RESEARCH ARTICLE

Linking Landscape Characteristics to Mineral Site Use by Band-Tailed Pigeons in Western Oregon: Coarse-Filter Conservation with Fine-Filter Tuning

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ABSTRACT: Mineral sites are scarce resources of high ion concentration used heavily by the Pacific Coast subpopulation of band-tailed pigeons. Over 20% of all known mineral sites used by band-tailed pigeons in western Oregon, including all hot springs, have been abandoned. Prior investigations have not analyzed stand or landscape level habitat composition in relation to band-tailed pigeon use of mineral sites. We used logistic regression models to evaluate the influence of habitat types, identified from Gap Analysis Program (GAP) products at two spatial scales, on the odds of mineral site use in Oregon (n = 69 currently used and 20 historically used). Our results indicated that the odds of current use were negatively associated with non-forested terrestrial and private land area around mineral sites. Similarly, the odds of current mineral site use were positively associated with forested and special status (GAP stewardship codes 1 and 2) land area. The most important variable associated with the odds of mineral site use was the amount of non-forested land cover at either spatial scale. Our results demonstrate the utility of meso-scale geographic information designed for regional, coarse-filter approaches to conservation in fine-filter investigation of wildlife-habitat relationships. Adjacent landcover and ownership status explain the pattern of use for known mineral sites in western Oregon. In order for conservation and management activities for band-tailed pigeons to be successful, mineral sites need to be addressed as important and vulnerable resources. Management of band-tailed pigeons should incorporate the potential for forest management activities and land ownership patterns to influence the risk of mineral site abandonment.

Index terms: band-tailed pigeon, multi-scale analysis, Oregon, *Patagioenas fasciata* Say, wildlife-habitat relationships

INTRODUCTION

The band-tailed pigeon of the Pacific Coast (*Patagioenas fasciata monilis* Say) uses discrete areas of high mineral concentration, especially during the breeding season (Neff 1947, Smith 1968, March and Sadlier 1972, Jarvis and Passmore 1992, Sanders and Jarvis 2000). These mineral sites (e.g., estuaries, mineral springs, hot springs, etc.) are visited by band-tailed pigeons regularly and appear to provide a social function as well as satisfy physiological needs (Jarvis and Passmore 1992, Sanders 1999). Although necessary for egg and crop milk production, calcium concentrations were highly variable at mineral sites and there is no evidence of a calcium deficiency in breeding band-tailed pigeons (March and Sadlier 1970, 1972; Sanders and Jarvis 2000). Sodium was the only consistently abundant mineral found in sites frequented by band-tailed pigeons (Sanders and Jarvis 2000). Additionally, band-tailed pigeons in Oregon were found to feed mostly on fruits containing large amounts of potassium (Sanders and Jarvis 2000). Potassium: sodium cation imbalance may be a causal factor necessitating ion intake at mineral sites, but this theory has not been fully tested (Sanders and Jarvis 2000).

Current methods of indexing band-tailed pigeon population change indicate long-term declines throughout the species' Pacific Coast breeding range (Casazza et al., in press). Coincident with this decline has been the abandonment of several mineral sites in Oregon (T. Sanders, Oregon State University, unpubl. data). Local (small scale) disturbances have been implicated as the proximate cause of abandonment for some of these sites and include anthropogenic habitat change through forest conversion or urbanization (one site was flooded through the creation of a reservoir), as well as "natural" habitat change such as tree fall (R. Jarvis, Oregon State University, pers. comm.). However, landscape (large scale) characteristics associated with abandoned mineral sites have not been investigated. An understanding of the landscape context associated with mineral site use and persistence is needed. To address this need, we developed logistic regression models predicting mineral site use by band-tailed pigeons in relation to landcover types and land stewardship information at multiple scales.

Conservation and maintenance of rare habitat types/elements are important for the maintenance of regional biodiversity (Noss 1987, Noss et al. 1995). Regional approaches to conservation are becoming more viable as large-scale analyses become technologically feasible (Scott et al. 1996, Scott and Csuti 1997). The Gap

Analysis Program (GAP), administered by the U.S. Geological Survey (USGS), has coordinated an effort to map current vegetation cover types, vertebrate species distributions, and the degree of biodiversity protection established under current land management practices (Crist 2000). The goals of GAP are to identify ecologically important areas that are not adequately represented in the current system of protected areas (reserves and parks) in the United States (Scott et al. 1993, Jennings 2000). Land use and conservation planning utilizing GAP information often rely on a mixture of coarse-filter and fine-filter strategies (Scott et al. 1999, Jennings 2000). However, the spatial scale at which GAP products are analyzed is often too coarse to identify specific and diffuse resources (e.g., mineral sites) that are critical for individual species.

