

PETREL AND SHEARWATER SURVEYS NEAR A COMMUNICATIONS TOWER NEAR VOLCANO, HAWAII, JULY 2004

FINAL REPORT

Prepared for

Clayton Group Services, Inc.
970 North Kalaheo Avenue, Suite C-316
Kailua, HI 96734

Prepared by

Robert H. Day
John R. Rose
ABR, Inc.—Environmental Research & Services
P.O. Box 80410
Fairbanks, AK 99708-0410

and

Brian A. Cooper
ABR, Inc.—Environmental Research & Services
P.O. Box 249
Forest Grove, OR 97116

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EXECUTIVE SUMMARY

- Documented recent declines in numbers of endangered Hawaiian Petrels (*Pterodroma sandwichensis*) and threatened Newell's Shearwaters (*Puffinus auricularis newelli*) on Kauai have led to increased concern about the construction of tall structures anywhere on the Hawaiian Islands. Because the proposed use of an existing 85-ft (26-m) tower by Verizon Wireless and ATT Wireless in Hawaii Volcanoes National Park raised concerns that there might be incidental take of either species, we conducted in July 2004 a radar and visual study of the movements and behavior of these bird species near the site of this tower.
- The objectives of this study were to: (1) determine movements of Hawaiian Petrels and Newell's Shearwaters in the vicinity of this tower with ornithological radar; (2) measure movement rates, behavior, and flight altitudes of these bird species near this tower; and (3) assess the probability of collision and mortality of these bird species with this tower. This report summarizes the results of these surveys in July 2004, in the middle of the breeding season.
- The study area was located in the Kau District of Hawaii Island, with the primary sampling site near the Visitors' Center at Hawaii Volcanoes National Park, adjacent to the tower site.
- We recorded a total of three targets on radar over the four nights of data collection (we were completely rained out from sampling on the fifth night). All of these targets were seen in the morning.
- Mean nightly movement rates were 0 targets/h in the evening and ranged between 0 and 0.2 targets/h in the morning.
- Mean flight directions varied little among nights; the circular standard deviation was small, indicating little variation in flight directions, which ranged between 217° and 230° (i.e., toward the southwest and, hence, toward the base of Mauna Loa).
- We recorded no Hawaiian Petrels or Newell's Shearwaters visually during our visual sampling over the 5 nights of research. Hence, we are unable to present any information on flight altitudes or behavior of either of these species.
- We estimate movement rates of ~139 birds/year (both species combined) over the vicinity of the proposed tower and estimate that the probability that a bird flying through this area will be flying in a location where it might interact with the tower is 0.037%. Based on data from Kauai, we estimate that 9.1% of the birds flying through this area are flying at altitudes low enough to interact with the tower. The estimated mortality rate is 0.00440 birds/year, with $\leq 25\%$ consisting of Hawaiian Petrels and $\geq 75\%$ consisting of Newell's Shearwaters.
- At this site, it appeared that the birds were overflying us while heading toward locations on the southeastern slopes of nearby Mauna Loa.
- Although we were unable to observe any of the birds visually to determine their identity, we believe that few, if any, were Hawaiian Petrels and that most, if not all, were Newell's Shearwaters, based on the timing of movements.
- If the total population of both Hawaiian Petrels and Newell's Shearwaters on Hawaii Island is ~2,000 birds each (rough estimates), these above estimated mortality rates would represent 0.00006% of the total island-wide population of Hawaiian Petrels and 0.00016% of the total island-wide population of Newell's Shearwaters being killed/year from collisions with this tower.

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INTRODUCTION

Hawaiian Petrels (*Pterodroma sandwichensis*) and Newell's Shearwaters (*Puffinus auricularis newelli*) are endemic Hawaiian seabirds about which there is great conservation concern. Both species are known to breed on at least some of the Main Hawaiian Islands (e.g., Harrison 1990, Hodges 1994; Cooper and Day 1995, 2003; Day and Cooper 1995, Ainley et al. 1997, Simons and Hodges 1998; Day et al. 2003a, 2003b; Hodges and Nagata 2001). The petrels are known to occur in abundance only on Maui and probably Kauai, and the shearwaters are known to occur in abundance only on Kauai; populations of both species on the other islands are believed to be small.

Because nesting colonies are very difficult to locate and conduct research in, the development of programs for studying and monitoring the populations of the Newell's Shearwater has been limited (Telfer et al. 1987, Ainley et al. 2001; T. C. Telfer, unpubl. data). Ornithological radar, combined with visual sampling, is useful for studying the movements and behaviors of these birds and is particularly useful in monitoring local populations of these two species of nocturnal seabirds. This research tool, which has been used in the Hawaiian Islands since 1992, has enabled much to be learned about the basic movements, behavior, distribution, and/or local population changes of these species around Kauai (e.g., Cooper and Day 1995, Day and Cooper 1995, Day et al. 2003b), Maui (Cooper and Day 2003), Molokai (Day et al., in review), and Hawaii (e.g., Cooper and David 1995, Cooper et al. 1996, Reynolds et al. 1997, Day et al. 2003a). Site-specific data on the movements of birds, collected with ornithological radar and visual techniques, also enable the prediction of mortality rates around proposed or existing towers and other structures and, hence, provide a quantitative technique for assessing the risk of collision-caused mortality of these species (Day and Cooper 2002, 2003, 2004; Day et al. 2003c).

Recent declines in numbers of petrels and shearwaters on Kauai (Day et al. 2003b) have led to increased concern about the construction and use of tall structures anywhere on the Hawaiian Islands. The Newell's Shearwater population, in particular, has been shown to be negatively

affected by collision-caused mortality (Cooper and Day 1998, Ainley et al. 2001). Because of the proposed use of a 26-m-high antenna tower by Verizon Wireless and ATT Wireless near Volcano, Hawaii Island, we were contracted to conduct a baseline study of the movements and behavior of these bird species near this tower and to assess the possibility for mortality of these bird species at this tower.

The objectives of this study were to:

- determine movements of Hawaiian Petrels and Newell's Shearwaters in the vicinity of this tower with ornithological radar;
- measure movement rates, behavior, and flight altitudes of these bird species near this tower; and
- assess the probability of collision and mortality of these bird species with this tower.

To meet these objectives, we conducted a radar and visual study of the movements and behavior of Hawaiian Petrels and Newell's Shearwaters near the site of this proposed tower. This study was conducted in summer (July) 2004, in the middle of the breeding season for both species and before the proposed tower was constructed.

