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HABITAT USE AND LIMITING FACTORS IN A POPULATION OF HAWAIIAN DARK-RUMPED PETRELS ON MAUNA LOA, HAWAI'I

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Abstract. Through field surveys and geographic information system analysis, Dark-rumped Petrel (*Pterodroma phaeopygia sandwichensis*) nest sites on southeast Mauna Loa were characterized at two scales. Regionally, nests occurred in weathered pāhoehoe flows, most over 2,000 years old. At the scale of the individual burrow, nearly half the active nests occurred in human-modified pits; the rest were placed in various naturally occurring openings. In 1995, when feral cat (*Felis catus*) predation was limited, the nest success rate was independent of burrow type. However, in 1996, when predation was heavier, burrows placed in human-altered pits suffered higher losses. Population viability analysis suggests that at current rates of predation, the southeast Mauna Loa population of Dark-rumped petrels may not persist.

Key Words: bird catching; Dark-rumped Petrel; excavated pits; feral cats; nest success; population viability analysis; predation; *Pterodroma phaeopygia sandwichensis*; 'Ua'u.

The Hawaiian Dark-rumped Petrel (*Pterodroma phaeopygia sandwichensis*) was one of five procellariid seabirds found in the main Hawaiian Islands prior to human contact, three of which remain today (Olson and James 1982b). Breeding only in Hawai'i, these petrels enter and exit underground burrows nocturnally during the late February to November nesting season (Simons 1985). The subspecies is federally listed as endangered (USFWS 1983b). Recent electrophoretic comparisons have bolstered earlier suggestions, based on morphology and behavior, to reclassify the Hawaiian and Galápagos subspecies as full species (Browne et al. 1997).

Historical, ethnographic, archeological, and paleontological evidence suggest that prior to human arrival, the Dark-rumped Petrel occurred on all the main Hawaiian Islands from sea level to at least mid-elevations. At low elevations, it was found both offshore (e.g., Makuko'oniki [probably a variant or misspelling of Moku-ho'oniki] Islet off Moloka'i, Banko 1980d; Mānana Island off O'ahu, Handy and Handy 1972) and on the main islands themselves (e.g., 'Ewa Plains sinkholes on O'ahu, Olson and James 1982b; near South Point on Hawai'i, Moniz 1997). Munro (1960) states that the Dark-rumped Petrel nested up to 1,524 m, and large quantities of petrel bones have been found at archeological sites at approximately 1,830 m, possible evidence of nesting in the vicinity (J. Moniz, pers. comm.).

The Dark-rumped Petrel was abundant across a range of elevations as well. It was the "most abundantly represented bird in the [sea level] O'ahu deposits" examined by Olson and James (1982b:43) and was the most common species found in a paleontologically rich lava tube on Hualālai that runs from 1,310 to 1,890 m elevation (Giffin 1993).

Presently, Dark-rumped Petrels breed on Haleakalā on Maui (Hodges and Nagata *this volume*), on Mauna Loa on the island of Hawai'i, and on Kaua'i (Simons 1983, Hodges 1994, Ainley et al. 1997a). Colonies may still occur on Lāna'i, Moloka'i, and elsewhere on Hawai'i (Hirai 1978, Banko 1980d, Berger 1981, Conant 1980, Pyle 1987, Bartle et al. 1993). Estimates of the statewide population range from the thousands to perhaps low tens of thousands (Simons and Hodges 1998).

The Haleakalā colony is the subspecies' largest known population. The primary threat to its 500 or more breeding pairs is predation from introduced mammals: roof rats (*Rattus rattus*), small Indian mongooses (*Herpestes auropunctatus*), feral cats (*Felis catus*), and dogs (*Canis familiaris*; Simons 1983, Hodges 1994, Hodges and Nagata *this volume*). An ongoing and aggressive predator control program has halted most losses, and this important colony appears secure.

When found fortuitously in 1990, the southeast Mauna Loa population of the Dark-rumped Petrel was already under attack by feral cats. After the initial discovery, consisting of 11 depredated carcasses (P. Banko, unpubl. report), several subsequent surveys yielded a handful of active nests, most in the vicinity of the original site (C. Hodges, unpubl. report). Little additional work was conducted prior to the start of our fieldwork. Our goals were to locate as many nests as possible to allow us to (1) characterize habitat use at both regional and local scales, (2) estimate nest success, and (3) assess the seriousness of the predation threat.