Modeling associations between mineral site use and landscape-level habitat characteristics (i.e., GAP products) merge both fine-filter (mineral site/resource use) and coarse-filter (landscape associations) approaches to conservation and regional land use planning. Results from this approach provide land use planners information regarding the effect of land use activities on band-tailed pigeon use of mineral sites. By identifying landscape-level characteristics associated with persistent use of specific resources, we identified regions with relatively favorable ecological conditions. Change in land use can be used to predict change in probability of mineral site use. These results can be used to formulate effective conservation actions to maintain existing sites or protect endangered ones and establish efficient long term monitoring programs.

METHODS

Mineral site database

Since the 1950s, records of mineral sites used by band-tailed pigeons in Oregon have been maintained by the Oregon Department of Fish and Wildlife (Morse 1950). Investigation of mineral sites in Oregon during the 1990s resulted in a database of 101 mineral sites known or suspected of being visited by band-tailed pigeons either currently or historically. Sites recorded as potentially used were investigated during the summers of 2001 and 2002; new information on previously unknown mineral sites was also recorded. Documentation of band-tailed pigeons concentrating at a mineral site during the previous five years constituted current use. Five years was used as a cutoff to classify band-tailed pigeon use in order to include the most recent systematic survey of mineral sites. Mineral sites where use was not adequately determined were excluded from analysis due to uncertainty in classification. A final list of 69 currently used and 20 historically used mineral sites was included in our analysis. Known mineral sites in western Oregon occur predominately in the northern portion of the state at lower elevations. These 89 sites represent the most complete list of known mineral sites in Oregon for which use and/or abandonment by band-tailed pigeons has been confirmed.

Four historically used mineral sites located in the high Cascades near large wilderness areas were classified as hot springs (Figure 1). All four hot springs had generally high levels of modification for human use. Because band-tailed pigeons in Oregon are not known to currently use hot springs as a mineral source, model selection techniques could not use this mineral source type to distinguish between current and historical use. Due to the unique human value placed on these hot springs and the potential high level of disturbance to wildlife, use by band-tailed pigeons was considered separately for all other mineral sources, resulting in 85 sites used for our analysis.

GIS database, GAP landscape variable generation

A geographic information system (GIS) database of dominant vegetative attributes (hereafter landcover) was generated using GAP products for Oregon, Washington, and Idaho (USGS Gap Analysis Program). The original landcover data layer contained at a resolution of 30 m and minimum mapping units ranging from 40 to 100 ha (Karl et al., unpubl. data). The 40 original GAP landcover classifications were reclassified into eight biologically relevant categories: coniferous, deciduous, and mixed type dominated forest, harvested/disturbed forestland, agriculture/grassland, urban, water, and other (includes shrub land, lava flows, glaciers, mud flats, etc.). Final landcover data layers contained eight landcover types in 100 ha minimum mapping units. Reclassification allowed us to compare mineral sites in differing physiographic regions and reduced the spatial dependency associated with rare or highly localized landcover types, thus eliminating the probability of falsely characterizing the importance or unimportance of distinct, but functionally similar, landcover types (Diniz-Filho et al. 2003). We also used land stewardship data layers developed by GAP, which describe four ownership patterns based on the relative protection afforded by management activities. Original classifications were determined from Landsat imagery obtained in the early 1990's (Cassidy 1997, Kagan et al. 1999) and corresponded with prior investigations into mineral site use by band-tailed pigeons (Sanders 1999). Our approach was to investigate current landcover and stewardship characteristics, and we surmised that available habitat classifications were generated at a suitable period to use in this modeling effort. All data manipulation was performed using ARCGIS 8.2 and ArcView 3.2 software, with the PatchAnalyst extension (Environmental Systems Research Institute, Redlands, California; Rempel and Carr 2003).

Landcover and stewardship characteristics were described at two spatial scales around mineral sites. A 5 km radius (~7800 ha) was selected to approximate home range sizes for band-tailed pigeons during the breeding season (Casazza et al., unpubl. data). This scale is expected to describe the landscape available for most birds visiting a mineral site, and will be referred to as the home range scale. A 10 km radius (31,400 ha) described the landscape at a scale larger than home range and will be referred to as the broad scale. The broad scale is expected to describe the landscape to a larger spatial extent than actually used by most birds visiting a mineral site and may, in comparison to the home range scale,