STUDY AREA

The tower is located in the Kau District of Hawaii, within Hawaii Volcanoes National Park and ~1.5 mi (~2.4 km) west of the town of Volcano (Fig. 1). This tower is located on a small hill behind the Visitors' Center for the park, near warehouses and water-catchment basins (19°25.56'N 155°15.36'W). The elevation of this tower is ~4,000 ft (~1,220 m) above sea level. The radar sampling site (19°25.718'N 155°15.406'W) was located near the eastern end of the Visitor Center parking lot, adjacent to the road. This area consists of a mixture of buildings and native forest, including ohia (*Metrosideros polymorpha*) and koa (*Acacia koa*) trees, hapuu tree-ferns (*Cibotium* spp.), and other native plant species. The tower is 85 ft (~26 m) high and consists of a circular tubular frame ~42 in (~1.1 m) on a side (Fig. 2). This tower has no supporting guy wires.

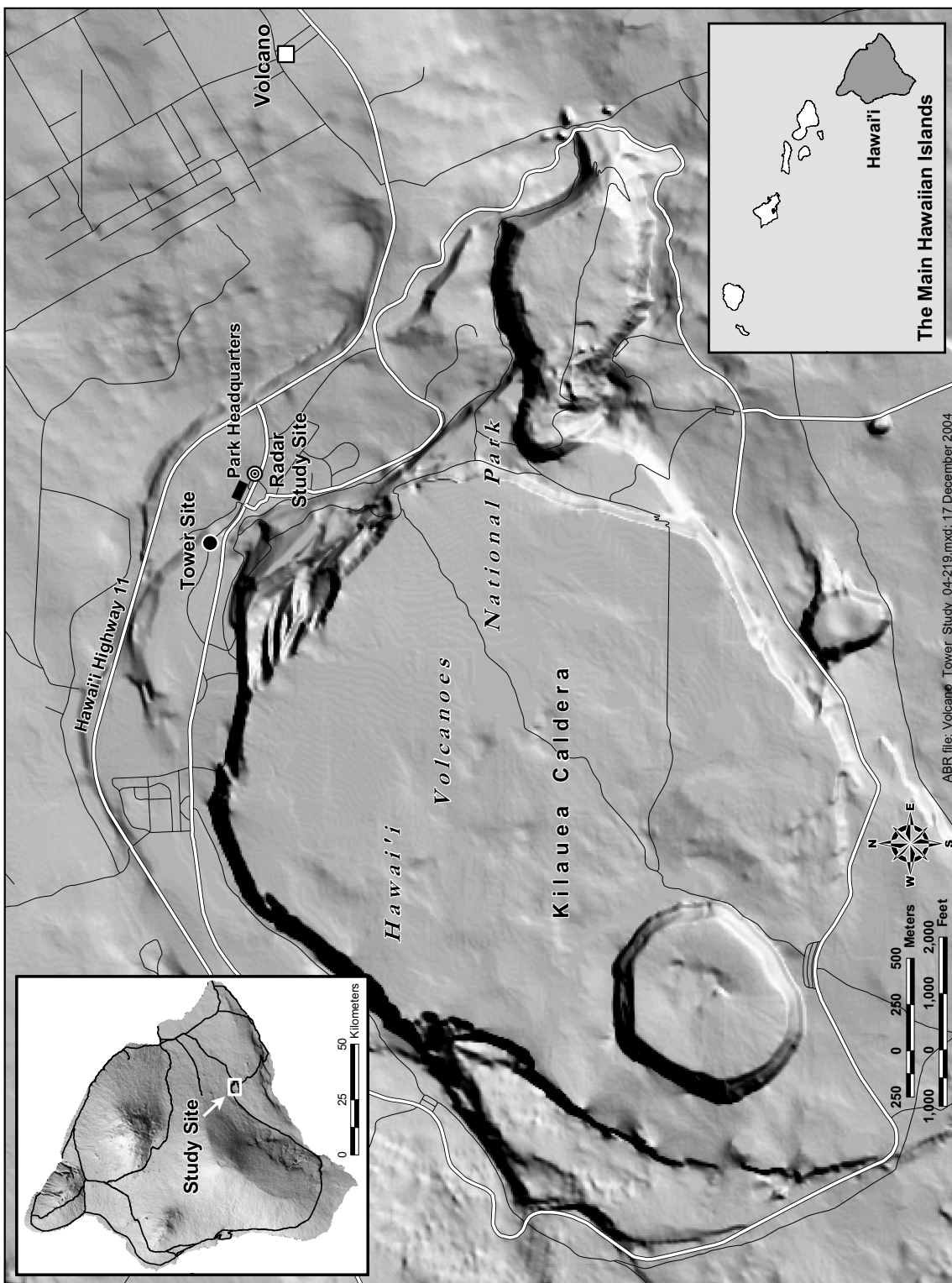


Figure 1. Location of study sites near Volcano, Hawaii, in July 2004.



Figure 2. Existing tower located near Volcano, Hawaii, in July 2004.

METHODS

We collected data on the movements, behavior, and flight altitudes of Hawaiian Petrels and Newell's Shearwaters during five nights in mid-July 2004 (Table 1). We sampled with ornithological radar for ~11 h/night, from just prior to sunset to just prior to sunrise. If we recorded a bird target on the radar, we used visual equipment (both 10X binoculars and night-vision equipment with a 5X eyepiece) to try to locate and identify the target; however, we did not do extensive visual sampling. A night's sampling was split into two time periods, one from 1900 to 0000 (evening) and the other from 0000 to 0600 (morning). These samples covered the evening and morning peaks of activity (Day and Cooper 1995), plus additional sampling time when few birds were flying; these additional hours of sampling were designed to increase our probability of seeing birds of interest and determining where they were flying. For the purpose of recording data, a calendar day began at 0700 and ended at 0659 the following morning;

that way, an evening and the following morning (i.e., an entire night's sampling) were classified as occurring on the same day.

We attempted to collect data during 25-min sampling sessions; we then used 5-min breaks between periods of data collection to collect weather data and to give observers a short break. Actual lengths of sampling sessions were 0–25 min for radar data (some time was lost when precipitation obscured significant portions of the radar screen), with nearly all sessions being 25 min long. We lost a total of 39 min of time, during 88 sampling sessions over the 4 nights of data collection, plus we had 1 entire night's sampling (the fifth night) prevented by rain (Appendices 1 and 2); overall, we lost some time during 3 of the 5 nights of sampling at this site. We do not believe, however, that this loss of sampling time significantly affected our results or conclusions: although rain occurred most often early in the evening or late in the night, which is when the most birds are flying (Day and Cooper 1995), the time

Table 1. Sampling schedule for radar and visual observations of Hawaiian Petrels and Newell's Shearwaters near Volcano, Hawaii, July 2004.

