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SCALE-DEPENDENT ASSOCIATIONS OF BAND-TAILED PIGEON COUNTS AT MINERAL SITES

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ABSTRACT—The abundance of Band-tailed Pigeons (*Patagioenas fasciata monilis*) has declined substantially from historic numbers along the Pacific Coast. Identification of patterns and causative factors of this decline are hampered because habitat use data are limited, and temporal and spatial variability patterns associated with population indices are not known. Furthermore, counts are influenced not only by pigeon abundance but also by rate of visitation to mineral sites, which may not be consistent. To address these issues, we conducted mineral site counts during 2001 and 2002 at 20 locations from 4 regions in the Pacific Northwest, including central Oregon and western Washington, USA, and British Columbia, Canada. We developed inference models that consisted of environmental factors and spatial characteristics at multiple spatial scales. Based on information theory, we compared models within a final set that included variables measured at 3 spatial scales (0.03 ha, 3.14 ha, and 7850 ha). Pigeon counts increased from central Oregon through northern Oregon and decreased into British Columbia. After accounting for this spatial pattern, we found that pigeon counts increased $12\% \pm 2.7$ with a 10% increase in the amount of deciduous forested area within 100 m from a mineral site. Also, distance from the mineral site of interest to the nearest known mineral site was positively related to pigeon counts. These findings provide direction for future research focusing on understanding the relationships between indices of relative abundance and complete counts (censuses) of pigeon populations by identifying habitat characteristics that might influence visitation rates. Furthermore, our results suggest that spatial arrangement of mineral sites influences Band-tailed Pigeon counts and the populations which those counts represent.

Key words: Band-tailed Pigeon, counts, distribution, habitat, index, mineral sites, Pacific Northwest, *Patagioenas fasciata monilis*, populations

Long-term data from the Breeding Bird Survey (1966–2000) and other species-specific surveys indicated a $\geq 2\%/y$ decline in indices of Band-tailed Pigeon (*Patagioenas fasciata monilis*) abundance within populations of the Pacific Coast (Jeffrey 1989; Casazza and others 2005; Sauer and others 2005). In 1994, research needs for pigeons were defined by the Pacific Coast Band-tailed Pigeon subcommittee and others (Braun 1994; Western Migratory Upland Game Bird Technical Committee 1994). Studies to develop pigeon surveys and to examine the effects of environmental factors on population abundance were considered high priority. The

few studies which have attempted to identify pigeon habitat by linking environmental factors to Band-tailed Pigeon abundance have occurred only at regional scales (Keppie and others 1971; Jeffrey 1989; Sanders and Jarvis 2003). Because pigeons are generalists that inhabit forested ecosystems, patterns in resource selection or abundance have been challenging to identify using different survey methods. In western Oregon, environmental factors were not linked to pigeon counts at points, and pigeons did not seem to be limited by the availability of potential nesting and foraging cover (Sanders 1999). Additionally, no effect of tree stand type (for instance coniferous) on pigeon abundance in Washington was detected using call counts (Jeffrey 1989). Call count routes provide limited knowledge and are biased by differences in the

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ability of observers to detect calls between habitat types (Keppie and others 1971).

The Pacific Coast subspecies of Band-tailed Pigeon frequents discrete mineral sources such as sea water and hot springs, which are thought to be areas pigeons use to consume sodium as a dietary supplement, especially during the breeding season (Neff 1947; Smith 1968; Passmore 1977; Jarvis and Passmore 1992; Keppie and Braun 2000; Sanders and Jarvis 2000). Mineral sites are widely dispersed in the Band-tailed Pigeon breeding range in the Pacific Coast region, but have not been documented to limit relative population abundance (Sanders and Jarvis 2003). Mineral site surveys provide the greatest potential to monitor breeding populations over a wide area and detect short-term population trends (Casazza and others 2005).