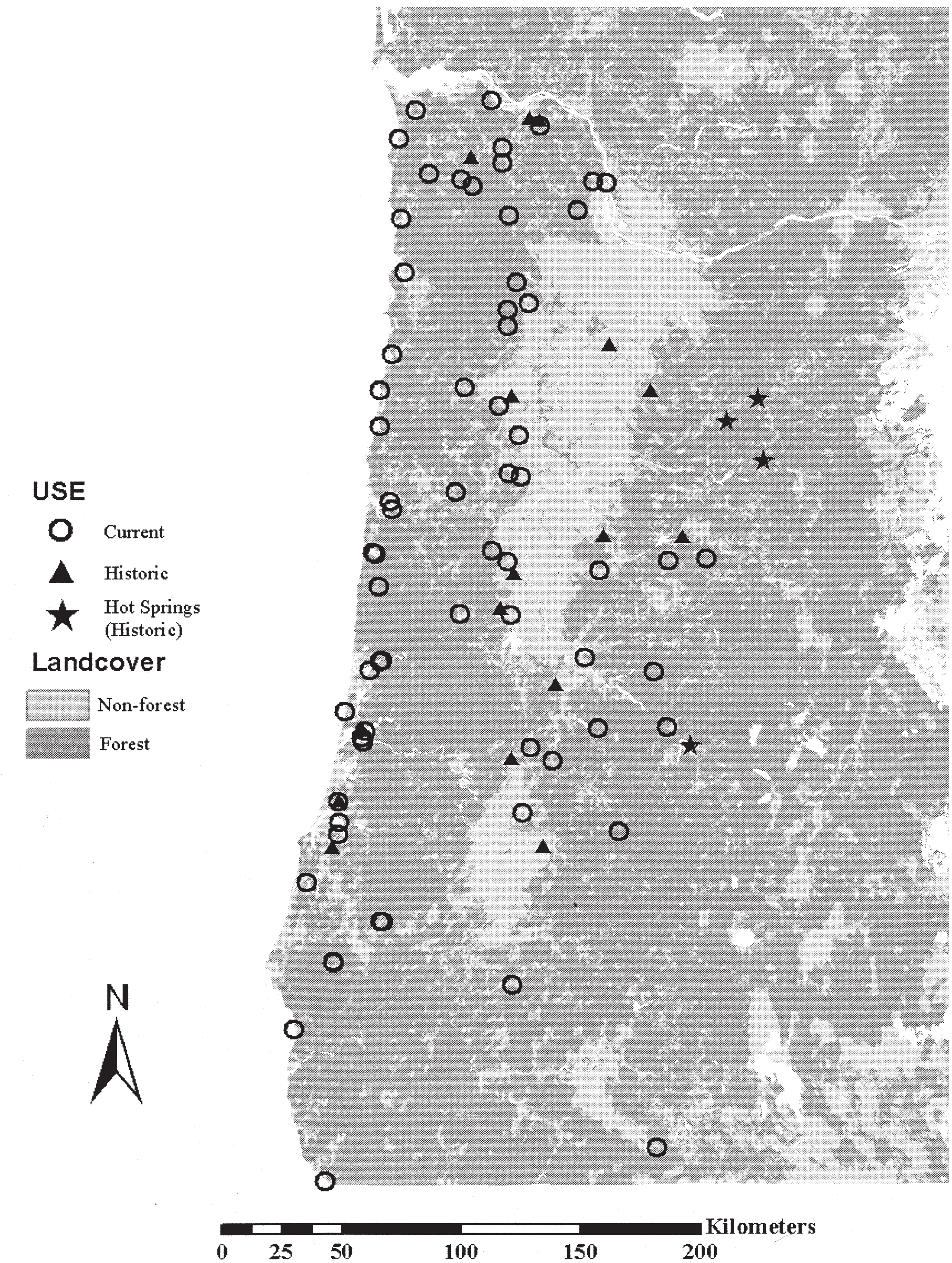

Figure 1. Location of 89 mineral sites in Western Oregon and category of use by band-tailed pigeons during 2001-2002. Hot springs (all historically used) indicated by stars.

demonstrate disparate effects on mineral site use by band-tailed pigeons.

The landscape level variables are sub-classified into two parts: habitat area measures and diversity indices. Habitat area measurements are the area within each individual landcover or stewardship class for each scale of investigation (i.e., 16 landcover and 8 stewardship classes). Grouping individual landcover classes, such as the amount of forested or non-forested land,

and special status stewardship land, generated additional variables. Three measures of diversity were generated for landcover types at each scale: Shannon's Diversity Index (SHDI), Shannon's Evenness Index (SHEI), and Relative Patch Richness (PR). These statistics were calculated using the FragStats Extension in ArcView (McGarigal and Marks 1995). SHDI increases without limit as patch (e.g., landcover class) richness increases and as patch area becomes more even. Shannon's Evenness Index is a function of PR and SHDI. SHEI is 0 with only 1 patch (i.e., complete dominance of a single landcover) and approaches 1 as multiple habitat types are more equal in area. Each metric describes the landscape in a different manner. None of these metrics could be expected a priori to provide a measure of landscape diversity that was more relevant, with respect to band-tailed pigeon use of mineral sites, than the others. Therefore, all metrics were evaluated. We did not consider edge metrics in this analysis because horizontal accuracy of Gap Analysis data layers had not been determined and the coarse resolution of mapped landcover classes (100 ha minimal mapping unit) would likely result in a bias of edge distance. The mineral source type (i.e., spring, estuary, other) and the distance between adjacent mineral sites potentially affect band-tailed pigeon use and were incorporated into our analysis.

Statistical Methods – Model Selection Methods

We used logistic regression models to associate landscape characteristics with the odds of a mineral site being currently used. Akaike's Information Criterion adjusted for small sample size (AIC_C) was used to select the best approximating multiple logistic regression models based on weight of evidence (Burnham and Anderson 1998). Models were considered competing if AICc values were within 2.0 of the lowest AICc value (Burnham and Anderson 1998). Akaike's weights (the likelihood of a given model being the best approximating model) were also generated to illustrate the relative importance of each model (Burnham and Anderson 1998). All model selection procedures were performed using the SAS software package (SAS Institute 1997).