Date	Time period	Time of sampling	Comments
8 July	evening	1905–2359	light rain 1900–2300; winds light; insect activity very light; lost sampling time to rain 1935–1939, 2023–2029, 2122–2129, 2224–2227
	morning	0005–0559	clearing to cloudless skies; winds light; insect activity nearly nonexistent; lost sampling time to battery failure 0551–0559
9 July	evening	1905–2359	clear and cool; high winds becoming light winds; insect activity very light
	morning	0005–0559	very few clouds; winds light; insect activity nonexistent
10 July	evening	1905–2359	drizzle to light rain; winds light, from NE; insect activity very light
	morning	0005–0559	drizzle to light rain, stopping late in the morning; winds light, from NE; insect activity nonexistent; lost sampling time to battery change 0507–0513
11 July	evening	1905–2359	rainy, clearing after ~2 hr; insect activity light
	morning	0005–0559	rain alternating with clear skies; insect activity essentially nonexistent
12 July	evening	1905–2259	rain and high winds most of evening; sampling cancelled because unable to use radar
	morning	–	sampling cancelled

lost to rain did not extend over a long period, no sampling sessions were completely lost during the four nights we could sample, and we corrected for the number of minutes lost to precipitation in the calculation of movement rates.

We recorded the following weather and environmental data at the beginning of each sampling session:

- ordinal wind direction (10 categories)—north, northeast, east, southeast, south, southwest, west, northwest, variable/erratic, none (calm);
- wind speed (to nearest 8 km/h [5 mi/h]);
- cloud cover (to the nearest 5%);
- ceiling height (10 categories)—0 m agl, 1–50 m, 51–100 m, 101–150 m, 151–500 m, 501–1,000 m, 1,001–2,500 m, 2,501–5,000 m, >5,000 m, clear sky;
- minimal horizontal visibility in a cardinal direction (7 categories)—0–50 m, 51–100 m, 101–500 m, 501–1,000 m, 1,001–2,500 m, 2,501–5,000 m, >5,000 m;
- light condition (6 categories)—daylight with or without precipitation, crepuscular (i.e., civil twilight) with or without precipitation, darkness (i.e., the period between the end of civil twilight in the evening and the beginning of civil twilight in the morning) with or without precipitation;
- precipitation (6 categories)—none, fog, drizzle, light rain, heavy rain, scattered showers; and
- moon phase (16 categories)—moon up or not up and phase as New Moon, waxing crescent, First Quarter, waxing gibbous, Full Moon, waning gibbous, Third Quarter, waning crescent.

These standardized weather and environmental data are collected during all of our radar studies. All information on lunar phases, sunrise and sunset times, and moonrise and moonset times was taken for Kailua, Hawaii, from the website <http://www.sunrisesunset.com>.

DATA COLLECTION

Radar data-collection protocols were identical to previous studies conducted in the area and followed Cooper and Day (1995), Day and Cooper (1995, 2002, 2003), and Day et al. (2001, 2003c). The Furuno FR-1510 surveillance radar was an X-band radar transmitting at 9.410 GHz with a peak power output of 12 kW. The range of this radar was set at 1.50 km, the pulse length was set at 0.07 μ sec, and the plotting function was set to "continuous." Plotting of targets enhanced our ability to detect birds moving across the landscape. A similar radar unit is described in Cooper et al. (1991).

The radar scanned a 360° arc around the mobile radar laboratory and was used to obtain information on movement rates, flight paths, and ground speeds of birds. At the short pulse length used in this study, echo definition was high and provided precise information on target location. (An echo is a picture of a target on the radar display screen; a target is one or more birds displayed as a single echo on the radar display screen.) This radar has a digital color display with several scientifically useful features, including on-screen plotting of a sequence of echoes (to depict flight paths) and True North correction for the display screen (to determine flight directions easily). Because this radar plots the location of a target at fixed time intervals, ground speed is directly proportional to the distance between consecutive echoes and can be measured with a hand-held scale.

Whenever energy is reflected from the ground, surrounding vegetation, and other objects that surround the radar unit, a "ground-clutter" echo appears on the display screen. Because ground-clutter echoes can obscure bird echoes, we attempted to minimize the ground clutter by elevating the forward edge of the antenna (described in Cooper et al. 1991) and positioning the radar so that nearby vegetation acted as a radar fence (see Eastwood 1967). We had little ground clutter at this site.

We recorded the following data for each echo seen on the radar display screen:

- time;
- flight direction (to the nearest 1°);

- flight behavior (3 categories)—straight-line directional, erratic, circling;
- cardinal transect crossed (4 categories)—north, east, south, west (the four primary compass bearings that are used to tell in which general direction from the laboratory the radar target occurred);
- minimal distance from the radar laboratory (used to reconstruct flight tracklines of birds, if needed); and
- flight velocity (to the nearest 5 mi/h [8 km/h]).

We collected data only on targets flying ≥ 30 mi/h (≥ 48 km/h) and over land (following Day and Cooper 1995). We also included any targets flying < 30 mi/h (< 48 km/h) that we identified visually as being of either of the two species of interest and excluded any targets flying the appropriate speed but of another species; however, we detected no targets of these species flying < 30 mi/h and excluded no targets of other species that were flying otherwise-appropriate speeds during this study.

DATA ANALYSIS

We used the software Excel for all data summaries. Overall sample sizes and numbers of birds seen were too small to make statistical tests useful.

We tabulated counts of numbers of targets recorded during each sampling session, then converted these counts to estimates of movement rates of birds (radar targets/h), based on the number of minutes sampled. Because rain showers sometimes obscured significant portions of the screen (Table 1, Appendices 1 and 2), we subtracted that time during which we could not sample from the 25-min sampling session and used the resulting adjusted time in the calculation of movement rates for each session. We then used all of the estimated movement rates across sampling sessions at a site to calculate the mean ± 1 standard error (SE) nightly movement rate by time period (evening, morning) and for the entire 5-night sample.

We used the flight-direction data to calculate the mean flight direction ± 1 circular standard deviation of flight direction by time period

(evening, morning) and for the entire 5-night sample. To do these calculations, we converted flight directions to radians and calculated the mean direction and circular standard deviation following Zar (1984).

