PREDICTIVE APPROACHES TO HABITAT QUANTIFICATION: DARK-RUMPED PETRELS ON HALEAKALA, MAUI

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ABSTRACT.—Physical characteristics of the nesting habitat of the endangered Hawaiian Dark-rumped Petrel (*Pterodroma phaeopygia sandwichensis*), nesting on Haleakala volcano, Maui, were quantified in order to determine whether birds were choosing nesting sites nonrandomly. Nesting habitat was sampled at three spatial scales: burrow (within immediate vicinity of a petrel burrow), colony (10–60 m from a petrel burrow), and landscape (1,000-m transects through habitat containing colonies). We used a probability model based on logistic regression to discriminate among the three sampling scales. The model was quite successful in reclassifying the locations, correctly identifying over 91% of the burrow sites as such. In general, burrows were located on steep slopes under large rocks in the vicinity of shrub cover. This set of characteristics was not indicative of habitat at either the colony or landscape scales. Our study reveals two important aspects in evaluating habitat preferences for the Dark-rumped Petrel population on Haleakala: (1) habitat must be evaluated multidimensionally, and (2) important aspects of habitat associations may become apparent only at certain scales. The nesting range of the Dark-rumped Petrel is currently severely restricted from historical levels to extreme elevations within Haleakala National Park. Probability models such as ours can be useful in delineating suitable habitat patches where, in this case, Dark-rumped Petrel burrows have a higher probability of being found. This approach is powerful because it can make use of remotely sensed and stored data sets to direct and refine on-the-ground searches. *Received 1 June 1994, accepted 4 January 1995.*

THE HAWAIIAN DARK-RUMPED PETREL (*Pterodroma phaeopygia sandwichensis*) is a gadfly petrel endemic to the Hawaiian Islands. Prior to the arrival of the Polynesians, approximately 1,400 years BP, Dark-rumped Petrels nested on all the main islands of Hawaii except Niihau (Olsen and James 1982). Predation by Polynesians and associated animals (Polynesian rats [*Rattus exulans*], dogs, and pigs) eliminated these birds from Oahu and lowland areas of the remaining islands (Olsen and James 1982). European impact, including further faunal introductions (black rats [*R. rattus*], Norway rats [*R. norvegicus*], mongooses [*Herpestes auropunctatus*], cats, and goats) as well as habitat destruction, have reduced the population to such an extent that the Dark-rumped Petrel is currently listed as en-

dangered (Bartle et al. 1993). The only documented nesting colony occurs on the upper slopes of Haleakala volcano on Maui (estimated at 1,800 birds; Simons 1984), although vocalizations and other evidence of nesting Dark-rumped Petrels have been recorded on Kauai, Lanai, Hawaii, and Molokai (Bartle et al. 1993).

Prior to Polynesian colonization, Dark-rumped Petrels nested from the tops of the highest volcanoes (approximately 3,500 m) to sea level in a wide range of habitats spanning sparse, rocky outcroppings to wet, heavily vegetated slopes (Munro 1944, Simons 1985). At present, the Haleakala population nests in presumably suboptimal habitat (Simons 1985, Bartle et al. 1993) described as alpine dry shrubland, consisting of widely scattered shrubs with a total vegetative cover of less than 10% (Wagner et al. 1990). Over 75% of the known Dark-rumped Petrel burrows are found along the west rim of the Haleakala crater, with additional burrows scattered on the east and southern slopes,

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inside the southern rim, and on the eastern rim (Simons 1983, 1985). The majority of the colony is protected by a trap line maintained by the Park Service, which controls local populations of feral cats and mongooses.

Although Dark-rumped Petrels do not nest over the variety of habitat they once did, individual birds probably still select burrow sites on the basis of habitat quality, perhaps within a reduced range of options. Habitat quality, the result of both biotic and abiotic factors, can have a large effect on reproductive success. Biotic factors—including the presence of conspecifics, mates, food, or predators—can affect recruitment, adult mortality, and reproductive success (Cody 1985, Furness and Monaghan 1987); they will not be treated in this study. Instead, we focus on abiotic factors, the physical aspects of the habitat. Simons (1985) found the vast majority of Dark-rumped Petrel burrows beneath boulders or at the base of rock outcrops, although some were under shrubs or bunchgrasses.