Variable Selection Methods

We created an a priori list of candidate models based on resources used by band-tailed pigeons (e.g., coniferous or mixed forests used for nesting) or landcover classes suspected of being avoided (e.g., agriculture/grasslands; Table 1). Variables from separate scales were not included in the same model because an important aspect of our study was to identify the scale upon which habitat relationships are apparent. Additionally, complimentary effects were not included in the candidate set

Table 1. Landcover and stewardship variables used to generate logistic models of band-tailed pigeon use of 85 mineral sites in Oregon. Metrics derived from Gap Analysis Program products for Washington, Oregon, and Idaho (Karl et al. 1999).

Habitat Area Measures (ha)
Coniferous Forest
Mixed Forest
Agriculture/Grassland
Water
Deciduous Forest
Harvested/Disturbed Forest
Urban
Other (shrub land, lava flows, glaciers, mud flats, etc.)
Forested Land (i.e. Coniferous + Deciduous + Mixed Forests)
Non-forested land (i.e. Harvested Forest + Agricultural Land + Urban + Other)
Amount of GAP stewardship code (Crist 2000) within scale (ha)
Stewardship Code 1 (Permanent protection from landcover conversion maintained in a natural state with natural or managed disturbance events; e.g. National Parks, Ecological Reserves)
Stewardship Code 2 (Permanent protection from landcover conversion maintained primarily in a natural state, but may receive management that degrade natural communities; e.g. Wildlife Refuges)
Stewardship Code 3 (Permanent protection from landcover conversion for majority of area but subject to extractive uses; e.g. Forest Service administered land)
Stewardship Code 4 (No public or private mandates legally recognized that prevent conversion of natural landcover classes; e.g. Private)
Special Status Land (Stewardship Code 1 or 2)
Diversity Indices for landcover types
Shannon's Diversity Index
Shannon's Evenness Index
Patch Richness
Miscellaneous Characteristics
Mineral source type (Spring, Estuary, Other)
Kilometers to nearest mineral site.

of models. For instance, special status land (GAP codes 1 and 2) was not included in a model with lands that have no recognized easements or deed restrictions (Code 4). A model containing lands with permanent protection from habitat conversion but allowing resource extraction (Code 3) predicted the same effects and retained an extra degree of freedom for error estimation. Similarly, water, forested, and non-forested land comprised all possible landcover classes. Of these three variables, no two were included together in candidate models, as the exact opposite effect could be predicted using only the third variable. We removed models containing highly correlated variables to reduce issues of multicolinearity in model selection (Ramsey and Schafer 1997). No models contained more than three explanatory variables to prevent over-fitting the available dataset and to make results readily interpretable.

Landcover classes included in analysis reflect habitats used (e.g., for nesting) or not used (e.g., water) by band-tailed pigeons, landscape diversity indices, and spatial position of mineral sites. The final suite of biologically interpretable candidate models included: 52 models containing habitat characteristics from each the home range and broad scales; one model containing an indicator for mineral source type; one model incorporating the spatial arrangement of sites and a null model (intercept only), creating a final suite of 107 unique candidate models. Models were considered competing if they had AICc weights within 2.0 units of the lowest (best) ranked model (Burnham and Anderson 1998). Importance of individual variables was assessed from variable weights (Burnham and Anderson 1998) scaled to include only the competing models. Conditional averages of each variable were developed only from competing models.

RESULTS

Our analysis of landscape patterns surrounding 85 mineral sites in Oregon resulted in nine competing models (within 2 AIC_C units) explaining current mineral site use by band-tailed pigeons. Eight unique measurements, four habitat characteristics in each of the two spatial scales, were represented (Table 2). Landcover characteristics represented included forest and non-forested land area near a mineral site; land stewardship status was represented by special status or private land near a mineral site. Non-forested landcover at both spatial scales had the highest variable weights in competing models ($\Delta AIC_C \leq 2.0$). Additionally, these variables and broad scale forested landcover were the only characteristics that remained statistically significant effects after conditional model averaging (estimates include only models containing variable of interest; Table 2). Variables in competing models estimate the odds of mineral site use by band-tailed pigeons to be positively associated with forested landcover and special status lands around a mineral site (Table 2). Similarly, mineral site use was negatively associated with non-forested land cover and private land area near a mineral site (Table 2).

Figure 2 presents the probability of a mineral site being currently used in relation to habitat characteristics in the top ranked model. Response surfaces for other models follow similar patterns with lower slopes for broad scale measurements. Likelihood ratio confidence intervals for half of the stewardship characteristics included zero and all model-averaged estimates were not statistically significant (Table 2). However, the information gained from including these variables in the model is sufficient to explain differences between currently and historically used mineral sites and warrants inclusion in competing models (Burnham and Anderson 1998). We interpret the relatively high variable weight for non-forested landcover characteristics (at both scales), and the statistically significant differences in model averaged effects, as evidence that these characteristics will be most useful for managers in determining risks to mineral site persistence.