We summarized the data on flight behavior by calculating the total number of targets exhibiting each behavior. Because of the small sample sizes and uniform behaviors, we did not conduct statistical tests on these data.

We also estimated the potential for interaction and mortality of these birds with the proposed tower. To do so, we examined movement rates, the probability of interacting with an object of this size within our radar survey area, the probability of interacting with an object this high (based on what we know about flight altitudes of these birds), and the probability of mortality if an interaction occurs. Detailed information on the mortality estimation is provided in Results, so that the steps of these complicated calculations can be explained along with the results of those calculations.

RESULTS

During the five nights of data collection, the moon ranged from the Last Quarter (which occurred on the evening of 8 July) to four days after the Last Quarter. Sunset ranged from 1903 on 8 July to 1903 on 12 July, and sunrise ranged from 0547 on 9 July to 0549 on 13 July. Moonrise ranged from 0014 on 9 July (there was no moonrise on 8 July) to 0241 on 13 July, and moonset ranged from 1205 on 8 July to 1531 on 12 July.

RADAR

We recorded a total of three targets on radar over the four complete nights of sampling (we were unable to collect data on the fifth night, which was completely rained out). On the four nights that we could sample, we had few problems with data collection on radar (Table 1). We did lose some time to rain, but we do not believe that that loss affected our results or conclusions because we collected data on every sampling session and we lost a small total amount of sampling time on only 6 of 88 sessions.

MOVEMENT RATES

Movement rates varied between time periods and among nights (Table 2) and among sampling sessions (Appendices 1 and 2). We recorded no birds in the evening; instead, we recorded them only in the morning, one at 0153, one at 0420, and one at 0537. Based on the timing of movement, the first two targets probably were of Newell's Shearwaters; however, the third target could have been of either species.

Mean nightly movement rates were 0 targets/h in the evening, ranged between 0 and 0.2 targets/h in the morning, and were very low overall; we recorded single birds on only three of the four nights (Table 2). For individual sampling sessions, movement rates were 0 targets/h in the evening (Appendix 1) and ranged between 0 and 2.4 targets/h in the morning (Appendix 2). Among-night variation in movement rates was large, probably because of the low mean movement rates overall and the one night with zero targets: the CV was 100% for the four nights of sampling.

FLIGHT DIRECTION

Mean flight directions varied little among nights (Table 3), although the sample size was small (only 3 targets). The circular standard deviation was small, indicating little variation in flight directions, which ranged between 217° and 230°. Hence, all birds were flying toward the southwest and, hence, toward the base of Mauna Loa. Two of the targets passed to the southeast of us, and the third target passed to the northwest of us.

BEHAVIOR

Flight behaviors were quite consistent across all nights. Of the three targets recorded over the four nights of sampling, all targets (i.e., 100.0%) were flying with straight-line flight. Two targets were flying 35 mi/h (~56 km/h), and one was flying 45 mi/h (~72 km/h).

COLLISION POTENTIAL

We assessed the risk of collision by using the radar-movement data and the visual flight-altitude data and information on the physical characteristics of the tower itself to estimate the number of birds that might interact with the tower on a night and year (based on 180 nights/year that these species are present on the islands). We then used dimensions of the tower to estimate the annual interaction and mortality rates (Fig. 3, Table 4). This estimate then is combined with the mortality probability to estimate the annual mortality rate. We discuss here each of the main variables involved in generating these estimates.

The **movement rate** is an estimate of the average number of birds passing in the vicinity of the tower on a day, as indicated by what is seen on the radar screen. It is generated from the radar data by dividing the total number of targets recorded across all nights (if one has entire nights of sampling) by the number of nights of sampling and by multiplying that number by the mean number of birds/target and the number of days/year the birds are visiting colonies on land, to generate estimates of the number of birds passing in the vicinity of the tower during an average night and an average year. (Based on the timing of movement, we believe that

Table 2. Movement rates (targets/h) of Hawaiian Petrels and Newell's Shearwaters as determined by ornithological radar near Volcano, Hawaii, July 2004, by date and time period. Data are expressed as the mean movement rate $\pm$ 1 SE (*n*). Sample sizes for individual dates represent number of sampling sessions; sample sizes for the "total" row represent numbers of nights.

Date	Time period		Total
	Evening	Morning	
8 July	0 $\pm$ 0 (10)	0 $\pm$ 0 (12)	0 $\pm$ 0 (22)
9 July	0 $\pm$ 0 (10)	0.2 $\pm$ 0.2 (12)	0.1 $\pm$ 0.1 (22)
10 July	0 $\pm$ 0 (10)	0.2 $\pm$ 0.2 (11)	0.1 $\pm$ 0.1 (21)
11 July	0 $\pm$ 0 (10)	0.2 $\pm$ 0.2 (11)	0.1 $\pm$ 0.1 (21)
Total	0 $\pm$ 0 (4)	0.2 $\pm$ 0.2 (4)	0.1 $\pm$ 0.1 (4)

Table 3. Flight directions of Hawaiian Petrels and Newell's Shearwaters as determined by ornithological radar near Volcano, Hawaii, July 2004, by date and time period. Data are expressed as the mean flight direction $\pm$ 1 circular standard deviation (n); sample sizes represent numbers of radar targets.

Date	Time period		Total
	Evening	Morning	
8 July	$- \pm - (0)$	$- \pm - (0)$	$- \pm - (0)$
9 July	$- \pm - (0)$	$217 \pm - (1)$	$217 \pm - (1)$
10 July	$- \pm - (0)$	$230 \pm - (1)$	$230 \pm - (1)$
11 July	$- \pm - (0)$	$218 \pm - (1)$	$218 \pm - (1)$
Total	$- \pm - (0)$	$222 \pm 6 (3)$	$222 \pm 6 (3)$