Aside from this general characterization, as well as a more detailed description of burrow length, opening dimensions, and nest material (Simons 1983), physical aspects of the habitat important to nest-site selection by Dark-rumped Petrels have not been quantified. Important physical characteristics of the nesting habitat have been determined for other burrow-nesting sea birds and include: factors related to thermal stress such as vegetation, cavity size, and shading (Burger and Gochfeld 1991); factors related to burrow stability like slope, depth, and substrate texture (Stokes and Boersma 1991); burrow orientation (Walsberg 1985); and the presence of obstructions near the nest (Burger and Gochfeld 1985). Because these factors individually or in combination may be important in Dark-rumped Petrel nest-site selection, we attempted to quantify differences in habitat characteristics with both univariate and multivariate analyses.

Management of any endangered species restricted to a fringe habitat must be based, in part, on an assessment of nest-site availability within the existing range of the species (Duffy 1992). Because we often rely on subsampling to quantify habitat, we may overestimate or underestimate the existence of quality sites depending on the sampling scale (Wiens et al. 1986, Wiens 1989, Noss 1992). Small scales may not accurately reflect the patchy quality of the environment, whereas large scales (in which variables are usually presented as averages) may underrepresent the presence of quality sites. To correct this problem, as well as determine which factors Dark-rumped Petrel may treat as definitive within the larger environment, we investigated whether and how physical features of the habitat were related to burrow placement on several scales, ranging from the immediate vicinity of the burrow to a "landscape" scale. At the lower end of the scale, we quantified physical characteristics of the burrows and their immediate surroundings. At the intermediate scale (colony), we measured a similar set of variables from random locations within a 60-m radius of each sampled Dark-rumped Petrel burrow. We used this latter set of measurements as indicative of the habitat available within nesting colonies. Because colonies themselves may not be representative of the larger habitat within which Dark-rumped Petrels nest, we also examined habitat variables on a third scale—that of the alpine dry shrubland. This scale was sampled from transects spanning the nesting range of the Dark-rumped Petrel on the western side of Haleakala.

Once relevant habitat characteristics have been identified, management of an endangered species also requires delineation of suitable habitat within the larger available area. If only one habitat variable is important in differentiating suitable from unsuitable habitat, it is a fairly simple task to identify all habitat that may support the species of interest. However, if several parameters are important, the task of habitat identification can become complex, given that the relative importance of parameters may not be evident. To address this issue, we used our field data to build a simple probability model which can be used to predict the suitability of new locations vis-a-vis Dark-rumped Petrel habitat. Thus, the initial analysis results can be used to guide further field sampling, and new data can be tested with the model. If an automated data system, such as a geographic information system (GIS), is available, a wide array of points can be sampled for suitability. Either approach can be used to create suitability contours within the larger area.

METHODS

Study site and sampling design.—Our study area was confined to the Dark-rumped Petrel nesting colonies

(defined as physically distinct sets of burrows) located on the western rim of Haleakala south of Kilohana Point and on the eastern and southern slopes of the Haleakala summit (Fig. 1). These areas contain the majority of the known burrows, although additional burrows occur north of Kilohana Point and inside the eastern and southern rims. In 1990, 484 burrows were surveyed, 80% of which were active and all of which occurred along the inside of the west rim of Haleakala crater (Hodges unpubl. data). In 1991, there were approximately 700 known burrows, of which 484 were known to be active. We randomly selected 29 known to be active burrows and the nearest-neighbor burrow of each (i.e. $n = 58$ burrows) for burrow-scale measurements. Active was defined as having been used within the last year according to Park Service records. Surveys were conducted during 10 days in March 1991.

To avoid overlap in physical-habitat measurement, each selected burrow was more than 100 m from all previously sampled burrows. Habitat variables then were evaluated at the selected burrow and its nearest neighbor. The burrow entrance, usually beneath a large rock served as the sampling point. Sampling points representative of habitat at the colony scale were selected by randomly generating a vector (compass angle and distance between 10 and 60 m) originating from each sampled burrow ($n = 58$). The rock, greater than 10 cm in diameter, and nearest the vector terminus, served as the colony-scale sampling point. All colony-scale habitat variables were measured from this point.