Despite the potential of mineral site surveys to inform Band-tailed Pigeon population trends, mineral site use by Band-tailed Pigeons remains poorly understood. Some evidence indicates that the amount of forest that surrounds a mineral site is associated with long-term use of that site by pigeons (Overton and others 2006). The effects of seasonal and climatologic factors on mineral survey counts of pigeons visiting mineral sites have also been investigated (Casazza and others 2005; Overton and others 2005). However, the link between counts and population abundance remains elusive, because population estimates have not been attempted independently of mineral site counts, and the rate of visitation to mineral sites may or may not be consistent between sites.

Here we describe the relationship of counts of Band-tailed Pigeons at 20 non-randomly selected mineral sites in the Pacific Northwest to landscape and local environmental factors. Our objective was to develop models of Band-tailed Pigeon counts from mineral sites as a response to biologically relevant environmental factors measured at multiple spatial scales. An understanding of factors (such as tree canopy cover at a mineral site) that affect counts will be useful to inform decisions to adaptively manage and conserve Band-tailed Pigeon populations.

METHODS

We conducted surveys at 20 mineral sites in 4 regions of the Pacific Northwest at elevations

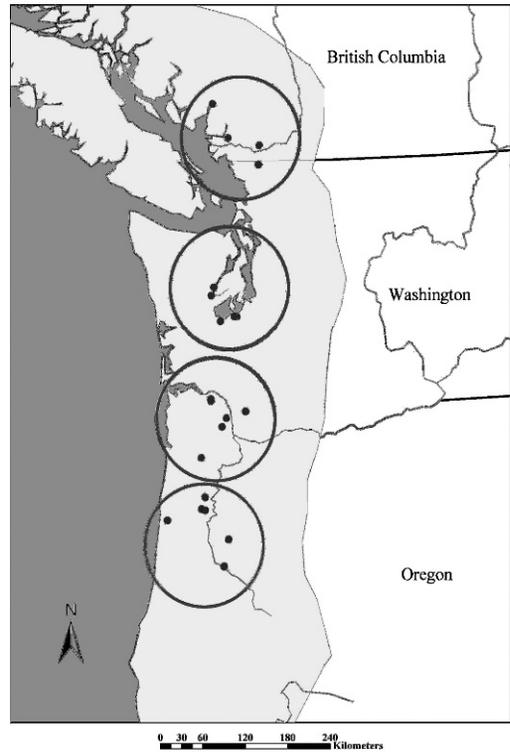


FIGURE 1. Four regions of mineral sites in the Pacific Northwest. Shaded area represents distribution of the Pacific Coast subpopulation of Band-tailed Pigeon. Dots denote location of mineral sites.

ranging from sea level to >300 m (Fig. 1). These sites were in the Coast Ranges and Cascade Range of Washington and Oregon, the Willamette Valley in Oregon, and the Puget Sound lowlands of Washington. In British Columbia, sampled mineral sites were located in the southwestern region of the lower mainland, and the Pacific and Cascade Ranges. In Washington and Oregon, vegetation at mineral sites included Sitka Spruce (*Picea sitchensis*) and Western Hemlock (*Tsuga heterophylla*) in ecoregions of Willamette Forest-Prairie and Cascade Subalpine. These ecoregions are subjected to human land-use activities including logging, agriculture, and urbanization. Annual precipitation averaged >121 cm/y, and winters are mild and wet while summers were dry and cool (Highsmith and Kimerling 1979).

Mineral sites occurred naturally ($n = 15$; beaches, estuaries, and mineral springs) or were artificially created as artesian wells during natural gas exploration ($n = 3$), or associated

with waste material and settling ponds from paper production ($n = 2$). We used 2 criteria to select mineral sites: logistically accessible for repeated counts, and moderate to high use by pigeons. As such, our findings may not adequately represent all Pacific Northwest mineral sites.

We recorded the number of Band-tailed Pigeons every 3 to 7 d as they arrived at mineral sites during 15 June to 30 July of 2001 and 2002. We chose this period to avoid variability in pigeon counts which occurs during months of fall and spring migration (Casazza and others 2005). Counts were conducted from the onset of morning civil twilight (approximately 30 min before sunrise) until noon using binoculars and spotting scopes from fixed concealed areas that were located >50 m from the mineral site. We excluded counts that were conducted during periods of >1.5 h of rainfall or periods of heavy fog from our analyses.

