this species (Jarvis and Passmore 1992, Sanders and Jarvis 2000, 2003). Jarvis and Passmore (1992) reported that mineral deposits may be more important than food or nesting sites in affecting the distribution of this population during the nesting season, but Sanders and Jarvis (2003) reported that relative pigeon abundance was not associated with availability of known mineral sites in western Oregon (the max. distance to the nearest known mineral site was 37 km).

Despite the large number of band-tailed pigeons that consumed supplemental sodium at our mineral stations, and despite high rates of homing (91% for M and 100% for F), our data provide evidence that some pigeons may not use mineral sites. Only 38.4% of the marked pigeons were ever detected at the mineral stations during June through early October when we provided only minerals (i.e., no corn), and only 30% the year of marking. Approximately 25% of the uniquely marked pigeons were last detected at mineral stations just before we removed corn on 1 June (Figs. 3 and 8), particularly for males. Pigeons have prolonged spring migration, and consequently some pigeons may have continued their migration to other nesting areas, but others may have remained in the area and not used the mineral stations. The latter scenario seems possible considering that our data shows reduced movement by early June, most adult pigeons attempt nesting each year, and nest initiation peaks in mid-to-late June (Jarvis and Passmore 1992, Leonard 1998, Sanders and Braun 2013). Furthermore, some pigeons visited our mineral stations only once or few (≤ 3) times when we provided only minerals. These infrequent uses occurred throughout the period when we provided only minerals, and indicated that these birds may have been using the area during the nesting season rather than passing through. Passmore (1977) reported that some pigeons visited mineral site areas but did not consume minerals.

Use of supplemental sodium has been observed for several avian species (Coleman et al. 1985). However, regular use of supplemental sodium and congregations of birds at supplemental sodium sources are rare, and is not a universal characteristic among any avian Family. Among birds, mineral use is most notable among a few species of pigeons and doves (Goodwin 1983), parrots and macaws (Emmons and Stark 1979, Gilardi and Munn 1998, Powell et al. 2009), and finches (Fraser 1985). Sanders and Jarvis (2000) identified 5 plausible physiological hypotheses to explain supplemental mineral use among birds. Dietary supplement and electrolyte balance are the most likely hypotheses for pigeons and doves, especially the fruit eaters (compared to the seed or fruit and seed eaters) during egg production and when regurgitating crop milk to feed young (March and Sadleir 1972, Goodwin 1983, Jarvis and Passmore 1992, Sanders and Jarvis 2000, Hayslette and Mirarchi 2002). Eggs and crop milk are high in sodium content; eggs 0.9% of dry weight (Hayslette and Mirarchi 2002) and band-tailed pigeon crop milk $0.14 \pm 0.01\%$ (T. A. Sanders, unpublished data; $n = 20$).

Supplemental sodium use among pigeons and doves is highly variable within and among species. Sodium has been reported to be effective for attracting and trapping mourning doves (*Zenaida macroura*) in some areas (Tabor 1926, Reeves et al. 1968) but not in others (Lewis and Morrison 1973). Hayslette and Mirarchi (2002) reported that selection for supplemental sodium is weak in mourning doves; adults will consume supplemental sodium, particularly during the week following hatching when young are fed primarily crop milk, but supplemental sodium use was not necessary for reproduction. The passenger pigeon (*Ectopistes migratorius*) was known to use supplemental sodium, and sodium was used to attract and trap these birds (Mitchell 1935, Schorger 1955). Sodium was reported to be effective in attracting passenger pigeons when the primary food item was beechnuts but was not effective for attracting pigeons that fed on acorns and grains (Schorger 1955). Interior band-tailed pigeons (*P. F. fasciata*) do not use supplemental sodium to any extent, which may be related to properties of food and grit items (potassium, sodium, and moisture content) consumed (Braun 1994, Sanders and Jarvis 2000). White-winged doves (*Z. asiatica*) feed on a variety of seeds, grains, and fruits, and do not appear to use supplemental sodium (Cottam and Trefethen 1968; W. H. Kiel, retired U.S. Fish and Wildlife Service, personal communication). Fruit-eating pigeons in the Caribbean, which have a diet similar to band-tailed pigeons, do not appear to use supplemental sodium to any extent (F. F. Rivera Milán, U.S. Fish and Wildlife Service, personal communication).

Detailed information necessary for understanding mineral metabolism and requirements of band-tailed pigeons is lacking; however, Sanders and Jarvis (2000) demonstrated that Pacific Coast band-tailed pigeons likely have an increased need for sodium during the nesting season based on diet and reproductive activities. Pacific Coast band-tailed pigeons primarily consume berry food items during the nesting season but also buds, inflorescences, and young leaves of trees and shrubs before berries are available (Keppie and Braun 2000). These food items are relatively low in sodium, 0.002–0.025% on dry matter basis, but are high in moisture content (71.5–82.7%) and potassium (0.125–0.270%; Klasing 1998, Sanders and Jarvis 2000). Excessive water and potassium intake (potassium loading) can decrease sodium absorption and retention and lead to an increased need for sodium for sodium:potassium cation electrolyte balance critical for cellular functions and osmotic and acid-base relationships (Robbins 1993, Klasing 1998, Sanders and Jarvis 2000, Holdo et al. 2002). High levels of water and or potassium intake result in the excretion of dilute urine and wet droppings, and concomitant loss of sodium (Weeks and Kirkpatrick 1976, Robbins 1993, Klasing 1998). Furthermore, parents that regurgitate food for their young, particularly milk high in minerals, lose electrolytes in the process, and this exacerbates marginal dietary levels (Robbins 1993, Klasing 1998).