Sampling points representative of the landscape scale (i.e. indicative of nesting range of Dark-rumped Petrels within the alpine dry shrubland) were selected by randomly generating compass angles for five 1-km vectors originating from five man-made features along the approximate midline of the potential nesting habitat (see Fig. 1). As was done in the colony-scale sampling, the rock greater than 10 cm in diameter that lay nearest each 100-m interval along the vector constituted the sampling point for the landscape samples (i.e. $n = 50$). All distances were determined by pacing.

At all three habitat scales (burrow, colony, and landscape), we measured field slope, field (or burrow) aspect, distance to nearest shrub, species of nearest shrub, soil color, average soil particle size, size class of rock at sample point (e.g. the burrow rock at burrow scale), and average size class of rocks within 10 m of sampling point. Additional measurements made at each Dark-rumped Petrel burrow included burrow width and height, angle of slope at the mouth of the burrow, and distance to the nearest-neighbor burrow.

Using a Suunto declinometer, we measured field slope as the greatest angular declination defined by the 30-m field around the sampling point. Aspect was the orientation of the burrow entrance or the sampling point field (colony and landscape samples) as
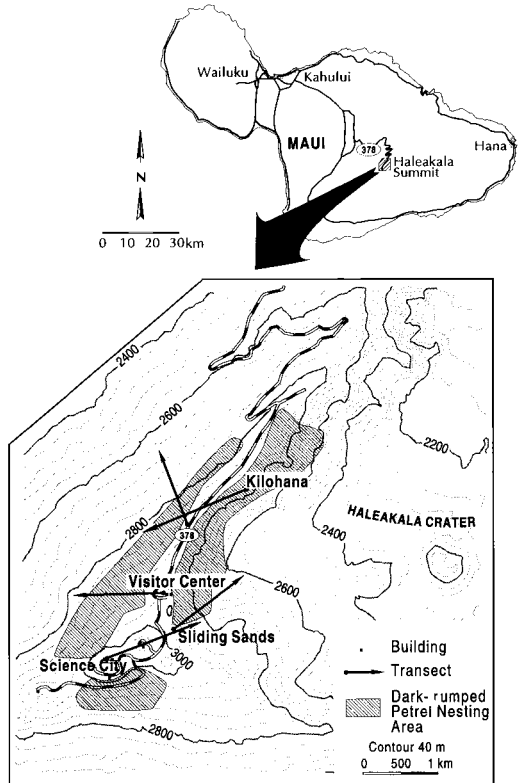

Fig. 1.   Location of Dark-rumped Petrel nesting areas and study areas on Haleakala.

measured by a compass corrected for local declination. We determined soil-particle sizes by averaging measurements of grab samples taken from the top 2 cm of soil nearest the sampling point. Soil color was classified as none (i.e. no soil was present), red, brown, or black. Average surface-rock size was evaluated using two 10-m transects oriented parallel to elevation contours, one originating at the sample point (lower or burrow transect) and the second 10 m upslope (upper transect). Along each transect, rock diameter was estimated at 1-m intervals. Diameters were classified into five groups: 0 to 10 cm, >10 to 50 cm, >50 to 100 cm, >100 to 150 cm, and >150 cm. These groups also were used for the burrow rock.

Analysis and probability model.—Logistic regression based on negative log likelihood was used to discriminate among the three classes of sampling locations. To test for the significance of a particular habitat characteristic (regressor), the model was run with and without it. The significance test used the chi square for the regressor, defined as twice the difference in negative log likelihood between the two models. The logistic regression was run in a stepwise manner to select a parsimonious set of regressors. The selection

criterion was to retain those that had a chi square probability less than 0.05, and rerun the model with the retained subset of regressors. The regression was run until all remaining regressors met the criterion.