METHODS

We report here on work conducted between July 1993 and April 1997 within Hawai'i Volcanoes Na-

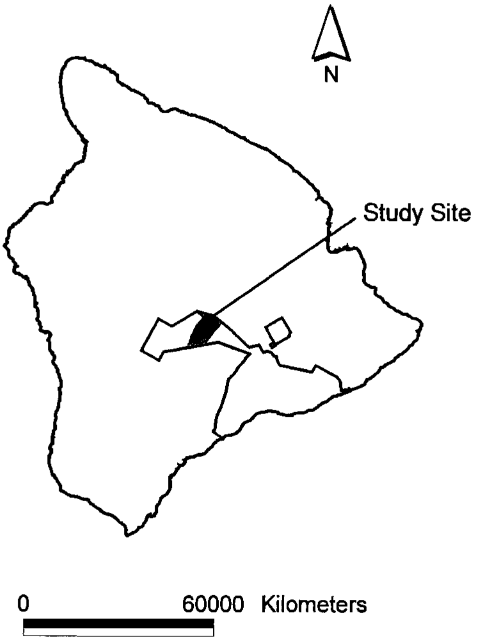

FIGURE 1. Dark-rumped Petrel study area within Hawai'i Volcanoes National Park on the island of Hawai'i. The study area lies between approximately 8,000 and 9,500 ft elevation.

tional Park (HVNP) between approximately 2,440 and 2,900 m elevation on the southeast flank of Mauna Loa (Fig. 1). Because Mauna Loa is an active volcano, last erupting in 1984, its slopes are a patchwork of lava flows of different ages and textures. On older flows, vegetation at these elevations consists of sparse subalpine scrub, with native shrubs predominating. Newer flows are unvegetated. Due to limited funding, we confined our surveys to pāhoehoe lava flows, which were previously identified as the most likely substrate for use by nesting Dark-rumped Petrels (C. Hodges, unpubl. report). Pāhoehoe lava is relatively fluid when molten; once hardened, it has a smooth, sometimes ropey surface (Hazlett 1993).

Surveys consisted of searches on foot to look for active nests, indicated by droppings splashed around the burrow entrance, or past use as evidenced by petrel remains. In most areas, we also listened for calling birds at night as an indication of active nests in the vicinity.

Whenever possible, burrow locations were recorded using a global positioning system with a typical accuracy of approximately 8 m. Locations of a few nests found early in the study were recorded with an instrument accurate only to within 25 m. Nest locations were then mapped on a geographic information system-generated flow map. Beginning in 1996, we also noted the type of geologic or archeological feature used for nesting. Some burrows found early in our work and not revisited lack this information. Since few nests had accessible or visible nest chambers, we used a variety of indirect cues to assess burrow activity and success. These included posting toothpick 'fences' across burrow entrances and then returning to look for signs of entry or exit, as well as the presence of footprints, feathers, tufts of down, splashes of excrement, and the musty smell characteristic of petrels. Nests then were categorized as inactive or active, and active nests were assigned a fate of fledged, failed, or unknown (Table 1). From these data we calculated nest success, the proportion of active nests that fledged a chick (Hodges 1994). All tests of independence were calculated using the G statistic and Williams' correction (Sokal and Rohlf 1981).

TABLE 1. NEST SUCCESS DEFINITIONS USED FOR ACTIVE DARK-RUMPED PETREL BURROWS MONITORED ON MAUNA LOA, HAWAI'I[a]

Outcome	Criteria
Fledged monitored >1 time	droppings or footprints seen up to mid-Sept., and down at burrow entrance after mid-Sept.; or droppings or footprints seen up to mid-Sept. and activity after mid-Sept., although down (due to large entrance, recent rain, or a late check) not detected.
Fledged monitored once in Sept. or later	down at entrance; or evidence of recent entry or occupation (droppings or footprints), but down not detected (entrance large, recent rain, or late check).
Failed	carcass in or near burrow entrance, or quantities of feathers inside; or egg fragments at burrow entrance and no down present late in season; or activity (droppings, footprints) prior to mid-Sept., but no sign of later entry or exit, and no down at burrow entrance.
Unknown	checked only once late in season and older droppings present (indicating probable activity earlier in season), but down not detected (due to large entrance, rain, or lateness of season); or activity noted on midseason check(s), but not monitored between mid-Sept. and mid-Nov.