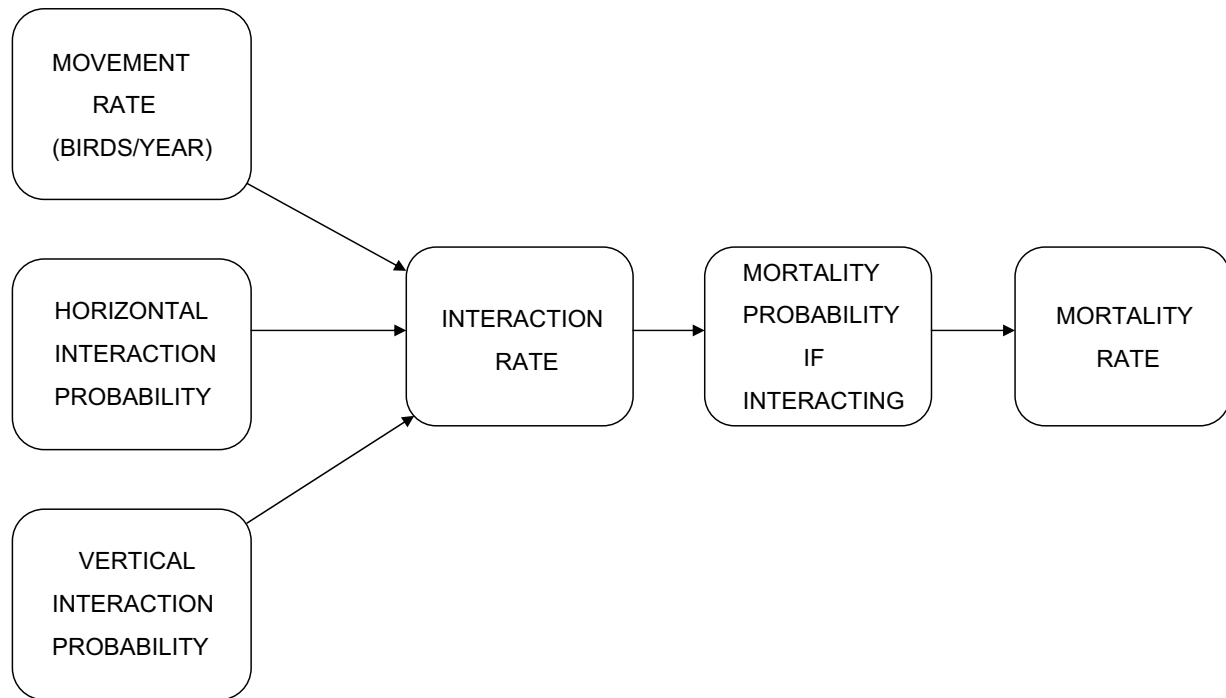


Figure 3. Major variables used in estimating mortality of Newell's Shearwaters near Volcano, Hawaii, in July 2004. See Table 4 for details on estimation.

Table 4. Steps used in estimation of mortality rates of Hawaiian Petrels (HAPE) or Newell's Shearwaters (NESH) near Volcano, Hawaii, July 2004. Important numbers for variables used in mortality estimation are enclosed in boxes.

Variable/parameter	Estimate
MOVEMENT RATE (MVR)	
(A) Number of targets recorded on all-night sessions	3
(B) Number of nights sampled	4
(C) Mean number of HAPE or NESH/target	1.025
(D) Movement rate (birds/d)	0.77
(E) Mortality domain (days/yr)	180
(F) Movement rate (birds/yr)	138.38
(G) Movement rate (birds/yr; rounded to next whole number)	139
HORIZONTAL INTERACTION PROBABILITY (IP_H)	
(H) Mean width/diameter of tower (m)	1.1
(I) Mean width/diameter of tower (km)	0.0011
(J) Diameter of radar screen (km)	3.00
(K) Horizontal interaction probability (proportion of screen width occupied by tower width; rounded to 8 decimal places)	0.00036667
VERTICAL INTERACTION PROBABILITY (IP_V)	
(L) Tower height (ft)	85
(M) Tower height (m)	26
(N) Bird data source	Kauai; all data
(O) Number of birds examined for flight altitudes	1,825
(P) Minimal flight altitude	8
(Q) Maximal flight altitude	1,000
(R) Number of birds flying ? tower height	166
(S) Vertical interaction probability (proportion flying ? tower height; rounded to 8 decimal places)	0.09095890
INTERACTION RATE (IR ; = $MVR * IP_H * IP_V$)	
(T) Interaction rate (birds/yr; rounded to 8 decimal places)	0.00463591
MORTALITY PROBABILITY IF INTERACTING (MP)	
(U) Tower type	solid monopole, unguyed
(V) Probability of striking frame if in airspace	1.00
(W) Probability of mortality if striking frame	0.95
(X) Probability of mortality if an interaction (= $V * W$; rounded to 5 decimal places)	0.95000
MORTALITY RATE (= $IR * MP$)	
(Y) Mortality rate (birds/yr)	0.00440411

most, if not all birds, were Newell's Shearwaters, but we used data on flock sizes as an average between the two species because it was possible that one of the targets was a Hawaiian Petrel; see Discussion.) The estimate of mean flock size for targets of both species combined was calculated as an average between the two species from all visual data on these species on Kauai between 1992 and 2002 (mean = 1.02 for Hawaiian Petrel and 1.03 for Newell's Shearwater; Day and Cooper, unpubl. data). Because the resulting estimate of the number of birds/year is not an integer, we then round it upward to the next whole number to generate an estimate of the average number of birds passing by the tower in a 180-day year. This upward-rounding generates a deliberately conservative estimate (i.e., it results in inflated mortality estimates), which is appropriate when estimating the risk of mortality for an endangered species, given the uncertainty in some of the model estimation parameters. Because movement rates tend to decrease between summer and fall (Day and Cooper 1995, unpubl. data), the use of movement rates from a summer sampling period will tend to overestimate the interaction and annual mortality rates, whereas the use of movement rates from a fall sampling period will tend to underestimate the interaction and annual mortality rates, for the entire 180-day breeding period.

We separated the interaction probabilities into horizontal and vertical components to make their estimation more tractable. The **horizontal interaction probability** is the probability of passing through the airspace occupied by the tower in two (horizontal) dimensions. The horizontal component involves comparing the diameter of the tower with the dimensions of the area sampled by the radar screen to determine the interaction probability. The ensuing numbers indicate the probability of interacting with (i.e., flying through the airspace of) the tower. This radar had a symmetrical screen, so only one probability estimate was generated.

The **vertical interaction probability** is the probability that a bird is flying at a low enough altitude that it might pass through the airspace occupied by a tower located somewhere on the radar screen. It is calculated from visual flight-altitude data and information on the tower's height. In effect, we use all of the visual data from

Kauai (where we have reasonable sample sizes; $n = 1,825$ birds; Day and Cooper, unpubl. data) to estimate the percentage of birds of either species flying at or below the height of this tower; sample sizes from the island of Hawaii are too small for us to be able to use data from that island. Because we do not have sufficient data to determine whether flight altitudes differ between summer and fall, we assume here that flight altitudes do not vary seasonally.