The stepwise linear regression incorporated both nominal (coded as a dummy variable) and quantitative variables to generate functions that were then used to define the probability that a given site belonged to any given class (i.e. burrow, colony, or landscape). Sites were then recategorized as burrow, colony, or landscape locations on the basis of the parameter estimates from the stepwise logistic regression. The probability (P_B) that a given site would be a potential burrow location is:

$$P_B = e^{\text{Lin } B} P_L, \tag{1}$$

where Lin B is the linear combination of parameter estimates obtained from the logistic regression and P_L is the probability that a given site is not a burrow or colony location (i.e. a landscape location). The latter is calculated as

$$P_L = 1/(1 + e^{\text{Lin } B} + e^{\text{Lin } C}), \tag{2}$$

where Lin C is the linear combination of parameter estimates from the logistic regression. Finally, the probability that a given site is a potential colony location is

$$P_C = e^{\text{Lin } C} P_L. \tag{3}$$

RESULTS

Dark-rumped Petrel burrows were not randomly distributed in space but were grouped, with the nearest burrow located between 1 and 50 m from the sampled burrow ($\bar{x} = 13$ m). Burrows typically were located on steep slopes (>25°), although the burrows themselves were dug on a shallower angle into the substrate. The slope at all but one burrow fell off away from the burrow entrance, but even at the anomalous burrow the main tunnel led up into the burrow rather than down. Burrows were oriented on average toward the east, although all compass directions were represented in the sample. No burrow was found more than 5 m from shrubs; 15 burrows were only 10 cm from the nearest shrub. The shrub nearest the burrows was commonly kupaoa (*Dubautia menzesii*; 45 of 58 cases). Pukiawe (*Styphelia tameiameiae*) was the shrub nearest 10 burrows, and ohelo (*Vaccinium reticulatum*) was the nearest shrub in 3 cases.

Burrows had a mean width-to-height ratio of 2.5:1, with some entrances as much as 100 cm wide. Wide entrances appeared to be the result of natural features (e.g. where sheet erosion had undercut large rocks to form a ledge) rather

than as a result of excavation by the bird. Burrow height was much less variable than width, with no entrances over 25 cm in height. Soils at the burrows were generally coarse. Soil color at the 58 burrows was typically red (25), black (21) or brown (12). The most consistent feature of Dark-rumped Petrel burrows was the large size of overlying rocks. All but two of the sampled burrows had been excavated beneath rocks larger than 150 cm in diameter. The two exceptions were under rocks in the >100 to 150 cm class. On the burrow transect, rock size averaged almost 100 cm in diameter; upslope, the average was smaller (i.e. in the middle of the >50 to 100 cm class).

The distribution of quantitative environmental variables overlapped across the three habitat scales, although there were apparent differences in location and spread (Fig. 2). Dark-rumped Petrels situated their burrows in areas where large rocks were especially common. Rocks above burrows were larger than those commonly available in the colony or the landscape. Furthermore, rock sizes on both the lower (i.e. burrow) and upper transects at burrow sites were larger than those of the general habitat. The distance to shrubs also was less at burrows than that generally found at either the colony or the landscape level. In addition, burrows appeared to be in steeper areas than the average for the habitat type in general. No strong differences were noted among habitat scales in terms of soil particle size.

Some environmental characteristics were less variable at the burrow level than within the habitat in general (see Fig. 2). The slope of the field near burrows was less variable than the slope in the colony. Shrub proximity and soil particle size were less variable near burrows and in the colony than at the landscape scale. Finally, burrow rocks were less variable in size than those available in the colony or habitat, although this difference could be due entirely to the truncated size classification.

Qualitative features of Dark-rumped Petrel burrows also differed from those representative of the colony and landscape (Fig. 3). Soil color at the burrows was significantly different from that available in the general habitat ($X^2 = 35.81$, $P < 0.001$). Red soil was more common at Dark-rumped Petrel burrows than expected (burrow vs. colony, $X^2 = 5.44$, $P < 0.025$; burrow vs. landscape, $X^2 = 7.53$, $P < 0.010$). Although Dark-rumped Petrel burrows were located more often

Aspect (degrees)

Soil Size (mm)

Field Slope (degrees)

Transect 1 - Average (cm)

Nearest Shrub (m)