[a] Modified from Hodges (1994).

To assess the effect of observed predation on HVNP's Dark-rumped Petrel population, we conducted a population viability analysis (PVA) using Version 7 of the program VORTEX (Lacy et al. 1995). VORTEX models population growth deterministically, but can also include stochastic, demographic, genetic, and environmental processes, including catastrophes, that imperil small populations. All simulations were iterated

TABLE 2. INPUT PARAMETERS FOR FIVE SIMULATIONS OF THE DARK-RUMPED PETREL POPULATION IN HAWAI'I VOLCANOES NATIONAL PARK USING THE POPULATION VIABILITY ANALYSIS PROGRAM VORTEX

		Mauna Loa predation		Stochastic predation	
Model parameter	Stable population	1995	1996	A	B
Inbreeding depression	recessive lethal	recessive lethal	recessive lethal	recessive lethal	recessive lethal
Age at 1st reproduction	6	6	6	6	6
Age at last reproduction	35	35	35	35	35
Adult males in breeding pool	89%	89%	89%	89%	89%
Density dependence	yes	yes	yes	yes	yes
First year mortality ± SD[a]	34.0 ± 10%	38.5 ± 15%	41.7 ± 15%	34.0 ± 10%	34.0 ± 10%
2nd–5th year mortality ± SD[a]	19.7 ± 10%	19.7 ± 10%	19.7 ± 10%	19.7 ± 10%	19.7 ± 10%
Adult mortality ± SD[a]	7.0 ± 10%	8.3 ± 10%	17.4 ± 10%	7.0 ± 10%	7.0 ± 10%
Starting population	1000	1000	1000	1000	1000
Carrying capacity ± SD[a]	2500 ± 10%	2500 ± 10%	2500 ± 10%	2500 ± 10%	2500 ± 10%
El Niño catastrophe					
Probability of occurrence	3%/y	3%/y	3%/y	3%/y	3%/y
Effect on reproduction	−43%	−43%	−43%	−43%	−43%
Effect on survival	−0%	−0%	−0%	−0%	−0%
Eruption catastrophe					
Probability of occurrence	0.49%/y	0.49%/y	0.49%/y	0.49%/y	0.49%/y
Effect on reproduction	−33.3%	−33.3%	−33.3%	−33.3%	−33.3%
Effect on survival	−16.7%	−16.7%	−16.7%	−16.7%	−16.7%
Predation catastrophe					
Probability of occurrence	not included	not included	not included	33.3%/y	20%/y
Effect on reproduction				−7.7%	−7.7%
Effect on survival				−10.4%	−10.4%

[a] Standard deviations reflect environmental variation.

1,000 times and modeled population growth over a 200-year time span. Initially, we modeled a stable population based largely on Simons' (1984) population model of the Haleakalā colony. Two additional runs substituted mortality data collected from HVNP in 1995 and 1996. Because cats in the subalpine habitats appeared to range widely, were absent from some nest groups in both years, and may not necessarily encounter petrel breeding areas at a time when birds are most vulnerable (i.e., when adults are calling or when fledglings emerge prior to departure), the final two runs modeled cat predation as a catastrophe with different probabilities of occurrence (Table 2). The effects of catastrophic predation on reproduction and survival were based on the predation-related mortality documented in 1996.

RESULTS

To date, we have surveyed approximately two-thirds of the appropriate habitat. Because of time and funding constraints, the northeast portion of the study area was surveyed more thoroughly than the less accessible southwest end. In total, we found 50 nests ranging in elevation from 2,440 to 2,800 m.

At a regional scale, most nests were clustered into four distinct groups, with all or most nests within each group placed on the same lava flow. Utilized flows ranged in age from 2,000 to 8,999 years old (Fig. 2). A few additional nests found outside the main groups were on flows 1,000–2,999 years old. Despite the extensive age range, the surfaces of all nesting flows were oxidized and broken.

