FINAL REPORT

PETREL AND SHEARWATER SURVEYS NEAR KALAUPAPA, MOLOKAI ISLAND, JUNE 2002

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EXECUTIVE SUMMARY

- Hawaiian Petrels (*Pterodroma sandwichensis*; formerly Dark-rumped Petrels *Pterodroma phaeopygia sandwichensis*) and Newell's Shearwaters (*Puffinus auricularis newelli*) are endemic Hawaiian subspecies of tropical Pacific species of seabirds that are endangered and threatened, respectively. Essentially nothing is known about their current status on Molokai Island.
- We used ornithological radar and visual techniques to survey for both species at four sites on the Kalaupapa Peninsula of northern Molokai during 25–29 June 2002. The emphasis was on determining whether either species occurs there today and, if so, in approximately what numbers.
- We saw radar targets that we considered to be probable petrels or shearwaters entering the Waikolu Valley, the Waialeia Valley, and the Waihanau Valley; we also saw targets entering the pali, but we believe that they were circling over the island before entering one or more of the valleys.
- The timing of movements suggested that Hawaiian Petrels occurred at three sites (Waialeia, Waihanau, and Waikolu/Waialeia) and may have occurred at the fourth (Pali) and that Newell's Shearwaters occurred at only three sites (Waialeia, Pali, and Waikolu/Waialeia). We caution, however, that we have no visual verification of either of these species.
- Mean nightly movement rates ranged between 0.8 and 9.6 targets/h, with the highest mean nightly movement rates occurring at the coastal Waikolu/Waialeia and Waialeia sites and the lowest mean nightly movement rates occurring at the inland Waihanau and Pali sites. Movement rates into the Waikolu Valley are underestimated because of a radar shadow.
- Mean overall flight directions varied, both among nights and among sites, and ranged between 216° and 257°; the moderately-sized circular standard deviations reflected variation in flight directions and, occasionally, the effects of small sample sizes.
- Flight behaviors were predominantly directional, with 38 of 42 targets exhibiting straight-line (directional) behavior.
- We recorded two unidentified petrels/shearwaters visually during the five nights of sampling. Both of these were seen at the Waialeia site and were flying at altitudes of 40 m and 500 m above ground level.
- The timing of the movement data suggests that both Hawaiian Petrels and Newell's Shearwaters still occur, and presumably still nest, on Molokai; the flight behavior of the targets on the radar display screen reinforce this view.
- Movement rates of petrel/shearwater targets at all sites were small, with mean nightly rates at the Waikolu/Waialeia and Waialeia sites comparable to the lowest rates on Kauai and rates at the other two sites much lower than any sites on Kauai but comparable to rates along most of the shoreline of Hawaii and southwestern Maui.
- Flight directions and behaviors suggested that the targets that we believe were petrels and shearwaters were birds entering/leaving nesting colonies in the valleys.
- Our preliminary survey of just three of the eight valleys on the northeastern part of Molokai suggests that both Hawaiian Petrels and Newell's Shearwaters nest there. We suspect that one or both species still nest today in probably most or all of the eight major valleys on Molokai, with the Pelekunu and Wailau valleys having the greatest potential for nesting birds.
- We recommend that further surveys on Molokai be conducted to delineate better the distribution and abundance of these species there.

TABLE OF CONTENTS

EXECUTIVE SUMMARY i
LIST OF FIGURES ii
INTRODUCTION 1
STUDY AREA 1
METHODS 3
DATA COLLECTION 5
RADAR 5
VISUAL 5
DATA ANALYSIS 6
RADAR 6
VISUAL 6
RESULTS 6
RADAR 6
SITE CHARACTERISTICS 6
TARGET IDENTIFICATION 7
MOVEMENT RATES 8
FLIGHT PATHS 8
FLIGHT DIRECTION 9
BEHAVIOR 9
VISUAL 9
DISCUSSION 9
TARGET IDENTIFICATION 9
DISTRIBUTION AND ABUNDANCE 11
FLIGHT ALTITUDES 12
BEHAVIOR 12
CONCLUSIONS AND RECOMMENDATIONS 12
LITERATURE CITED 13