DISCUSSION

Implicit in any investigation of band-tailed pigeon habitat is the incorporation of forest cover as a significant resource utilized by band-tailed pigeons. Despite several references to band-tailed pigeon use of trees and

Table 2. Variable weights and average estimates and standard error for all variables included in competing models ($AIC_C < 2.0$) to predict band-tailed pigeon use of mineral sites in Oregon. Variables with average effects significantly different from zero indicated in bold ($\alpha = 0.05$).

Variable	Akaike weight[a]	Model Averaged Estimate[b]	Model Averaged Standard Error[b]
Intercept	**1.0000**	**2.1899**	**0.8196**
Home range scale			
Non-forested land	**0.3921**	**-0.0199**	**0.0088**
Forested land	0.0822	0.0133	0.0088
Special Status land	0.1779	0.0975	0.0791
Private Land	0.2818	-0.0353	0.0197
Broad scale			
Non-forested land	**0.352**	**-0.0068**	**0.0026**
Forested land	**0.1012**	**0.0052**	**0.0026**
Special Status land	0.0708	0.0027	0.0045
Private Land	0.2139	-0.0024	0.0022

a = Variable weight scaled to total of competing model weights.

b = Model averaged estimate for competing models ($AIC_C < 2.0$) containing this variable.

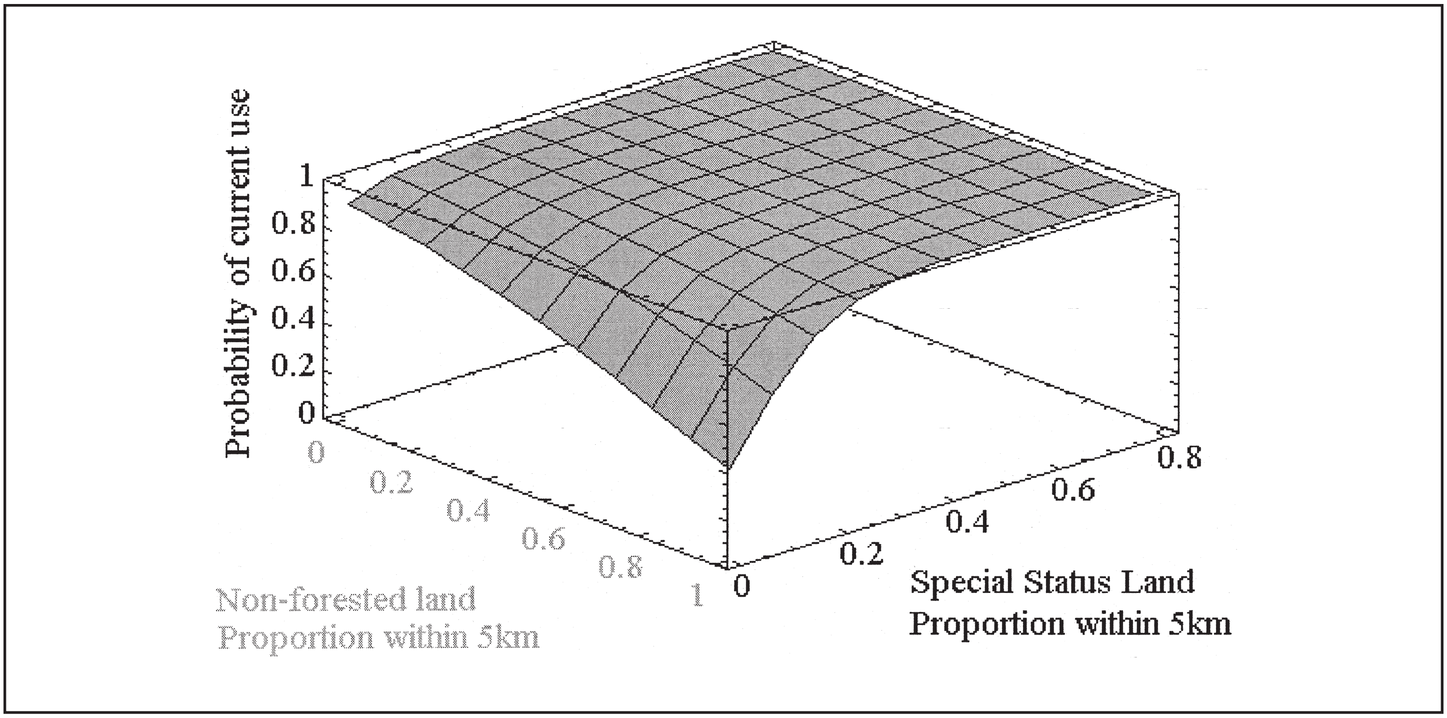

Figure 2. Response surface for the probability of current mineral site use by band-tailed pigeons in Oregon. Parameter estimates from top ranked model at the home range scale (3,700 ha): Non-forested Land Area + Special Status Land.