At the scale of the individual nest, 21 (52.5%) of the 40 burrows we classified were located in various naturally occurring features including lava tubes (12 nests), cracks in tumuli (fractured hills on the surface of pāhoehoe flows; Hazlett 1993; three nests), spaces created by the uplift of pāhoehoe slabs (three nests), and miscellaneous natural features (three nests). The remaining 19 burrows were located in pāhoehoe pits that showed evidence of human modification. Modification consisted of excavation of chunks of pāhoehoe, as evidenced by more recently exposed (less weathered) surfaces both on excavated material and pit edges. It is unclear if excavations were performed to enlarge existing holes or to create new ones. Regardless, the resultant pits provide access to the space between the surface and the underlying flow (Fig. 3) where petrels currently nest. Based on our examinations to date, it appears excavations were

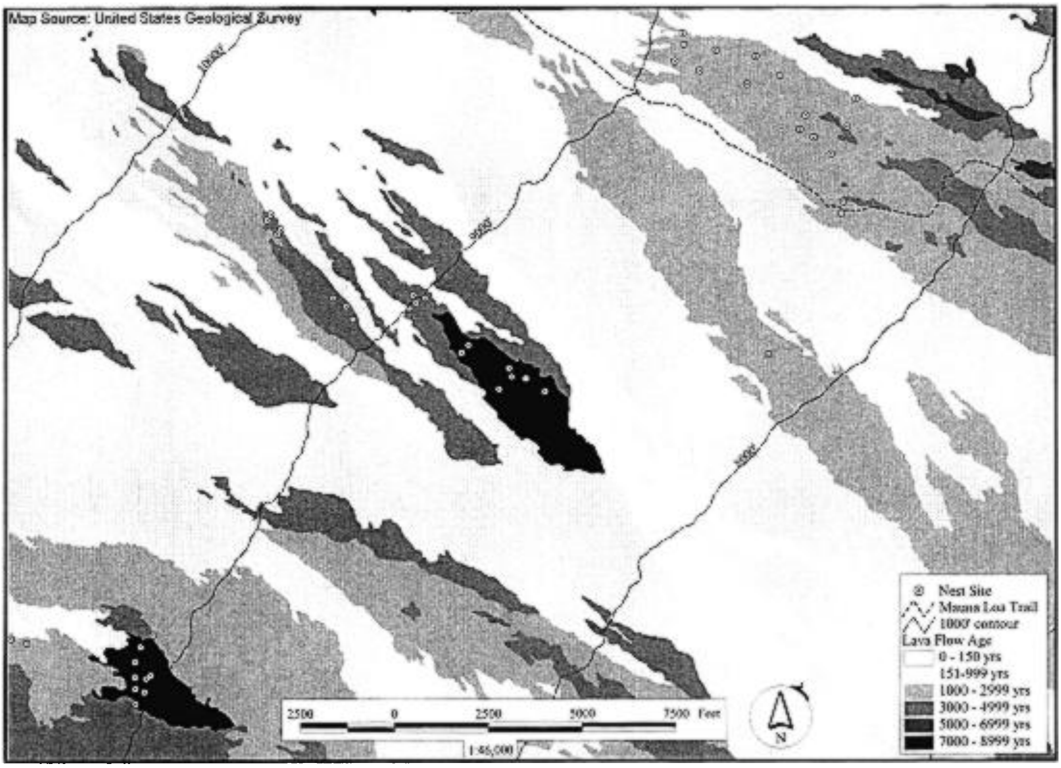

FIGURE 2. Distribution of Dark-rumped Petrel nests found during this study in relation to age of surface lava flows on southeast Mauna Loa, Hawai'i. Geologic map courtesy of F. Trusdell and J. Lockwood (unpubl. data), U.S. Geological Survey, Hawaiian Volcano Observatory.

performed either prehistorically (pre-1778) or in early historical times.

In 1995, monitored burrows in the easternmost group of nests suffered limited cat predation. A single cat was trapped in late summer, probably preventing more extensive losses. We noted no predation following the capture, and success for all nests that year was 61.5%. In 1996 we conducted no trapping. Nest success dropped to 41.7%, mainly due to cat predation in one of the central nest groups (Table 3). Nest success was associated with year (G_{adj} = 6.43, P = 0.040, df = 2, N = 63). In 1995, the year of limited predation, success was independent of burrow type (G_{adj} = 1.70, P = 0.42, df = 2, N = 35). In 1996, the year of heavy predation, success was associated with burrow type (G_{adj} = 7.54, P = 0.023, df = 2, N = 24): nests placed in anthropogenic pits failed more frequently than those placed in natural features.