We measured habitat characteristics at 4 spatial scales: source-specific (0.03 ha), local (3.14 ha), home range (7850 ha), and broad (40,000 ha). At the source-specific scale, we measured microhabitat factors within 10 m (0.03 ha) of the mineral source. The local scale encompassed habitat factors that were measured on the ground within 100 m (3.14 ha) of the mineral site. At the source-specific and local scales, we identified boundaries using a 100-m tape measure, and canopy cover and species composition were obtained from *ad hoc* visual estimation after a thorough examination of the site. Vegetation density was estimated using a coverboard viewed 10 m from the mineral site (Nudds 1977). Vegetation height was measured using a tape measure on maximum droop height, where it was feasible, and a clinometer was used for taller vegetation. We chose to measure habitat at a home range scale of 78.5 km² (7850 ha), based on literature of the average of home range sizes during the breeding season (Casazza and others 2001). Because the mineral site may not be the center point of each home range, it is likely that not all home ranges were encompassed entirely at this scale. Therefore, we examined environmental factors at a broader scale (40,000 ha) to increase the likelihood of encompassing all home ranges of pigeons that visited the counted mineral site.

To measure habitat characteristics at home range and broad scales, we used a geographic

information system (GIS) database of dominant vegetation attributes (hereafter landcover). This database was generated using the Gap Analysis Program (GAP) and Broad Ecosystem Inventory (BEI) of the Pacific Northwest (Crist and Jennings 1997; Resources Inventory Committee 1998). First, we used 100-ha minimum mapping units to classify landcover into 7 categories: Coniferous, Deciduous, and Mixed Type dominated forest; and Harvested/Disturbed Forestland, Agricultural/Grassland, Urban, and Water. GIS analyses were carried out using the Patch Analyst and Spatial Analyst extensions (McGarigal and Marks 1995; Rempel and others 1999) in ArcGIS 8.2 and ArcView 3.2 (Environmental Systems Research Institute, Redlands, CA).

We included landcover area and evenness indices in home range and broad scale measurements. We used Shannon's Evenness Index (SHEI) (Magurran 2004) at the home range scale and broad scale. SHEI was zero with only 1 patch (complete dominance of a single landcover) and this metric approaches 1 as multiple habitat types are more equal in area. We used the FRAGSTATS utility in the Patch Analyst Extension (McGarigal and Marks 1995) to conduct calculations. We did not obtain SHEI from local and source-specific scales because the resolution of the GAP and BC-BEI products were too coarse a scale to carry out calculations. We evaluated whether or not counts of Band-tailed Pigeons using mineral sites varied predictably by latitude (using the UTM Zone 10 Northing coordinate, NAD27), quantified as linear and quadratic. The coordinate variables were also excluded to determine if counts varied only with the habitat characteristics. We also included Euclidean distance from the mineral site of interest to the nearest known mineral site.

We chose habitat factors at each spatial scale based on the literature or biological rationale (Table 1). We conducted an exploratory analysis (Burnham and Anderson 1998) by developing a set of candidate models that included combinations of variables in each model. We did not include more than 2 habitat variables in any one model to avoid over-fitting a model, because our dataset was limited and this technique allowed for straightforward interpretation of model results. The exploratory approach was

TABLE 1. Description of explanatory variables used to develop models of Band-tailed Pigeon abundance at source-specific (SS) (0.03 ha), local (L) (3.14 ha), home range (HR) (7850 ha), and broad (B) (40,000 ha) scales in the Pacific Northwest during 2001 and 2002.