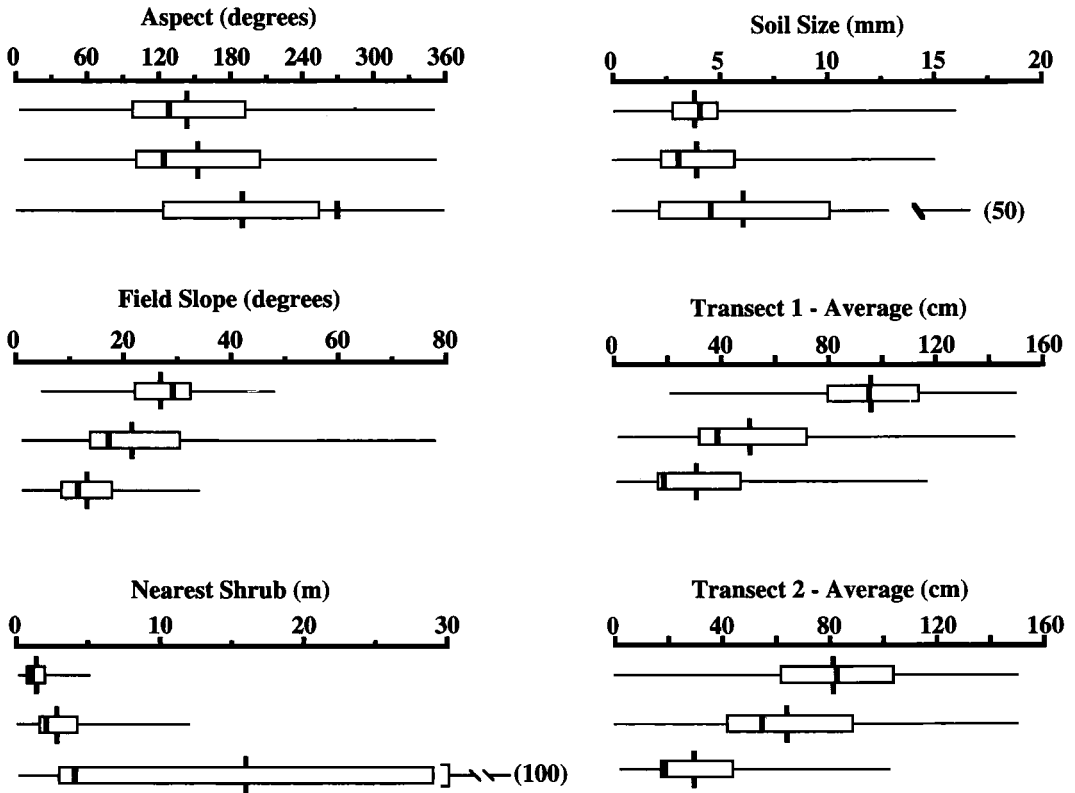## Transect 2 - Average (cm)

Fig. 2. Box-and-whisker plots of six quantitative, physical habitat characteristics: aspect, slope, nearest shrub, soil size, and average rock size at upper transect (no. 1) and lower transect (no. 2). For each variable, top box is burrow scale, middle box colony scale, and lower box landscape scale. Long vertical bars are means, short vertical bars are medians, boxes are standard deviations, and whiskers are ranges.

near *Dubautia* than either of the other shrubs, this apparently was only a reflection of the relative ubiquity of *Dubautia* in the habitat. There were no significant differences between the burrow and larger habitat scales on the basis of shrub species nearest the burrow/sampling point ($X^2 = 6.64$, $P = 0.156$).

The median rock size class did not differ between lower and upper transects within any of the three sampling scales (Friedman two-way ANOVA, by scale, $P > 0.07$). However, at the burrow scale, the average rock size classes were only weakly correlated (Spearman $r = 0.278$, $P = 0.027$). In contrast, at the colony and especially landscape scales stronger correlations existed between paired transects (Spearman $r = 0.392$ and 0.786, respectively, $P < 0.001$). The weak correlation between transects at the burrow scale was not due to the unusually large size of the burrow rock. When burrow rocks were exclud-

ed from the data for the downslope transects, the overall correlation was not improved (Spearman $r = 0.278$, $P = 0.028$). The pattern of these correlations suggest that the majority of burrows were located on the margins of breaks in the Haleakala terrain (e.g. at tops or bottoms of cliffs).