The **interaction rate** is calculated as the product of the preceding three variables (Fig. 3). As such, it is an estimate of the number of birds flying in the vicinity of the tower (i.e., crossing the radar screen) that could fly in a horizontal location and at an altitude low enough that they could interact with the tower. Only one interaction rate is generated because only one horizontal interaction probability is estimated.

Not all birds possibly interacting with the tower might be killed by it, however, necessitating the estimation of the **mortality probability**. This estimate is derived as the product of the probability of colliding with the tower if the bird enters the airspace occupied by the tower and the probability of dying if it hits the tower. The former probability is 100% because, in this case, the tower is a solid structure. On the other hand, a bird hitting the tower will have a high probability of actually dying, although a few birds may only graze the tower and escape; we used an estimate of 95% for that parameter.

The **mortality rate**, then, is calculated as the product of the interaction rate (the number of birds that might fly in the airspace occupied by the tower) and the mortality probability (the probability of dying by hitting something if the bird actually flies within that airspace). It is generated as one estimate of the number of birds killed/year as a result of the tower (i.e., the annual mortality). Again, only one mortality rate is generated because only one horizontal collision probability is estimated (above).

The major variables involved in this mortality estimation are presented in Figure 3, and the individual steps and estimates involved in these calculations are shown in Table 4. Based on data from July 2004, we estimate movement rates of ~ 0.77 bird/day and ~ 139 birds/year over the vicinity of the proposed tower and estimate that the

probability that a bird flying through this area will be flying in a location where it might interact with the tower is $\sim 0.037\%$. Based on data from Kauai, we estimate that $\sim 9\%$ of the birds flying through this area are flying at altitudes low enough to interact with the tower. Hence, the mortality rate is estimated to be 0.00440 birds/year, with $\leq 25\%$ (≤ 0.00110102 birds/year) being apportioned to Hawaiian Petrels and $\geq 75\%$ (≥ 0.00330308 birds/year) being apportioned to Newell's Shearwaters.

These estimated mortality rates assume that there will be no large lights illuminating the tower. Because bright lights attract petrels and shearwaters (Reed et al. 1985, Telfer et al. 1987), they would increase overall mortality rates by inflating movement rates in the immediate vicinity of the tower.

DISCUSSION

MOVEMENTS

Although we were unable to observe any of the birds visually to determine their identity, based on previous studies and on the timing of movements of these birds, we believe that most, if not all, were Newell's Shearwaters; however, the latest radar target was recorded during that part of the morning when both species are moving (Day and Cooper 1995). Hawaiian Petrels have been recorded repeatedly in Hawaii Volcanoes National Park (Baldwin and Hubbard 1949, van Riper and Barbee 1978, Banko 1980a; Pyle 1984, 1986; D. Hu, Hawaii Volcanoes National Park, in litt.) and on Mauna Loa (Banko 1980a, Conant 1980, Pyle 1992, Hu et al. 2001; Day and Cooper, unpubl. data). Further, radar surveys in this part of the island suggest that, based on the timing of movements, Hawaiian Petrels probably occurred at Holei Sea Arch and Punaluu and that the species probably also occurred in the Puna District, even though there were no other records of that species in that district in at least 30 years (Day et al. 2003a). Newell's Shearwaters formerly nested in the Puna District (Reynolds and Richotte 1997) and probably still do today, based on recent records on ornithological radar (Day et al. 2003a, 2003c). They were recorded breeding in Hawaii Volcanoes National Park in 1972 (Kepler et al. 1979),

although none have been recorded breeding since (Banko 1980b). Recent records on ornithological radar within the Park (Reynolds et al. 1997) were later questioned (Day et al. 2003a), but recent research by Day et al. suggested that the species occurred in very low numbers at Holei Sea Arch and possibly at Punaluu. The species is believed to nest on the wet, steep southeastern slopes of Mauna Loa (Day et al. 2003a), which would explain the records from the Park and possibly Punaluu.

These data suggest that the movement rate of birds in this part of the Kau District is very low, perhaps ~ 1 bird/night over a specific area. The Kau District and surrounding areas have low movement rates of both species (Day et al. 2003a). For example, in 2001, Day et al. recorded mean movement rates of 1.2 targets/h at Kehena, 1.2 targets/h at the Holei Sea Arch, and 1.6 targets/h at Punaluu during that part of the night when the most birds are moving (i.e., movement rates were inflated over what they would be for an entire night; Day et al. 2003a). Hence, we believe that Newell's Shearwaters and Hawaiian Petrels still fly over Hawaii Volcanoes National Park and the surrounding area, albeit in low numbers.

Mean flight directions, and, indeed, all records, were consistently in an inland/upslope trend. Our impression was that the birds were heading inland toward the slopes of Mauna Loa. Although this might seem late for birds to be headed inland, small numbers move inland all night (Day and Cooper 1995), and we have even seen Hawaiian Petrels flying inland on Kauai after the sun has risen (Day et al. 2001)

FLIGHT ALTITUDES

Because we did not observe any birds visually, we were unable to collect any flight-altitude data on any of the targets that we recorded. From our experience, however, we usually detect visually only 1–2% of all targets seen on radar (Day and Cooper, unpubl. data). Thus, we would have been extremely lucky to have detected any of the three birds visually during this four-day study.

Although we have no data on flight altitudes of these birds in the study area, altitude data are available from Kauai. Day and Cooper (1995) found at coastal locations that both species tend to

fly at higher altitudes in the evening than in the morning. Flight altitudes also tend to be higher inland than they are at coastal locations (Cooper and Day 1998), although there is considerable among-site variation in flight altitudes (Cooper and Day 1995; Day and Cooper 1995, unpubl. data). The only flight-altitude data that we have from Hawaii Island are of one Hawaiian Petrel flying at 30 m agl in the Pohakuloa Training Area and of one Newell's Shearwater flying at 25 m agl, one flying at 75 m agl, and six flying at 125–250 m agl at scattered locations around the island (Day and Cooper, unpubl. data); hence, only one of eight Newell's Shearwaters on this island has been recorded flying anywhere nearly as low as the height of this tower. It will, however, require more data before we can determine mean flight altitudes of either species at this particular location with any degree of confidence.