Explanatory variable ^a	Description	Scale			
		SS	L	HR	B
EVEN	Shannon's evenness index (0–1)			X	X
CF*	Coniferous forest		X	X	X
DF*	Deciduous forest		X	X	X
MF*	Mixed forest		X	X	X
FO*	Total forest		X	X	X
NF*	Non-forested land		X	X	X
AG*	Agriculture areas and grassland		X	X	X
URB*	Urban areas		X	X	X
WTR*	Amount of water		X	X	X
CC	Canopy c over at mineral site (%)	X			
TRCC	Canopy cover at trees near site (%)	X			
VCB	Vegetation cover board at mineral site (%)	X			
TYPE	Type of source (spring, estuary, artificial)	X			
PERCH	Distance from edge to perch site (m)	-	-	-	-
NEAR	Distance from site to nearest mineral site (km)	-	-	-	-

^a Variables denoted with asterisks were measured as percent cover at the local scale and number of ha at the home range and broad scales.

appropriate because factors that influence pigeon counts were not known prior to this study and, thus, many combinations of variables were biologically feasible. Also, Band-tailed Pigeons are known to be generalists in selecting forage and nesting sites at regional scales (Sanders and Jarvis 2003). Thus, the most parsimonious models identified here will provide a basis for predicting pigeon counts and could subsequently be challenged by specific theoretical models.

We estimated model parameters and derived information criterion using generalized mixed effect model analyses in Program R (specified Gaussian error distribution; package 'lme4', Bates 2007; R Development Core Team 2008). A logarithm transformation was used to meet the assumptions of normality (Gaussian error distribution). We treated year and study site as random effects (Littell and others 1998) to avoid biases associated with pseudoreplication. Also, we treated latitude as a fixed effect to estimate the slope coefficient while accounting for possible confounding effects on other fixed effect factors. We also treated ordinal date (days elapsed from 01 January of each year) as a fixed effect for each model under consideration. Because not all models have the same fixed effects, full maximum likelihood estimation was used to compare information criteria robustly among models. We did not include explanatory variables that showed evidence of correlation (>0.6 Pearson's correlation coefficient) in the

same model to avoid multicollinearity (Ramsey and Schafer 1997).

To evaluate models, we calculated Akaike's Information Criterion adjusted for small sample sizes (AIC_c), model probabilities (w_i), and evidence ratios (w_i/w_j) (Anderson 2008). We used model averaging because information in models ranked below the best model is useful to appropriately estimate parameters (Anderson 2008). Thus, we calculated average parameter estimates and their 95% confidence intervals. We calculated the relative importance of each factor (parameter likelihood) because each variable was equally represented within the model set. Values are reported as means \pm SE.

We chose to eliminate the broad spatial scale in our final candidate model set because habitat characteristics (such as deciduous forest) were highly correlated between home range and broad scales (Pearson's correlation coefficients ranged from 0.7–0.97) and all variables between scales were the same. Thus, variables were redundant and may have produced multicollinearity effects. Our rationale for retaining home range scale was based on results of comparing models at both scales. We did this in 2 steps. First, we calculated evidence ratios (w_i/w_j) for all models at each scale. For example, ratio of deciduous forest at the home range scale was calculated as the weight of deciduous forest at the home range scale divided by weight of deciduous forest (ha) at the broad scale. Second,

TABLE 2. Total mineral site counts (n) and mean number of Band-tailed Pigeons counted during 15 June to 30 July at 20 mineral sites in the Pacific Northwest during 2001 and 2002.

Year	Region	Full ^a			Restricted ^b		
		n	Mean	SE	n	Mean	SE
2001	Central Oregon	19	231.6	16.1	19	231.6	16.1
	Northern Oregon	11	305.0	58.6	11	305.0	58.6
	Washington	28	125.7	11.1	5	170.6	49.6
	British Columbia	8	101.3	14.1	8	101.3	14.1
	Total	66	183.2	14.7	43	219.0	20.1
2002	Central Oregon	36	173.2	11.0	36	173.2	11.0
	Northern Oregon	15	282.0	36.6	15	282.0	36.6
	Washington	23	125.9	11.4	6	104.0	22.0
	British Columbia	10	124.6	15.7	10	124.6	15.7
	Total	84	173.9	10.5	67	184.1	12.5

^a Full data set used 20 mineral sites to compare models between home range and broad scales.