Although there were apparent differences in the distribution of shrub species, soil particle size, and slope across habitat scales (Fig. 2), none of these parameters were significant predictors in the stepwise logistic regression ($P > 0.10$, 0.90, and 0.05, respectively) and, thus, were dropped from the model. The regressors retained in the final model were distance to the nearest shrub, substrate color, size of rock at both the sampling location and in the vicinity of the sampling location, and aspect (Table 1). The weighting factors for each of the remaining regressors (Table 2) provide an estimate of the
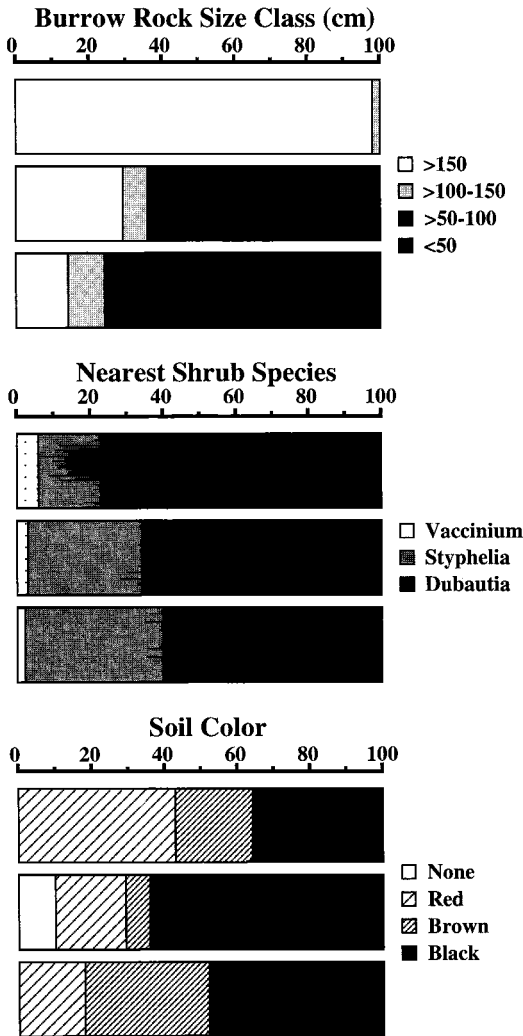
TABLE 1. Stepwise regression of physical habitat characteristics on three habitat categories (burrow, colony, landscape).

Regressor	df	X²
Shrub distance	2	19.17***
Substrate color	6	36.02***
Burrow rock	2	51.12***
Average rock	2	10.75**
Aspect	2	28.63***
Complete model	14	230.18***

**, $P < 0.01$; ***, $P < 0.001$.

Fig. 3. Percent occurence of three categorical, physical habitat characteristics: burrow rock size class, nearest shrub species, and soil color. For each variable, top box is burrow scale, middle box colony scale, and lower box landscape scale.

relative contribution of each physical characteristic in contributing to the classification of a site as belonging to the burrow or the colony. Burrow sites were characterized by large rock sizes (>1.5 m in diameter), unusually close proximity to shrubs, west-facing slopes, and soil color more often red or brown than black.

The final regression model was quite successful in reclassifying the locations, correctly identifying over 91% of the Dark-rumped Petrel burrow sites as burrow locations and over 70%

of the colony and landscape locations as such (Table 3). Misidentified colony sites were split between burrow and landscape classifications (Table 3), indicating that the colony scale has aspects of all three sampling scales.

DISCUSSION

Our study indicates two important aspects in evaluating habitat preferences for the Dark-rumped Petrel population on Haleakala. First, the habitat must be considered as an interacting set of individual characteristics. The multidimensional approach also has been used to distinguish microhabitat preferences among species, as well as to suggest factors important in habitat restoration (e.g. Rodrigues 1994). Second, aspects of habitat associations may manifest themselves only at certain scales. Indeed, some habitat characteristics may not exist, or be meaningful, at all scales. For instance, it is obvious that cinder flows are not a suitable microhabitat within which to nest. However, without recourse to specific measurements, it is not obvious that Dark-rumped Petrels are differentiating between boulder fields/terrain breaks (i.e. colony scale) or more specific feature combinations within that seemingly suitable habitat. Both multidimensionality and scale can be important when making management decisions about Dark-rumped Petrels, or any endangered species.