All runs of the PVA began with a population of 1,000 individuals. Because Mauna Loa surveys are incomplete, this starting population size was based on our crude approximation that the 50 known nests represent one-fourth of the breeding population and the estimate that some 40% of the population is nonbreeding (Spear et al. 1995). Applying mortality figures given by Simons (1984) for his hypothetical, stable Dark-rumped Petrel population resulted in an exponential growth rate, *r*, of near zero and persistence of the population in 97.5% of the iterations (Table 4). Substituting success and mortality figures from our 1995 work resulted in 28% of the iterations going extinct in an average of 158 years and the remaining populations slowly declining. Use of 1996 data resulted in the extinction of all 1,000 iterations in an average of 65 years. Compared to runs which modeled predation deterministically, the two runs in which predation was modeled as a stochastic variable yielded intermediate results for number of iterations going extinct, mean time to extinction, and mean growth rate of those iterations persisting. However, even the most optimistic scenario, in which severe predation of the magnitude observed in 1996 occurred only approximately every five years, resulted in the extinction of over half the iterations and a declining growth rate for those persisting 200 years.

FIGURE 3. A human-modified pit on Mauna Loa, Hawai'i. Rocks in the foreground were broken to make or enlarge the opening visible in the background. Photo by C. Glidden.

TABLE 3. OUTCOMES OF ACTIVE DARK-RUMPED PETREL NESTS ON MAUNA LOA, HAWAI'I IN 1995 AND 1996

Nest outcome	1995	1996
Fledged	24	10
Failed	5	10
Unknown	10	4
Total	39	24

DISCUSSION

Throughout the Hawaiian Archipelago, Dark-rumped Petrels still display considerable diversity in nesting habitat. On Maui, most petrel burrows are excavated in cinder substrate (Hodges 1994). Kaua'i lacks subalpine habitat, as do the other main islands where the species may persist; birds on these islands may nest on cliff faces or thickly vegetated ridges. This diversity in nesting habitat suggests that should factors now limiting the species ever be adequately controlled, Dark-rumped Petrels would not be behaviorally or physiologically limited to currently occupied nesting areas, some of which may have marginal temperature and humidity ranges for eggs and chicks.

In Mauna Loa's subalpine zone, Dark-rumped Petrels appear fairly narrowly circumscribed in their nesting by the presence of appropriate flows. However, the wide age range of utilized flows (1,000–8,000 yrs old) suggests age is an imperfect indicator of suitable substrate, and perhaps only correlated with other factors, such as the presence of shallow, accessible lava tubes. In many pāhoehoe flows, lava tube networks arise and are briefly active as part of the flow emplacement process. Freeze-thaw regimes and other forms of weathering subsequently create breaks in the surface, providing access to these tubes. The pace of weathering is not strictly a linear function of age but is also influenced by elevation, aspect, slope, and localized weather (B. Camara, pers. comm.). On Mauna Loa, lava tubes are favored for nesting both in their natural form and when access is provided via anthropogenic pits.

Archaeologically, the presence of human-modified pits at elevations ranging from 2,400 to 2,800 m is puzzling. The archaeological literature about Hawai'i proposes several functions for these types of features, none of which seem reasonable at this location. Possible functions include use as quarries for the extraction of building material or abrader blanks (Bevacqua 1972, Kirch 1979) or for growing crops (Barrera 1971; L. Carter, unpubl. report; J. Pantaleo et al., unpubl. report). Use of Mauna Loa pits for extracting building material is unlikely, as the project area lacks habitation sites. Nor does it seem like-

TABLE 4. RESULTS [MEAN (SE)] OF FIVE POPULATION VIABILITY ANALYSIS SCENARIOS FOR DARK-RUMPED PETRELS ON MAUNA LOA, HAWAI'I

	Stable population	Mauna Loa predation		Stochastic predation	
		1995	1996	A	B
Probability of extinction	0.0250 (0.0049)	0.276 (0.014)	1.00 (0.0)	0.958 (0.0063)	0.580 (0.016)
Years to extinction	161 (6.3)	158 (1.81)	65 (0.45)	123 (1.02)	146 (1.36)
Final size of surviving populations	921 (22.8)	280 (16.5)		19.0 (3.24)	98.4 (10.4)
Population growth rate (r)[a]	−0.0001 (0.0003)	−0.0174 (0.0003)	−0.0960 (0.0008)	−0.0481 (0.0005)	−0.0293 (0.0004)

[a] Growth rate is calculated from all simulated populations and prior to carrying capacity truncation.

ly that pits were used to extract abrader blanks, since the pāhoehoe in the area is large and blocky and unsuitable for manufacturing abraders.