LIST OF FIGURES

Figure 1. Location of study sites near Kalaupapa, Molokai, in June 2002. 2

LIST OF TABLES

Table 1. Sampling schedule for radar and visual observations of Hawaiian Petrels and Newell's Shearwaters near Kalaupapa, Molokai, June 2002. 4

Table 2. Estimated numbers of Hawaiian Petrels and Newell's Shearwaters as determined by timing of movements on ornithological radar near Kalaupapa, Molokai, June 2002, by site, date, and flight characteristics. 8

Table 3. Movement rates of Hawaiian Petrels and Newell's Shearwaters as determined by ornithological radar near Kalaupapa, Molokai, June 2002, by site, date, and target type. 9

Table 4. Mean flight directions of Hawaiian Petrels and Newell's Shearwaters as determined by ornithological radar near Kalaupapa, Molokai, June 2002, by site, date, and targets type. ... 10

LIST OF APPENDICES

Appendix 1. Locations of sampling sites during surveys near Kalaupapa, Molokai, June 2002 16

Appendix 2. Movement rates of petrel/shearwater targets on ornithological radar during the evening near Kalaupapa, Molokai, June2002, by site and date. 17

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INTRODUCTION

Hawaiian Petrels (*Pterodroma sandwichensis*; formerly Dark-rumped Petrels *Pterodroma phaeopygia sandwichensis*) and Newell's Shearwaters (*Puffinus auricularis newelli*) are endemic Hawaiian subspecies of tropical Pacific species of seabirds. Probably several thousand of the endangered petrels and many tens of thousands of the threatened shearwaters occur in the Hawaiian Islands (Harrison et al. 1984, Harrison 1990; Ainley et al. 1995, 1997, 1998; Cooper and Day 1995, in press; Simons and Hodges 1998; Day and Cooper 2001; Day et al., in press a, in press b).

Because of the inaccessibility of nesting colonies of both species, the ability to study and monitor the populations of these species on the ground has been limited (Telfer et al. 1987, Ainley et al. 2001; T. C. Telfer, unpubl. data). The most extensive work has been done on Kauai by Thomas C. Telfer, State of Hawaii Department of Land and Natural Resources, who helped to develop a program that aided in the recovery and release of juvenile birds, primarily Newell's Shearwaters, that become attracted to lights and collide with human-made structures or fall to the ground during the fall fledging period (Telfer et al. 1987). The "Save Our Shearwaters" (SOS) Program, which has operated continuously since 1978, has recovered and released ~30,000 young shearwaters since its inception (Telfer, unpubl. data).

Ornithological radar, combined with visual sampling, also is useful for studying the movements and behaviors of these two species of nocturnal seabirds and is especially useful in monitoring populations of these seabirds. This research tool, which has been used successfully in the Hawaiian Islands since 1992, has enabled much to be learned about the basic movements, behavior, distribution, and/or population changes of these species around Kauai (Cooper and Day 1995, 1998; Day and Cooper 1995, 1999b, 2001; Day et al. 2000, 2001, in press b), Maui (Day and Cooper 1999a; Cooper and Day, in press), and Hawaii (Cooper and David 1995; Cooper et al. 1996, 2002; Reynolds et al. 1997; Day et al. 2002a. 2002b, in press a). The most is known about movements of Hawaiian Petrels on Maui and Kauai, and the most is known about movements of Newell's Shearwaters on Kauai.

The number of Newell's Shearwaters collected by the SOS Program on Kauai has declined markedly since Hurricane Iniki devastated the island in September 1992 (Telfer, unpubl. data). More importantly, by 1999–2001, numbers of shearwaters and petrels recorded on ornithological radar around Kauai had declined by 60–62% overall from those recorded in 1993 (Day and Cooper 2001, in press b). These documented declines in numbers of shearwaters on Kauai have led to increased concern about the conservation of these two species on the Hawaiian Islands. One way to aid in the conservation of these species is to have better information than presently is available on the distribution and abundance of these species on all of the Main Islands, especially on those islands where no recent information is available. Because of the former occurrence of these species on Molokai (Bryan 1908) but a lack of recent information from there, we were contracted to survey for these birds on the Kalaupapa Peninsula of Molokai. This study discusses the results of the studies of movements and behavior of these birds in northern Molokai.