^b Restricted data set used 15 mineral sites to compare models among source-specific, local, and home range scales.

we counted all models with values >1 within each scale. We counted 3.9 times more models that were supported better by the data at the home range scale than at the broad scale. Because we did not measure source-specific and local scale habitat data at 5 sites, we used a restricted data set to include models with variables from all scales. It was appropriate to use the full data set to compare home range and broad scale because it contained more information at these scales. Therefore, our final set of candidate models contained 3 scales: source-specific, local, and home range; and the models were evaluated using a restricted data set.

RESULTS

We conducted 66 and 84 mineral site counts in 2001 and 2002, respectively, and these counts yielded a combined average of 177.9 ± 8.7 pigeons (Table 2). The central and northern Oregon regions had the highest counts each year, but these counts declined from 2001 to 2002; whereas counts in Washington remained

the same (full mean) or decreased (restricted mean), and those in British Columbia increased (Table 2).

The most parsimonious model contained the Northing covariate (quadratic function) and percent of deciduous forest at the local scale (Table 3). The model probability (w_1) was 0.70 and no other models resulted in $\Delta\text{AICc} < 2$. This model had 1635 times the strength of evidence relative to the null model (w_1/w_{null}). Therefore, this model showed substantial empirical support from the data. The quadratic effect was explained by counts of birds that increased from central Oregon through northern Oregon and decreased into British Columbia.

We calculated a likelihood value of 74% for the deciduous forest (local scale) variable as the most important habitat variable of those considered (Table 4). We found that pigeon counts increased $12\% \pm 2.7$ with a 10% increase in deciduous forest canopy coverage at the local scale. Deciduous forest was present within 100 m of 8 mineral sites and accounted for as

TABLE 3. Generalized linear mixed models of environmental factors and spatial characteristics explaining counts of Band-tailed Pigeons at mineral sites in the Pacific Northwest during 2001 and 2002. Only models with $\Delta\text{AICc} \leq 8.0$ are presented.

Model ^a	K ^b	AICc	ΔAICc	w^c	E^d
POS ² + DF (local scale)	7	104.6	0.0	0.70	1.0
POS ² + DIST	7	108.2	3.6	0.12	6.1
POS ² + DF (local scale) + TYPE	8	112.1	7.5	0.02	42.5
POS ² + DF (home range scale)	7	112.3	7.7	0.01	46.9

^a Abbreviations: POS² = Northing coordinate (UTM) of the mineral site (quadratic effect); DF = % of deciduous forest; DIST = distance to nearest known mineral site; and TYPE = type of mineral site (spring, estuary, or artificially created). Additionally, ordinal date was included as a fixed effect and year and mineral site were included as random effects (intercepts) in all models.

^b K denotes the number of parameters estimated in the model.

^c w represents Akaike's weight, which is the probability of best-approximating model (Anderson 2008).

^d E_j represents the strength of evidence (w_j/w_1) of the most parsimonious model (w_1) compared to the model of interest (w_j).

TABLE 4. Parameter estimates, confidence intervals, and relative importance of explanatory variables used to model Band-tailed Pigeon abundance at mineral sites in the Pacific Northwest during 2001 and 2002.

Explanatory Variable ^a	Estimate ^b	LCI (95%) ^c	UCI (95%) ^c	Likelihood ^d
DF (100m)	0.1156	0.0625	0.1687	0.74
DIST	0.0287	0.0122	0.0451	0.13
TYPE	-0.5882	-0.1857	-0.9907	0.03

^a Abbreviations: DF = percent of deciduous forest; DIST = distance to nearest known mineral site; and TYPE = type of mineral site (spring, estuary, or artificially created).

^b Averaged parameter estimate across all models and corrected using Akaike's weights (w_i) (Anderson 2008).

^c Averaged lower (LCI) and upper (UCI) 95% confidence intervals across all models corrected using Akaike's weights (w_i) (Anderson 2008).

^d Parameter likelihood is the relative importance of the explanatory variable in the presence of other variables, calculated by summing model weights of models that consisted of the variable of interest (Burnham and Anderson 1998).

high as 80% of the landcover surrounding an individual mineral site.