forests in general, few analytical investigations have quantified stand or landscape level associations with any population parameters including presence/absence (but see Jeffrey 1989, Leonard 1998, Sanders 1999, and Casazza et al., unpubl. data). We found the area of adjacent non-forested terrestrial land at both scales of investigation (home range and broad) to be associated with lower odds of current mineral site use by band-tailed pigeons. Similarly, a high amount of forested land around a mineral site was associated with higher odds of mineral site use. These results are important in that the specific composition of adjacent forests were not indicated as important factors explaining mineral site use by band-tailed pigeons. It was the amount of all forested landcover types, or conversely all non-forested types, which exhibited the strongest associates with mineral site use. Future investigations may focus on examining band-tailed pigeon abundance within forest types. Although forests in general provide suitable habitat for mineral site use, individual forest types may influence the size of local populations (Overton 2003).

The odds of mineral site use were positively associated with the amount of special status lands near a mineral site at either scale. Increasing private lands were associated with lower odds of mineral site use. Although, the effect sizes for stewardship categories are comparatively small with high variability, their presence in competing models suggests that they explain a substantial amount of the variability in the data (Burnham and Anderson 1998). Special stewardship lands may provide a more stable environment that promotes growth of nesting and foraging habitats, protection from disturbance, or simply locations more favorable to band-tailed pigeon presence. Future research might focus on the specific characteristics of protected lands in Oregon with respect to persistence and habitat use of band-tailed pigeons.

Measurements from both scales of investigation were selected in competing models suggesting that mineral site use can be evaluated by examining landscape characteristics both at a scale approximating the home range size of breeding band-tailed pigeons and at a scale much larger than home range size. Analysis using GAP data is not recommended when addressing landscape information at a scale less than several thousand hectares (Scott and Jennings 1998); therefore, smaller spatial scales should be addressed using other methods. The ability of our modeling to determine factors associated with current use of mineral sites by band-tailed pigeons is limited to the specific scales of investigation, time frame of classification, and landcover and stewardship attributes provided by GAP products for western Oregon. Our associations represent a "snapshot" of landcover and stewardship characteristics that are constantly in flux. Enhancements to our research might include expanding the area of interest throughout the Pacific Coast band-tailed pigeon range, including local landcover characteristics not available from GAP products, or assessing the degree of recent habitat change. Future research can use our associations to evaluate landcover change and future mineral site use conditions. Each of these avenues would provide land managers with additional information useful in developing conservation strategies, but would also require the collection of data that is currently unavailable.

Our research did not focus on proximate causes of site abandonment; instead, we looked at larger scale vegetation and land ownership patterns. One proximate factor associated with historic use of mineral sites is mineral source type. Hot springs provide excellent sources for band-tailed pigeons to obtain minerals; however, few hot springs occur within the Oregon breeding range of the band-tailed pigeon. Those that do occur are at relatively high elevations on the west slope of the Cascades and all hot springs known to have been used by band-tailed pigeons have been abandoned (T. Sanders, Oregon State University, unpubl. data). Many of these locations are popular recreation areas with modification designed to increase use by people. Band-tailed pigeons currently use hot springs in Washington, British Columbia, and California (M. Casazza, USGS, unpubl. data). However, anecdotal reports from hot spring users and landowners indicate a general decline in use by band-tailed pigeons over the past several decades. Hot springs should be considered a unique facet in the landscape; high social value and use by humans may be incompatible with many wildlife needs.

Anecdotal reports of site destruction or abandonment at non-hot spring sites have usually involved increasing urbanization in forest and agricultural practices of Oregon (especially in the Willamette Valley and coastal areas; R. Jarvis, Oregon State University, pers. comm.; N. Teneyck, Oregon Department of Fish and Wildlife, pers. comm.; Sanders 1999). Over-harvesting from hunting at some mineral sites has been implicated in the decline in abundance of local populations, but not of complete abandonment (Jarvis and Passmore 1992). Though not specifically addressed in this research, elevation is an important consideration when addressing mineral site conservation. Most historic mineral sites are coastal or along the margin of the Willamette Valley (Figure 1). The landcover types best represented in protected areas occur at high elevations, a trend noted at a national level as well as in Oregon (Jennings 2000, Scott et al. 2001). The elevational gradient in band-tailed pigeon abundance is still unknown, but several authors suggest band-tailed pigeons are more abundant along the coast or lower elevations and may experience a seasonal elevational migration in southern portions of their range (Jeffrey 1989, Sanders 1999, Keppie and Braun 2000).