The objectives of this study were:

- to determine movements of Hawaiian Petrels and Newell's Shearwaters near Kalaupapa, Molokai, with ornithological radar;
- to measure movement rates and the behavior of these bird species near Kalaupapa; and
- to determine flight altitudes and behaviors of these bird species near Kalaupapa.

To meet these objectives, we conducted a radar and visual study of the movements and behavior of Hawaiian Petrels and Newell's Shearwaters near Kalaupapa, Molokai. This study was conducted in summer (June) of 2002.

STUDY AREA

Molokai Island is ~38.5 mi (~68 km) in an east–west direction and ~12 mi (~20 km) in a north–south direction and has a total area of 259 mi² (~671 km²; Fig. 1). It consists of a fairly rolling western and a high, mountainous eastern end. The island is perhaps best known for the steep and high pali that runs along the eastern two-thirds of the island's northern coast; these are extremely high sea-cliffs that reach as much as ~2,500 ft

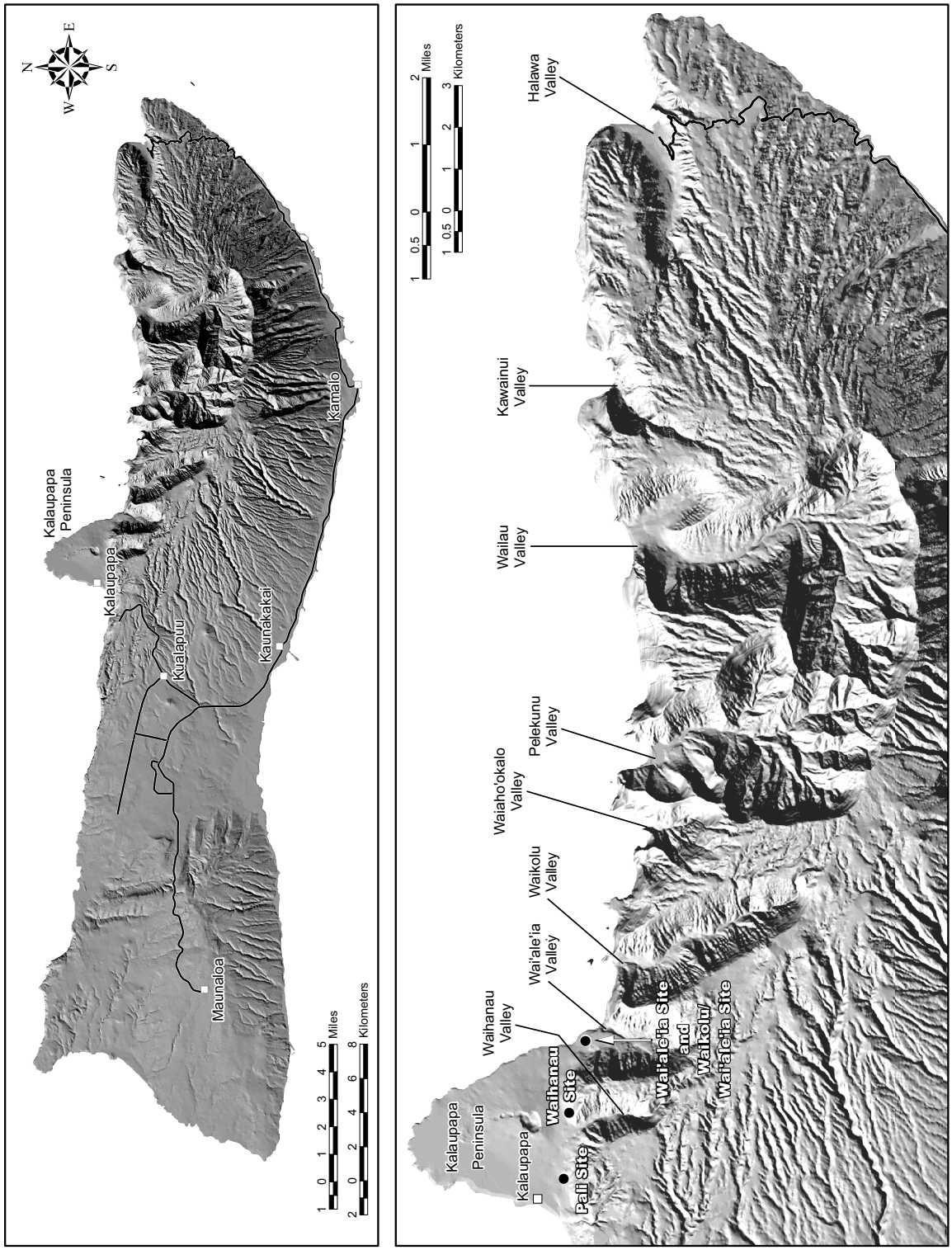

Figure 1. Location of study sites near Kalaupapa, Molokai, in June 2002. Also shown are large valleys of northeastern Molokai where Dark-rumped Petrels and Newell's Shearwaters may nest.