BEHAVIOR

The limited data collected by the radar suggested that all targets were flying in a straight-line direction. This strong tendency for straight-line flight is similar to that seen on Kauai in 1992–2002 and on Hawaii in 1994–2002 (Day and Cooper, unpubl. data). Flight velocities also were well within the range of speeds recorded on these islands. Again, our lack of visually observed birds within the study site prevents us from discussing any other aspects of flight behavior.

RISK ASSESSMENT

It is difficult for us to assess with certainty the probability of mortality of either Hawaiian Petrels or Newell's Shearwaters with the tower, although we have used some known information to estimate the probable mortality rate with as much accuracy and precision as we could. These estimates suggest that the mortality rate of both species combined will be very low: 0.00440 birds/year. Again, this estimate is slightly inflated because (1) we rounded up numbers in some of the steps of the mortality calculations to be conservative about the mortality of an endangered species, given the uncertainty in some of the model estimation parameters and (2) estimates based on movement rates only from the summer, which are higher than those from the fall,

will tend to overestimate mortality rates over an entire year.

It is difficult to put these estimated interaction and mortality rates in perspective because the size of the population of petrels and shearwaters flying over Hawaii Island is unknown. An extremely rough estimate of the island-wide population of Hawaiian Petrels is on the order of 2,000 birds (D. Hu, in litt.; see Day and Cooper 2004), suggesting that this mortality estimate (≤ 0.00110102 birds/year) would represent 0.00006% of the total island-wide population killed in a year. An extremely rough estimate of the island-wide population of Newell's Shearwaters also is on the order of 2,000 birds (Day and Cooper, unpubl. data; see Day and Cooper 2004), suggesting that this mortality estimate (≥ 0.00330308 birds/year) would represent 0.00016% of the total island-wide population killed in a year. We emphasize here that accurate island-wide population estimates of both species are lacking and are needed to put such mortality estimates in proper perspective.

LITERATURE CITED

- Ainley, D. R., T. C. Telfer, and M. H. Reynolds. 1997. Townsend's Shearwater (*Puffinus auricularis*). In A. Poole and F. Gill, eds. The Birds of North America, No. 297. Academy of Natural Sciences, Philadelphia, PA, and American Ornithologists' Union, Washington, DC. 20 pp.
- Ainley, D. G., R. Podolsky, L. de Forest, G. Spencer, and N. Nur. 2001. The status and population trends of the Newell's Shearwater on Kaua'i: insights from modeling. Pages 108–123 in J. M. Scott, S. Conant, and C. van Riper III, eds. Ecology, conservation, and management of endemic Hawaiian birds: a vanishing avifauna. Studies in Avian Biology 22.
- Baldwin, P. H., and D. H. Hubbard. 1949. The Dark-rumped Petrel reappears on Hawaii. Condor 51: 231–232.
- Banko, W. E. 1980a. Part I. Population histories—species accounts. Sea birds: Hawaiian Dark-rumped Petrel ('Ua'u). Cooperative National Park Resources Studies

- Unit, University of Hawaii at Manoa, Honolulu, HI. CPSU/UH Avian History Report 5B: History of Endemic Hawaiian Birds. 42 pp.
- Banko, W. E. 1980b. Part I. Population histories—species accounts. Sea birds: Newell Shearwater ('A'o). Cooperative National Park Resources Studies Unit, University of Hawaii at Manoa, Honolulu, HI. CPSU/UH Avian History Report 5B: History of Endemic Hawaiian Birds. 35 pp.
- Conant, S. 1980. Recent records of the 'Ua'u (Dark-rumped Petrel) and the 'A'o (Newell's Shearwater) in Hawaii. 'Elepaio 41: 11–13.
- Cooper, B. A., and R. E. David. 1995. Radar and visual survey of seabirds in the HELCO SPP Unit 71, Puna, Hawaii, during July 1995. Unpublished report prepared for R. M. Towill Corp., Honolulu, HI, by ABR, Inc., Forest Grove, OR, and Rana Productions, Ltd., Kailua-Kona, HI. 19 pp.
- Cooper, B. A., R. E. David, and R. J. Blaha. 1996. Radar and visual surveys of endangered seabirds and bats in the Pohakuloa Training Area, Hawai'i, during summer 1995. Unpublished report prepared for R. M. Towill Corporation, Honolulu, HI, by ABR, Inc., Forest Grove, OR, and Rana Productions, Ltd., Kailua-Kona, HI. 47 pp.
- Cooper, B. A., and R. H. Day. 1995. Kauai Endangered Seabird Study, Vol. 1: interactions of Dark-rumped Petrels and Newell's Shearwaters with utility structures on Kauai, Hawaii. Electric Power Research Institute, Palo Alto, CA, Final Report No. TR-105847-V1. 170 pp.
- Cooper, B. A., and R. H. Day. 1998. Summer behavior and mortality of Dark-rumped Petrels and Newell's Shearwaters at power lines on Kauai. Colonial Waterbirds 21: 11–19.
- Cooper, B. A., and R. H. Day. 2003. Movement of Hawaiian Petrels to inland breeding sites on Maui Island, Hawaii. Waterbirds 26: 62–71.
- Cooper, B. A., R. H. Day, R. J. Ritchie, and C. L. Cranor. 1991. An improved marine radar system for studies of bird migration. Journal of Field Ornithology 62: 367–377.
- Day, R. H., and B. A. Cooper. 1995. Patterns of movement of Dark-rumped Petrels and Newell's Shearwaters on Kauai. Condor 97: 1011–1027.
- Day, R. H., and B. A. Cooper. 2002. Petrel and shearwater surveys near a proposed tower near Pa'auilo, Hawai'i, June 2002. Unpublished report prepared for Clayton Group Services, Inc., Kailua, HI, and Crown Castle International, Waipio, HI, by ABR, Inc.—Environmental Research & Services, Fairbanks, AK, and Forest Grove, OR. 13 pp.
- Day, R. H., and B. A. Cooper. 2003. Petrel and shearwater surveys near County of Hawaii emergency communications towers, July 2003. Unpublished report prepared for Scientel America, Inc., and PBR Hawaii, Hilo, HI, by ABR, Inc.—Environmental Research & Services, Fairbanks, AK, and Forest Grove, OR. 24 pp.
- Day, R. H., and B. A. Cooper. 2004. Estimated mortality of petrels and shearwaters near a proposed USCG tower near Hilo, Hawaii Island. Unpublished report prepared for U.S. Coast Guard, Honolulu, HI, by ABR, Inc.—Environmental Research & Services, Fairbanks, AK, and Forest Grove, OR. 8 pp.
- Day, R. H., B. A. Cooper, and R. J. Blaha. 2003a. Movement patterns of Hawaiian Petrels and Newell's Shearwaters on the island of Hawai'i. Pacific Science 57: 147–159.
- Day, R. H., B. A. Cooper, R. Swift, and C. M. Stephens. In review. Radar studies of Hawaiian Petrels and Newell's Shearwaters on the Kalaupapa Peninsula, Moloka'i Island. 'Elepaio.
- Day, R. H., B. A. Cooper, and T. C. Telfer. 2003b. Decline of Townsend's (Newell's) Shearwaters (*Puffinus auricularis newelli*) on Kauai, Hawaii. Auk 120: 669–679.