Forage availability, a feature that is not available from the dominant vegetation classification utilized in the GAP program, has been implicated as a possible cause for distribution preferences with respect to elevation (Braun 1994). The lower elevation mineral sites, which generally have a lower probability of current use due to reduction of forest cover and few adjacent protected areas, may be important to a larger proportion of the population than mineral sites higher in the Cascades because of greater forage availability and population density (Jeffrey 1989, Sanders 1999). However, fewer high elevation mineral sites are known, and abandonment of high elevation mineral sites may have disproportionate effects on band-tailed pigeon distribution due to the scarcity of mineral resources. Their potential physiological need for sodium, and the tenacity with which they will return to mineral sites, suggests that mineral sites are a necessary resource (Jarvis and Passmore 1992, Sanders 1999). However, band-tailed pigeons are capable of fast flight and long distance daily movements (>20km; Leonard 1998). Loss of a mineral source may not preclude band-tailed pigeon local persistence but could strongly influence local distribution (Jeffrey 1989).

GAP analysis is a coarse-filter approach to identifying and preserving self-maintaining communities at a regional scale (Noss 1987, Scott et al. 1989, Scott et al. 1993, USGS Gap Analysis Program 2000). Conserving landscapes and ensuring protection of vegetation types and biodiversity are potential applications of GAP data (Scott et al. 1993, Scott and Csuti 1997). To the extent that landscape influences community and population ecology (Wiens 1969, Rotenberry and Wiens 1980, McGarigal and McComb 1995), implementation of such data can be used in "fine filter" approaches for species-specific conservation and identification of spatial associations with population parameters of interest (Noss 1987, Noss et al. 1995, Scott et al. 2001).

Regional approaches to conservation are likely to play a crucial role in the future. The distribution of band-tailed pigeons in Oregon is comparatively well represented with over 25% of its predicted distribution and associated habitats in protected lands (Kagan et al. 1999). However, mineral sites are a critical resource used by band-tailed pigeons and are not well protected, with over 86% in private ownership and most of the rest in lands managed for extractive uses (Sanders 1999). The identification of patterns in current protected area distribution will allow for a more comprehensive and inclusive approach to future reserve design and selection of landscapes to be conserved (Jennings 2000, Scott et al. 2001). However, coarse-filter conservation alone will not suffice to benefit all species. Band-tailed pigeons visit resources that are both highly localized and widely dispersed (Sanders 1999). The impact of conservation programs on this species may be negligible if these critical resources are not specifically addressed in fine-filter "tuning" of conservation goals. Management to reverse the apparent decline in band-tailed pigeon abundance should consider mineral sites as a resource of high ecological value for band-tailed pigeons as well as other species. Particular focus may be warranted on lower elevation mineral sites, most of which are under private ownership.

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LITERATURE CITED

Braun, C.E. 1994. Band-tailed pigeon. Pp. 61-74 *in* T. Tacha and C. E. Braun, ed., Migratory shore and upland game bird management in North America. International Association of Fish and Wildlife Agencies, Washington, D.C.

Burnham, K.P., and D.R. Anderson. 1998. Model selection and inference: a practical information-theoretic approach. Springer-Verlag, New York.

Casazza, M.L., J.L. Yee, M.R. Miller, D.L. Orthmeyer, D. Yparraguirre, and R.L. Jarvis. In press. Development of reliable population indices for band-tailed pigeons. USGS Final Report to Webless Migratory Game Bird Research Program, U.S. Geological Survey, Biological Resources Division, Denver, Colo.

Cassidy, K.M., C.E. Grue, M.R. Smith, and K.M. Dvornich. 1997. Washington State Gap Analysis Project, Final Report, Vol. 1. Land cover of Washington State: description and management. Washington Cooperative Fish and Wildlife Research Unit, University of Washington, Seattle.

Crist, P.J. 2000. Mapping and Categorization of Land Stewardship. Version 2.1.0. A handbook for conducting Gap Analysis. Available online <http://www.gap.uidaho.edu/handbook/Stewardship/default.htm>. Accessed 23 February 2000.

Diniz-Filho, J.A.F, L M. Bini, and B.A. Hawkins. 2003. Spatial autocorrelation and red herrings in geographical ecology. Global Ecology and Biogeography 12:53-64.

Jarvis, R.L., and M.F. Passmore. 1992. Ecology of band-tailed pigeons in Oregon. Biological Report No. 6., U.S. Fish and Wildlife Service, Washington, D.C.

Jeffrey, R. 1989. The band-tailed pigeon: distribution, effects of harvest regulations, mortality rates and habits of band-tailed pigeons 1968-1979. Washington Department of Wildlife, Olympia.

Jennings, M.D. 2000. Gap Analysis: concepts, methods, and recent results. Landscape Ecology 15:5-20.

Kagan, J.S., J.C. Hak, B. Csuti, C.W. Kiilsgaard, and E.P. Gaines. 1999. Oregon Gap Analysis Project final report: a geographic approach to planning for biodiversity. Oregon Natural Heritage Program, Portland.

Keppie, D.M., and C.E. Braun. 2000. Band-tailed pigeon (*Columba fasciata*). Pp. 1-28 *in* A. Poole and F. Gill, eds., The birds of North America, No. 530. The Birds of North America, Inc., Philadelphia, Pa.