A 2nd model with less empirical support within the candidate set contained the Northing variable (quadratic function) and distance to nearest mineral source ($\Delta AIC_c = 3.6$). The 1st model was 6 times (w_1/w_2) more likely to be the best-approximating model compared to the 2nd model (Table 3). The 2nd model, however, had 270 times the strength of evidence (w_2/w_{null}) relative to the null. We found that pigeon counts increased approximately $3\% \pm 0.08$ with a 1 km increase in distance to another mineral source. The likelihood that distance from nearest mineral source was the most important variable of those considered was 13%.

A model that consisted of Northing (quadratic function), deciduous forest (%) (local scale), and type of mineral source (spring or estuary) had slight evidence ($\Delta AIC_c = 7.5$). This model differed from the 1st model by including a variable for the type of mineral source. Mean counts at estuaries were 147.6 ± 17.5 , and mean counts at springs were 211.1 ± 12.8 . Model 1, however, was 42.5 times more likely to explain variation in mineral counts than model 3. All other models lacked support from the data.

DISCUSSION

Counts of Band-tailed Pigeons visiting mineral sites are used to index population change in the Pacific Coast population using route regression methods (Casazza and others 2005). This technique does not rely on the assumption that visitation rates are constant across mineral sites, but quantification of relative or absolute abundance between sites does require visitation rates to be constant. While our work does not address whether or not visitation rates are constant, the

covariates latitude and distances between mineral sites in our best-approximating models likely operated independently of visitation (representing abundance).

The strong quadratic Northing effect that we observed in Band-tailed Pigeon counts across the Pacific Northwest explains why a consistent trend has not been detected at smaller spatial scales (Jeffrey 1989; Jarvis and Passmore 1992; Sanders 1999). Other survey methods may not have covered sufficient area to elucidate a pattern in abundance in a north to south gradient, given weak effects over relatively small areas. The wide geographic area used in this study provides valuable knowledge of how relative abundance of pigeons varies across the Pacific Northwest. The estimated Northing effect from northern Oregon to southern Oregon, however, does not appear to extend southward, as substantial numbers of Band-tailed Pigeons were counted at mineral sites in northern California (Casazza and others 2005). Consistent with our findings, the Breeding Bird Survey indicated similar trends in population numbers range-wide using route regression analysis (Fig. 2; from Sauer and others 2008). While we assume the predicted latitudinal effect represents Band-tailed Pigeon abundance, which likely resulted from dispersal of birds throughout their breeding range, our ability to infer this relationship is limited. It is possible that specific resources (such as food availability) that also vary with latitude confounded the latitudinal gradient of our abundance indices. For example, specific forage resources could necessitate increased visitation rates to mineral sites by pigeons due to increased ion imbalance, suspected as being a primary reason Band-tailed Pigeons visit mineral sites (Sanders and Jarvis 2000). Measuring mineral content and