Burrow or crevice nesting is common throughout the family Procellariidae (Warham 1990). Our study supports a number of previous observations regarding nesting requirements of the two races of the Dark-rumped Petrel (Simons 1983, 1985, Cruz and Cruz 1990). The tendency of Dark-rumped Petrels to locate nests in relatively steep areas is consistent with observations of other gadfly petrels (e.g. Schramm

TABLE 2.   Parameter estimates for final stepwise logistic regression.

Term	Estimate ± SE	X^2
Lin B		
Intercept	−13.2 ± 31.4	0.18
Shrub distance	−0.547 ± 0.263	4.66*
Color [black-red]	0.547 ± 31.2	0.00
Color [brown-red]	−1.43 ± 31.2	0.00
Color [none-red]	−2.54 ± 93.7	0.00
Burrow rock	0.0664 ± 0.0205	10.51***
Aspect	0.0219 ± 0.00573	14.62***
Average rock	0.0407 ± 0.0136	9.01**
Lin C		
Intercept	−0.383 ± 23.8	0.00
Shrub distance	−0.182 ± 0.0887	4.20*
Color [black-red]	−1.67 ± 23.8	0.00
Color [brown-red]	−4.46 ± 23.8	0.04
Color [none-red]	7.13 ± 71.4	0.01
Burrow rock	0.00691 ± 0.00678	1.04
Aspect	0.0166 ± 0.00423	15.47***
Average rock	0.0145 ± 0.0101	2.08

*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

TABLE 3.   Proportion of sampled locations classified as burrow, colony, or landscape by stepwise logistic regression model.

Predicted	Actual		
	Burrow	Colony	Landscape
Burrow	0.91	0.16	0.02
Colony	0.05	0.71	0.24
Landscape	0.03	0.14	0.74

1983, Burger and Gochfeld 1991). Advantages of steep terrain over flatter ground may include rapid drainage, wide field of view from the burrow entrance, ease of excavation, and ease of takeoff and landing, especially when burrows are located in boulder fields or heavy cover. To date, studies of Dark-rumped Petrels provide no data to evaluate the relative merits of these potential benefits.

Locating burrows beneath large rocks should minimize the chance of burrow collapse. While coarse, cindery soil may allow rapid drainage during the occasionally very heavy rainfalls typical of the Haleakala summit, it provides little of the structural cohesiveness necessary to a stable burrow (e.g. Stokes and Boersma 1991) without other means of stiffening the walls and roof. Cohesion could be provided by burrowing beneath a heavy mass, such as a large boulder, which would stiffen the walls and at the same time provide a roof immune to collapse. Soil stiffening could also be provided by the networked roots of plants. Perhaps for this reason, Dark-rumped Petrel burrows not found under very large boulders or in natural cavities are located at the bases of bunchgrasses or shrubs (Simons 1985). Large burrow rocks may also minimize burrow collapse inadvertently caused by large mammals, although these introduced species were obviously not the selective agent responsible for this adaptation. Simons (1985)

noted that trampling by feral goats collapsed a number of burrows and may have been a significant source of mortality for nestling Dark-rumped Petrels before the goat-control program was initiated by the Haleakala National Park management. The characteristics of the collapsed burrows, especially with regard to the overlying rock, were not reported by Simons (1985).

The proximity of vegetative cover differed significantly between Dark-rumped Petrel burrows and random areas in the colony or landscape, and was a significant regressor in discriminating among the three classes of habitat. Shrubs may tend to occur closer to large rocks than to random points in the general habitat. Large rocks provide a shaded microclimate where young plants are protected from the intense ultraviolet radiation typical of the Haleakala summit, which otherwise severely restricts plant growth in this area (Wagner et al. 1990).

The low correlation between rock sizes uphill versus at the burrow suggests that Dark-rumped Petrels located the majority of burrows in areas with a sudden change in rock sizes. Such gradients are common at the margins of basalt outcrops. Siting burrows near such discontinuities might simplify locating burrows on return flights. Dark-rumped Petrels do not arrive at the Haleakala summit until several hours after sundown; thus, large-scale geomorphological features might serve as aids in nest location. Alternatively, rocky outcroppings and other sharp-relief features may serve as predator deterrents. Short-eared Owls (*Asio flammeus*) have been sighted in the Dark-rumped Petrel nesting habitat on Haleakala (C.N.H. pers. obs.).