Band-tailed pigeon use of supplemental sodium in our study was strongly associated with the seasonal occurrence of this species in the area, and to a somewhat lesser extent with hatching dates and the period when young are fed primarily crop milk or berry availability when pigeons feed exclusively on these food items (Sanders and Jarvis 2000, Sanders and Braun 2013). Band-tailed pigeons used our mineral stations well before red elderberry berries were available mid-June and droppings at this time indicated pigeons were primarily consuming buds, inflorescences, young leaves, and cherries. Band-tailed pigeon hatching dates are primarily May through mid-September and peak late June through mid-August (Leonard 1998, Sanders and Braun 2013). However, both male and female pigeons used supplemental sodium at our mineral stations equally and throughout most of the nesting season. Band-tailed pigeons can have 3 successful nests, each 40–50 days apart and generally with 1 egg, per breeding season (Jarvis and Passmore 1992, Leonard 1998, Keppie and Braun 2000), yet use of supplemental sodium in our study was season-long for individual pigeons and averaged once every 12 days. Also, only 7 of 12 (58%) band-tailed pigeons collected at a natural mineral site in southwestern Washington on 11 June 2010 had active crop glands (T. A. Sanders, unpublished data). Thus, we hypothesize that Pacific Coast band-tailed pigeon appetite for sodium is increased during egg and crop milk production combined with a diet low in sodium content and high in moisture and potassium, and use of supplemental sodium is related to the availability of discrete and predictable sodium sources that facilitate social gatherings but is not critical for survival and reproduction. Goodwin (1983) reported on the benefits of congregational sites and flocking behavior to individual pigeons and doves.

Use of mineral sites by band-tailed pigeons during winter is generally not known to occur. However, a mineral site recently discovered in central California is the southernmost mineral site known to be used by band-tailed pigeons and the only site we know to be used in winter. Of the 12 pigeons collected there during 16–26 December 2010, all had inactive crop glands and food items consumed were acorns of canyon liveoak (*Quercus chrysolepis*) and berries of Pacific madrone (*Arbutus menziesii*; T. A. Sanders, unpublished data). Thus, non-nesting band-tailed pigeons apparently will congregate at and use mineral sites during winter if available and when consuming food items other than berries, but this behavior during winter is not well documented. Japanese green pigeons (*Treron sieboldii*) similarly are well known for drinking sodium water during the breeding season, but there is no record of them drinking sodium water during the non-breeding season (Osaka et al. 2011). These birds have a seasonal diet similar to band-tailed pigeons (primarily fruit during the breading season and acorns during winter), and mineral use is assumed related to need for sodium:potassium balance while consuming fruit.

MANAGEMENT IMPLICATIONS

Supplemental mineral sites can be created for band-tailed pigeons if necessary for the conservation and monitoring of this species. However, we recommend that managers do not create mineral sites unless they have a plan for regular maintenance to ensure sodium availability and sanitary conditions. Mineral sites created, protected, or where pigeons are counted to index abundance should periodically be sampled to verify sodium availability.

Managers should consider our results in development of survey protocols to index abundance of band-tailed pigeons based on pigeon counts at mineral sites to ensure efficient data collection and unbiased inference. To be comparable across space and time, counts should generally be conducted during a set time not shorter than daylight through noon and over a short period of days, preferably in July when adult pigeons are most frequent at mineral sites, immigration and emigration are low, and weather is generally consistently warm and dry. Index counts of band-tailed pigeons at mineral sites from sunrise to noon 1 day in July can be expanded to approximate pigeons in the area by accounting for pigeons missed at mineral sites when counting only through noon (count $\times$ 1.333) and considering the mineral site visitation rate ($\sim$once every 12 days). Thus, a count of 300 pigeons using supplemental mineral through noon during a single day in July, such as at our site, represents 4,759 ($300 \times 1.333 \times 11.9$) individual pigeons using the mineral site during that month.

We caution, however, that counts of pigeons consuming supplemental mineral at a mineral site is not synonymous with counts of pigeons at a mineral site, and could lead to bias in comparing counts at mineral sites in space and time. We detected and counted only pigeons using supplemental minerals, and therefore our results are applicable only to these birds. If pigeon counts are restricted to those using supplemental mineral sources, pigeons are not likely to be counted more than once as the duration of mineral use was generally ≤2 minutes, but pigeons may return to the mineral source if flushed from the site before adequate mineral consumption occurs.

Some band-tailed pigeons may not use mineral sites. Comparisons of counts of pigeons using mineral sites over years should not be biased as long as the proportion of the population that uses mineral sites does not change systematically. The physiological need for supplemental sodium by band-tailed pigeons should be investigated to allow counts of pigeons at mineral sites to be better interpreted and to ensure that comparisons of counts over space and time are unbiased.

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