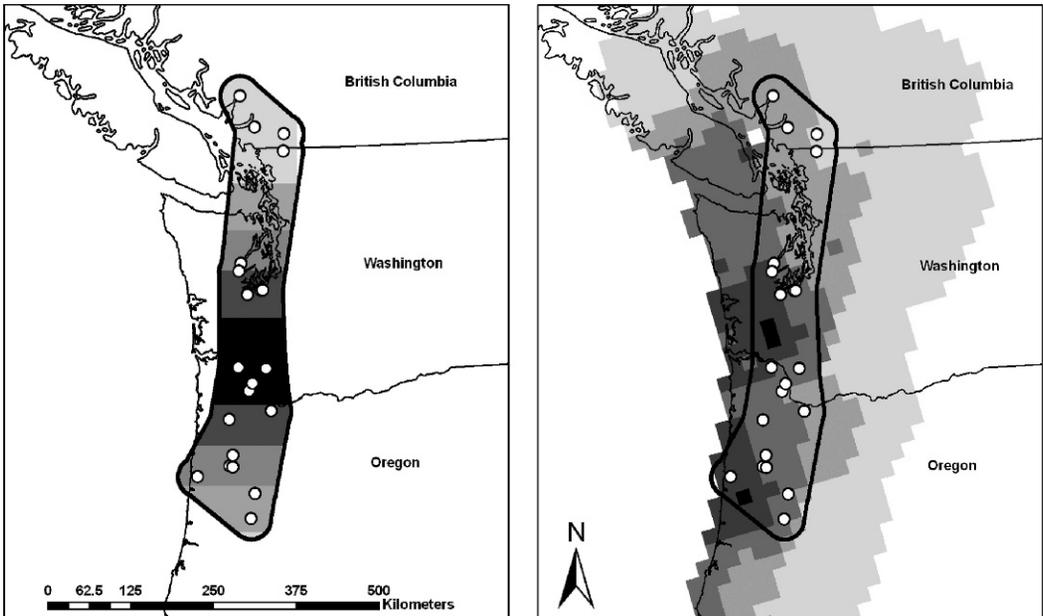


FIGURE 2. The estimated latitudinal pattern in number of Band-tailed Pigeons counted at mineral sites [left] shows a similar pattern over the extent of mineral sites counted as indices of pigeons detected during the Breeding Bird Survey [right] (Sauer and others 2005). Darker areas represent higher detection frequency or larger mineral site counts.

other diet components, however, were beyond the scope of our study. Research that compares our most parsimonious models with those that contain mineral content and other diet components would refine our knowledge by potentially providing further explanation to variation in mineral site counts, and provide insight into influence on visitation rates. Nevertheless, the corroboration of our results and the independent North American Breeding Bird Survey results, which were not affected by needs of pigeons at mineral sites, taken together suggests that the quadratic trend was indeed a function of Band-tailed Pigeon abundance. Research that estimates population density parameters of pigeons across the Band-tailed Pigeon range would be helpful.

The association between counts and distance to the nearest mineral site may be explained by the amount of available nesting habitat around mineral sites during June and July. Band-tailed Pigeons likely visit mineral sites that are closest to their nesting areas (Leonard 1998). Therefore, mineral sites that are farther apart likely attract pigeons from a wider area, which provides a larger available population per site than mineral

sites that are close together. However, the observed positive association between counts and distance to the nearest adjacent mineral site suggested that the distribution of mineral sites may have affected the distribution or movement of pigeons, a finding that has not been evident in other research (Sanders and Jarvis 2003). Given that pigeon counts increased 3%/km from the mineral site of interest to the nearest mineral site, and their typical home range was reported as approximately 50 km² (Casazza and others 2001), the distance effect appears to be limited. In other words, pigeons may not travel beyond a certain distance to visit mineral sites, although they are capable of traveling >27 km/d (Leonard 1998). We did not evaluate such threshold levels or non-linear associations, which could provide additional insight into pigeon distribution.

It is possible that not every available mineral site was accounted for in our study, which may have biased the estimated effect size to be low (Type II error). Although considerable efforts to discover mineral sites in northwestern Oregon were carried out, efforts in British Columbia and Washington were less rigorous and likely

missed active mineral sites (Kraege, Washington Department of Fish and Wildlife, unpubl. report). Additional data, therefore, are needed on the distribution and abundance of Band-tailed Pigeons in relation to the distribution of mineral sites, especially in Washington and British Columbia.

The major limitation in using counts of Band-tailed pigeons to estimate abundance is the possible confounding effects of variation in visitation rates. For example, if visitation rates are not constant across sites, then visitation rates may at least partly explain differences in counts. The amount of deciduous forest at the scale that we found to be influential (local scale) more likely represented differences in visitation rates rather than abundance of the population. Because pigeon populations function at a much larger scale than the local scale defined in our study, it is unlikely that the amount of deciduous trees influenced abundance. Thus, greater amounts of deciduous forest at the local scale may attract pigeons to the vicinity. Furthermore, the stronger support for a model with deciduous forest at the local scale compared to one at larger scales indicated that pigeons are attracted to patches of deciduous forest across the landscape.