- Day, R. H., R. E. David, and B. A. Cooper. 2001. Petrel and shearwater surveys near the Lihue Energy Service Center power line on Kauai, October 2001. Unpublished report prepared for Planning Solutions, Inc., Honolulu, HI, and Kauai Electric, Lihue, HI, by ABR, Inc., Environmental Research and Services, Fairbanks, AK, Rana Productions, Ltd., Kailua-Kona, HI, and ABR, Inc., Environmental Research and Services, Forest Grove, OR. 20 pp.
- Day, R. H., T. J. Mabee, and B. A. Cooper. 2003c. Petrel and shearwater surveys near a USCG tower at Pahoehoe, Hawaii, October 2002. Unpublished report prepared for U.S. Coast Guard, Honolulu, HI, by ABR, Inc.—Environmental Research & Services, Fairbanks, AK, and Forest Grove, OR. 24 pp.
- Eastwood, E. 1967. Radar ornithology. Methuen and Co., Ltd., London, United Kingdom. 278 pp.
- Harrison, C. S. 1990. Seabirds of Hawaii: natural history and conservation. Cornell University Press, Ithaca, NY. 249 pp.
- Hodges, C. S. N. 1994. Effects of introduced predators on the survival and fledging success of the endangered Hawaiian Dark-rumped Petrel (*Pterodroma phaeopygia sandwichensis*). M.S. Thesis, University of Washington, Seattle, WA. 49 pp.
- Hodges, C. S. N., and R. J. Nagata. 2001. Effects of predator control on the survival and breeding success of the endangered Hawaiian Dark-rumped Petrel. Pages 308–318 in J. M. Scott, S. Conant, and C. van Riper III, eds. Ecology, conservation, and management of endemic Hawaiian birds: a vanishing avifauna. Studies in Avian Biology 22.
- Hu, D., C. Glidden, J. S. Lippert, L. Schnell, J. S. MacIvor, and J. Meisler. 2001. Habitat use and limiting factors in a population of Hawaiian Dark-rumped Petrels on Mauna Loa, Hawai'i. Pages 234–242 in J. M. Scott, S. Conant, and C. van Riper III, eds. Ecology, conservation, and management of endemic Hawaiian birds: a vanishing avifauna. Studies in Avian Biology 22.
- Kepler, C. B., J. Jeffrey, and J. M. Scott. 1979. Possible breeding colonies of Manx Shearwater on the island of Hawaii. 'Elepaio 39: 115–116.
- Pyle, R. L. 1984. Hawaiian Islands Region (1 August–30 November 1984). American Birds 39: 105–107.
- Pyle, R. L. 1986. Hawaiian Islands Region (1 August–30 November 1985). American Birds 40: 161–163.
- Pyle, R. L. 1992. Hawaiian Islands Region (summer 1992). American Birds 46: 1181–1182.
- Reed, J. R., J. L. Sincock, and J. P. Hailman. 1985. Light attraction in endangered procellariiform birds: reduction by shielding upward radiation. Auk 102: 377–383.
- Reynolds, M. H., B. A. Cooper, and R. H. Day. 1997. Radar study of seabirds and bats on windward Hawaii. Pacific Science 51: 97–106.
- Reynolds, M. H., and G. L. Richotte. 1997. Evidence of Newell's Shearwater breeding in Puna District, Hawaii. Journal of Field Ornithology 68: 26–32.
- Simons, T. R., and C. N. Hodges. 1998. Dark-rumped Petrel (*Pterodroma phaeopygia*). In A. Poole and F. Gill, eds. The birds of North America, No. 345. The Birds of North America, Inc., Philadelphia, PA. 24 pp.
- Telfer, T. C., J. L. Sincock, G. V. Byrd, and J. R. Reed. 1987. Attraction of Hawaiian seabirds to lights: conservation efforts and effects of moon phase. Wildlife Society Bulletin 15: 406–413.
- van Riper, C., III, and R. D. Barbee. 1978. Dark-rumped Petrel at Hawaii Volcanoes National Park. Bird-Banding 49: 372.
- Zar, J. H. 1984. Biostatistical analysis. Second Edition. Prentice-Hall, Englewood Cliffs, NJ. 718 pp.

Appendix 1. Movement rates (targets/h) on radar during the evening near Volcano, Hawaii, July 2004, by date and sampling session. Actual lengths of sessions shortened by rain showers or other reasons are listed in parentheses after the movement rate; otherwise, session length is 25 min.

Date	Time of sampling			
	1905–1929	1935–1959	2005–2029	2035–2059
8 July	0	0 (20)	0 (19)	0
9 July	0	0	0	0
10 July	0	0	0	0
11 July	0	0	0	0
				0 (17)
				0
				0
				0

Date	Time of sampling			
	2135–2159	2205–2229	2235–2259	2305–2329
8 July	0	0 (21)	0	0
9 July	0	0	0	0
10 July	0	0	0	0
11 July	0	0	0	0
				0
				0
				0
				0

Appendix 2. Movement rates (targets/h) on radar in the morning near Volcano, Hawaii, July 2004, by date and sampling session. Actual lengths of sessions shortened by rain showers or other reasons are listed in parentheses after the movement rate; otherwise, session length is 25 min.

Date	Time of sampling				
	0005–0029	0035–0059	0105–0129	0135–0159	0205–0229
8 July	0	0	0	0	0
9 July	0	0	0	0	0
10 July	0	0	– (0)	0	0
11 July	0	0	0	2.4	0

Date	Time of sampling				
	0305–0329	0335–0359	0405–0429	0435–0459	0505–0529
8 July	0	0	0	0	0 (16)
9 July	0	0	0	0	2.4
10 July	0	0	2.4	0	0 (18)
11 July	0	0	0	0	0