Haleakala's summit does not provide a homogeneous nesting area, but instead includes large areas of ash and cinder flows that are not usable by Dark-rumped Petrels. Within the

TABLE 4. Means ± SE of quantitative regressors in final logistic model.

Parameter	Burrow	Colony	Landscape
Aspect (degrees)	144.36 ± 14.38	153.02 ± 14.38	190.62 ± 15.49
Burrow rock (cm)	149.12 ± 6.03	64.83 ± 6.03	42.60 ± 6.50
Average rock (cm)	106.58 ± 4.51	74.04 ± 4.51	46.14 ± 4.86
Shrub distance (cm)	1.37 ± 1.88	2.86 ± 1.88	15.82 ± 2.03

boulder fields and basalt outcrops, burrow sites are further restricted by rock size (and presumably distance to nearest shrub) and slope characteristics not widely represented in the colony or landscape. Further restrictions may be placed by the species' tendency to locate burrows near areas of rapid (i.e. detectable at the 10-m scale) change in rock size. Whether or not Dark-rumped Petrel populations are limited by the availability of nesting habitat is open to speculation, although Simons (1985) suggested there was no evidence of such physical limitation.

Studies such as ours can be useful in delineating suitable habitat patches. The final logistic model can be used to indicate which parameters are important at the burrow scale, as well as the range of values for which to search (Table 4). This information can be used to guide ground searches for additional habitat patches. Newly sampled sites can then be tested for suitability by the probability model. If burrows are actually discovered, the existing model can be ground-truthed and changed if necessary. Because field work is time consuming, a far more powerful technique would be to classify a wide array of points using remotely-sensed data and the model presented here, to define areas of habitat where Dark-rumped Petrel burrows have a higher probability of being found. Again, the initial field data could be used to direct the search for appropriate types and values of physical characteristics, in this case aspect, rock size, and presence of shrubs.

In 1992, the on-the-ground, directed-search approach was used to survey for Dark-rumped Petrel burrows on Mauna Loa, Hawaii. Two criteria were used in the search: (1) the presence of rocky outcrops or terrain breaks, and (2) the localized availability of soils (C.N.H. unpubl. data). The general habitat within which burrows were found differed from Haleakala in slope and soil characteristics. Mauna Loa has broad expanses of flat, unbroken lava (pahoe-

hoe) and fields of rough, sharp, undulating lava (a'a). The majority of the 15 burrows found (13 active) were located near the edges of outcrops (C.N.H. unpubl. data). Determining significant differences in habitat characteristics between burrow and colony/landscape scales on Mauna Loa will allow us to compare whether the birds use an identifiable set of criterion in nest-site selection.

The nesting range of the Dark-rumped Petrel on Maui has been severely restricted from historical levels (Munro 1944). That these birds are able to breed at all within the Haleakala National Park boundary is, in large part, because of the predator-control programs instituted by the Park Service. Burrows with identical physical characteristics located outside of the Park's trap lines suffer lowered reproductive success relative to the protected population (C.N.H. unpubl. data). Without an active predator-control program, physical differences in habitat quality and potential habitat limitation are moot.

The degree to which behavior limits nest-site selection by the Dark-rumped Petrel is unknown. To date, there has only been one return of a banded fledgling (C.N.H. unpubl. data). Many petrels are natally philopatric and will return to the same site once an initial nest site has been chosen (Warham 1990). Nest-site selection also may be based on the general presence of conspecifics in the area. Galapagos Dark-rumped Petrels were significantly more attracted to playbacks of colony calls then to either single bird calls or silence (Podolsky and Kress 1992), perhaps indicating that calling is used as an indicator of quality habitat. We suspect that the tendency for Dark-rumped Petrels to be attracted to conspecifics, combined with their susceptibility to terrestrial predators, may restrict their use of the environment to large, protected patches of physically suitable habitat. As with any endangered species, an accurate assessment of the amount and distribution of "preferred"

habitat must be made before conservation strategies can be accurately developed.

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