We hypothesize that these deciduous patches are a proxy for other ecological factors that influence visitation rates. One plausible explanation is that deciduous trees, such as Red Elderberry (*Sambucus racemosa*) and Cascara Buckthorn (*Rhamnus purshiana*), provide primary summer foods for Band-tailed Pigeons in the Pacific Northwest (Jarvis and Passmore 1992; Leonard 1998; Sanders 1999). Band-tailed Pigeons often flock together when feeding and when visiting mineral sites (Neff 1947; Smith 1968; Curtis and Braun 2000). Therefore, mineral sites with adjacent forage may attract pigeons, resulting in higher counts than areas with a smaller amount of adjacent deciduous forest.

While local characteristics probably play the greatest role in affecting visitation rates, landscape-level factors are more likely to affect abundance. Band-tailed Pigeons feed almost exclusively on a single food source until it is depleted (Neff 1947; Smith 1968; Keppie and Braun 2000). The generalist feeding behavior and high mobility of the Band-tailed Pigeon suggest that low to moderate habitat fragmen-

tation may not affect abundance. The distribution and amount of foraging habitat during the nesting season, however, may influence relative abundance at mineral sites. Forested habitat loss or fragmentation has been implicated in abandonment of mineral sites (Overton and others 2006), but this would not necessarily translate to lower counts of pigeons at active mineral sites. Analysis of the persistence of mineral sites included only a large dataset of sites in Oregon and did not include a latitudinal effect in the modeling (though distance between mineral sites was included). Additionally, only large-scale variables were used to model persistence. The widespread distribution of Band-tailed Pigeons throughout the Pacific Northwest coupled with the pigeon's ability to fly long distances demonstrates that pigeons can alternate between mineral sites.

The relative lack of support for models containing large-scale habitat characteristics is consistent with prior research that identified Band-tailed Pigeons as forest generalists. The relatively large minimal mapping unit in the GIS data layers precluded analysis of the association of small-scale habitat features such as forest gaps, young stands, and small clearcuts with pigeon counts. Feeding areas in Oregon are commonly found in such areas, where openings in the canopy allow fruit and mast-bearing shrubs to grow in large patches (Leonard 1998). Similarly, the thematic resolution of the data did not allow us to evaluate stand age, which has been associated with the calling rate, and presumably abundance, of Band-tailed Pigeons (Keppie and others 1971). Remotely-sensed data of a finer resolution, such as aerial photos, may be more appropriate to assess the impact of forage availability or stand age on the abundance of Band-tailed Pigeons. Silviculture practices influence the distribution of the forage plants that Band-tailed Pigeons use (Hansen and others 1991; Braun 1994); of special concern is the effect of herbicide treatments that reduce broadleaf species, as this can adversely affect forage-bearing plants (Jarvis and Passmore 1992; Braun 1994; Western Migratory Upland Game Bird Technical Committee 1994; Keppie and Braun 2000). The effect of availability and distribution of forage on distribution and local abundance of Band-tailed Pigeons should be directly investigated.

In conclusion, we recommend preserving the integrity of the mineral areas as integrated habitat areas of Band-tailed Pigeons. Trees and shrubs that can be found in patches of deciduous forest likely provide important food sources for Band-tailed Pigeons during the nesting period, and ion consumption at nearby mineral sites may prevent electrolyte imbalance following foraging bouts. The use of herbicides to control deciduous trees and shrubs may conflict with management for Band-tailed Pigeons when it reduces food-producing plants (Hansen and others 1991; Braun 1994). Furthermore, perch availability may be another factor influencing visitation rates, as deciduous trees near mineral sites are often used for perching (Pacific Flyway Council 2001). Although counts of Band-tailed Pigeons at mineral sites provide important population abundance indices for managers, estimates are reliable only when accounting for variation in visitation rates. Sources of potential variation in visitation rates include regional (available forage and phenology), source-specific (ion content or disturbance factors), or temporal (relation to breeding status or rainfall) factors (Overton and others 2005). Additional research that identifies the degree and cause of this variation would be beneficial. Our results suggest that latitudinal changes and mineral site positions influence count numbers and are likely to be reflected in population abundance. Establishment of new artificial mineral sites may be used to investigate these trends and provide additional population change index values for managers. Future research should address the role of deciduous forest as a factor influencing Band-tailed Pigeon visitation rates at mineral sites with the goal of establishing population abundance estimates from the current index values used to track population change.

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