The last proposed function, using the pits for growing crops, also is unlikely. Hawaiian varieties of sweet potato, the most likely crop, cannot tolerate the combination of cold, aridity, and lack of soil evident at this altitude on Mauna Loa (Yen 1974). At similar altitudes (approximately 2,750 m) in New Guinea, latitude 6° S, sweet potato growth is necessarily seasonal due to cold winter temperatures. Crops cultivated at high altitudes in New Guinea take from 7 to 12 months to mature, compared to 5 to 6 months in the lowlands (Bourke 1982). As in the drier regions elsewhere on the island, sweet potatoes would have been grown directly in the Mauna Loa pits with the addition of mulching material. Mulch would have been essential for crop growth, but the lack of vegetation in the vicinity of the pits would have made the collection of mulching material a time consuming and difficult practice. Finally, the lack of soil within this environment severely restricts the growth potential of all plants.

We speculate that pits in the subalpine lava flows on Mauna Loa instead may have been modified for catching seabirds, including Dark-rumped Petrels. These birds would have been an attractive food source for a number of reasons: they nest synchronously and colonially, their breeding chronology (including fledging) is predictable, they have high nest-site fidelity, and many species are somewhat awkward on land (Moniz 1997). Consistent with the hypothesis that these pits were modified for catching petrels, one explanation for the difference in failure rates we observed under heavy predation is that nests placed in modified pits are more accessible to predators.

Prehistorically, Dark-rumped Petrels were a favored source of food for Hawaiians. Strongly flavored adults were salted (Munro 1960, Wichman 1985), while nestlings were more highly prized and reserved for ruling chiefs (Henshaw 1902a, Munro 1960). On the island of Hawai'i, H. C. Shipman recounted stories from his childhood in which he heard of "native Hawaiians claiming different caves or nesting areas, presumably in the mountains, for capturing young for food" (Banko 1980d:3). Methods of capture included placing nets over burrow entrances (Wichman 1985) and insertion of long sticks into burrows to pluck the nestlings out while twisting the pole into the soft down (Henshaw 1902a). Midden remains of Dark-rumped Petrels found in many locations on Hawai'i substantiate the use of this species for food (Banko 1980d). Ethnographic information indicates that Hawaiians may have attempted to harvest Dark-rumped Petrels in a sustained manner: "The bird catchers did not take all the birds from a hole but took only from one to three and no more, so as to keep the birds in that hole, nor were the parents taken lest there be no birds there. . ." (Kahiolo 1863:1016). Although there is no location information attached to this account, the description further indicates that birds were nesting in close proximity, perhaps several pairs to a hole, as may have been the case in the modified pits found on Mauna Loa.

Most of the Dark-rumped Petrel nests we found on Mauna Loa had nest chambers that could not be viewed directly, necessitating indirect monitoring techniques that sometimes resulted in ambiguous reproductive outcomes. This was especially true for burrows with large openings, where fledgling down was both less likely to be snagged and more difficult to detect if present. In such instances, if there was no other sign of either success or failure and previous checks had indicated activity, we categorized those nests as successful. The rationale for this decision was that failure, especially predation, usually was quite obvious—either carcasses or large quantities of feathers at or near the burrow entrance. Thus, the risk here is of inflated estimates of nest success. When the year's initial surveys were conducted well into or even at the end of the breeding season, as widely occurred in 1996, early failing nests were more likely to have been wrongly classified as inactive for the season, again inflating nest success estimates. While these methodological shortcomings dictate that our estimates of nest success should not be considered highly precise, they are within the 35–72% range found by Simons (1984) and similar to the 42% and 57% figures (for areas without and with predator control) reported by Hodges (1994).

We also attempted to err conservatively on the following additional model parameters for which we lacked substantial information: density dependence, environmental variation in age-specific mortality, and inbreeding depression. While we feel these parameters did not substantially impact the results of the PVA, we discuss them here in the interest of completeness and repeatability of results.