Leonard, J.P. 1998. Nesting and foraging ecology of band-tailed pigeons in western Oregon (*Columba fasciata).* Ph.D. diss., Oregon State University, Corvallis.

McGarigal, K., and B.J. Marks. 1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. General Technical Report PNW-351, U.S. Department of Agriculture, Forest Service, Portland, Ore.

McGarigal, K., and W.C. McComb. 1995. Relationships between landscape structure and breeding birds in the Oregon coast range. Ecological Monographs 65:235-260.

March, G L., and R.M F.S. Sadleir. 1970. Studies on the band-tailed pigeon (*Columba fasciata*) in British Columbia. 1. Seasonal changes in gonadal development and crop gland activity. Canadian Journal of Zoology 48:1353-1357.

March, G.L., and R.M.F.S. Sadleir. 1972. Studies on the band-tailed pigeon (*Columba fasciata*) in British Columbia. 2. Food resource and mineral-gravelling activity. Syesis 5:279-284.

Morse, W.B. 1950. Observations on the Band-tailed Pigeon in Oregon. Proceedings of the Western Association of State Game and Fish Commissioners 30:102-104.

Neff, J.A. 1947. Habits, food and economic status of the band-tailed pigeon. North American Fauna 58:1-47.

Noss, R. F. 1987. From plant communities to landscapes in conservation inventories: a look at The Nature Conservancy (USA). Biological Conservation 41:11-37.

Noss, R.F., E.T. LaRoe, III, and J.M. Scott. 1995. Endangered ecosystems of the United States: a preliminary assessment of loss and degradation. Biological Report 28, U.S. Department of the Interior, National Biological Service, Washington, D.C.

Overton, C.T. 2003. Habitat characteristics associated with abundance of band-tailed pigeons and use of mineral sites in the Pacific Northwest. M.S. thesis, Oregon State University, Corvallis.

Ramsey, F.L., and D.W. Schafer. 1997. The Statistical Sleuth: a Course in Methods of Data Analysis. Duxbury Press, Belmont, Calif.

Rempel, R.S., and A.P. Carr. 2003. Patch Analyst extension for ArcView: version 3. Available online <http://flash.lakeheadu.ca/~rrempel/patch/index.html>.

Rotenberry, J.T., and J.A. Wiens. 1980. Habitat structure, patchiness, and avian communities in North American steppe vegetation: a multivariate analysis. Ecology 6:1228-1230.

Sanders, T.A. 1999. Habitat availability, dietary mineral supplement, and measuring abundance of band-tailed pigeons in western Oregon. Ph.D. diss., Oregon State University, Corvallis.

Sanders, T.A., and R.L. Jarvis. 2000. Do band-tailed pigeons seek a calcium supplement at mineral sites? Condor 102:855-863.

SAS Institute Inc. 1997. SAS/STAT Software: Changes and Enhancements through Release 6.12. SAS Institute, Cary, N.C.

Scott, J.M., B. Csuti, J.E. Estes, and H. Anderson. 1989. Status assessment of biodiversity protection. Conservation Biology 3:85-87.

Scott, J.M., F.W. Davis, B. Csuti, R. Noss, B. Butterfield, C. Groves, H. Anderson, S. Caicco, F. D'Erchia, T.C. Edwards, Jr., J. Ulliman, and G. Wright. 1993. GAP Analysis: a geographic approach to protection of biological diversity. Wildlife Monographs 123.

Scott, J.M., M.D. Jennings, R.G. Wright, and B. Csuti. 1996. Landscape approaches to mapping biodiversity. Bioscience 46:77-78.

Scott, J.M., and B. Csuti. 1997. Gap Analysis for biodiversity survey and maintenance. Pp. 321-340 *in* M.L. Reaka-Kudla, D.E. Wilson, and E.O. Wilson, eds., Biodiversity 2: Understanding and Protecting our Biological Resources. Joseph Henry Press. Washington, D.C.

Scott, J.M., and M.D. Jennings. 1998. Large-area mapping of biodiversity. Annals of the Missouri Botanical Garden 85:34-47.

Scott J.M., B. Csuti, R.G. Wright, P.J. Crist, and M.D. Jennings. 1999. Regional approaches to managing and conserving biodiversity. Pp. 55-70 *in* R.K. Baydack, H. Campa, III, and J.B. Haufler, eds., Practical Approaches to the Conservation of Biological Diversity. Island Press. Washington, D.C.

Scott J.M., F.W. Davis, R.G. McGhie, R.G. Wright, C. Groves, J. Estes. 2001. Nature reserves: do they capture the full range of America's biological diversity? Ecological Applications 11: 999-1007.

Smith, W.A. 1968. The band-tailed pigeon in California. California Fish and Game Bulletin 54:4-16.

USGS Gap Analysis Program. A handbook for conducting Gap Analysis. Available online <http://www.gap.uidaho.edu/handbook> Accessed 24 February 2000.

Wiens, J.A. 1969. An approach to the study of ecological relationships among grassland birds. Ornithological Monographs 8.