Density dependence probably operates for this species, with the most important effects manifested at low population levels. Because the Dark-rumped Petrel previously existed at much higher numbers, it seems unlikely that even large increases in existing populations would strain at sea-food resources (Simons 1985) or create shortages in nest sites (D. Hu, pers. obs.).

However, prospecting petrels may use the calls of other birds to select nesting colonies; attraction of Galápagos Dark-rumped Petrels (*P. p. phaeopygia*) was strongest to the sounds of a busy, thriving colony (Podolsky and Kress 1992). Thus, an Allee effect is possible at low numbers. The magnitude of such an effect may be somewhat ameliorated by the ability of petrels to prospect over large areas relatively quickly and easily in search of other calling birds.

VORTEX can include the following density dependence equation. We chose to include it in all runs:

$$P(N) = (P(0) - [(P(0) - P(K))(N/K)^{B}]) \times [N/(N + A)]$$

where

P(N) = percent females breeding at population size N;
P(0) = percent females breeding at population size near zero;
P(K) = percent females breeding at K;
B = relationship between percentage breeding and population size at large values of N;
A = the magnitude of the Allee effect.

For all runs, we set P(0) = 90% and P(K) = 80%. This was based in part on Simons' (1984) determination that 89% of adult Dark-rumped Petrels at Haleakalā bred annually, presumably reflecting the level of activity in a substantially reduced population. We followed the general recommendation for mammals and specified B = 2, prescribing a quadratic relationship for the density dependence curve (Fowler 1981). The Allee effect term equaled one in all runs, describing a mild decline in breeding activity at very low population levels.

We had little data on the amount of variation in mortality rates due to environmental variability. Choosing to include some variation, we arbitrarily set the SD in mortality at 10% for all age classes in the stable population simulation and in the two runs which modeled predation stochastically. Based on our two years of nest success data, we increased the SD in first year mortality to 15% for the two runs in which predation was modeled deterministically.

The final problematic input parameter was inbreeding depression. Here again, for the sake of realism we chose to incorporate the effect. However, we used the simpler, faster, but less realistic of the two models of inbreeding depression offered in VORTEX. In the recessive lethal model, the population contains a single recessive lethal allele. Each founder individual is heterozygous for the lethal allele, and progeny that inherit two lethal alleles are eliminated. Thus, the allele is slowly purged from the population. While Lacy et al. (1995) caution that this model underestimates the impact of inbreeding, we used it because the alternative heterosis model ran prohibitively slowly.

We included two catastrophes in all VORTEX runs: Occurrences of a severe El Niño-Southern Oscillation (ENSO) event and volcanic eruptions in which lava covers nesting habitat. The frequency of severe ENSOs was based on data from 1800 to the present (Glynn 1988). Their effect on petrel reproduction was determined by comparing fledging success from Haleakalā for 1982 to a multiple-year mean (C. Hodges, unpubl. data). We assumed no affect on adult survival. The frequency of Mauna Loa eruptions was taken from Kauahikaua et al. (1995). Effects on survival and reproduction were estimated by assuming that an eruption on Mauna Loa would impact only one of the known nest groups (western, central, or eastern), that only one adult would be in the burrow at any time, and that nests were roughly evenly distributed among the three general areas.

The lack of data for these parameters and other more basic life history components highlights the need for long-term monitoring of the species. For this population, we now face the dilemma of drawing erroneous conclusions because of our short-term view of the situation, or waiting to accumulate more data, perhaps only to document the local demise of the species.

Certainly, more data should be collected if possible. However, within the limits of current information, we believe our PVA results are robust. Modeling predation deterministically within VORTEX yielded qualitatively similar results to Simons's (1984) Leslie matrix model; even limited predation caused population decline, and more severe predation resulted in relatively quick population extirpation. When severe predation was modeled stochastically in VORTEX, the population responded similarly. Clearly, even without more data on the frequency and severity of predation on Mauna Loa petrels, control of feral cats should be the highest priority recovery action.

To conserve this population, cat control must occur regularly (Hodges and Nagata *this volume*) and in perpetuity, a commitment that requires considerable institutional support. However, any control efforts will benefit other members of Mauna Loa's avian subalpine community. Methodological improvements and related research also may aid the considerable number of bird species elsewhere in Hawai'i that are impacted by feline predation.

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