(~760 m) in elevation. The pali is incised by eight major valleys of various sizes in the northeastern quarter of the island (Fig. 1).

The sampling was conducted on the Kalaupapa Peninsula of north-central Molokai (Fig. 1, Appendix 1). The emphasis was on sampling near the pali that separates this peninsula from the southern part of the island, with special emphasis on the valleys that incised this pali. The elevation of the highest sampling site (Waihanau) was ~80–100 m (~250–300 ft); the highest spot on the Kalapuapa Peninsula, Kauhako Crater, is ~125 m (405 ft) high and lies directly north of this site. The vegetation on the Kalaupapa Peninsula predominantly consists of a mix of alien weedy species commonly associated with disturbed areas and lowlands in Hawaii.

METHODS

We collected data on the movements, behavior, and flight altitudes of Hawaiian Petrels and Newell's Shearwaters during five nights in late June 2002 (Table 1). We sampled with ornithological radar and visual equipment (both 10X binoculars and night-vision equipment with a 5X eyepiece) for ~3 h/night, from 1900 to 2200 in the evening. These samples covered the evening peak of movement, which is inland and toward the colonies (Day and Cooper 1995).

During sampling, we collected radar and visual data concurrently, so that we could use the radar to help the visual observer locate birds for identification and data collection. In return, the visual observer provided information to the radar operator on the identity of individual targets. Although we attempted to sample concurrently at all times, radar problems and rain occasionally prevented us from collecting radar data during all times (Table 1). During two nights (26 and 27 June), we also did some training on the operation of the radar, limiting the amount of night-vision sampling conducted after the peak of movement.

We attempted to collect data during 25-min sessions for both sampling methods; 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 15–25 min for radar data (some time was lost when precipitation obscured significant portions of the radar screen) and 25 min for visual data, with nearly all sessions of both types being 25 minutes long. We lost a total of 26 min of time during 3 of 24 sampling sessions over the 4 nights of data collection with radar (Table 1, Appendices 2 and 3). We do not believe, however, that this loss of sampling time significantly affected our results or conclusions, for we lost no entire sampling sessions and we corrected the number of minutes of time lost to precipitation in the calculations of movement rates.

We recorded the following weather 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 distance able to see 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., the time between the beginning of civil twilight and civil sunrise and the time between civil sunset and the end of civil twilight) with or without precipitation, darkness (i.e., the period when it was dark enough that one cannot read a typed page at arm's length) with or without precipitation [corresponds to that period between the end of civil twilight in the evening and the beginning of civil twilight in the morning];
- precipitation (6 categories)—none, fog, drizzle, light rain, heavy rain, scattered showers; and
- moon phase (16 categories)—moon up or not up and phase is New Moon, waxing

Table 1. Sampling schedule for radar and visual observations of Hawaiian Petrels and Newell's Shearwaters near Kalaupapa, Molokai, June 2002.

Date	Site	Time of sampling		Comments
		Radar	Visual	
25 June	Waialeia	–	1900–2200	insect activity appears to be low
26 June	Waialeia	1900–2200	1900–2030	insect activity moderate–high, disappearing after 2130; many large moths early on coming in off ocean to northeast, seen out to 800–1,000 m; scattered showers, but lost no sampling time
27 June	Waihanau	1900–2200	1900–2030	insect activity moderate, with many large moths out to 800–1,000 m; scattered showers (lost radar sampling time to precipitation 1938–1942, 2035–2042, 2050–2051)
28 June	Pali	1900–2200	1900–2200	insect activity moderate, with many large moths out to 800–1,000 m; high winds
29 June	Waikolu/Waialeia	1900–2200	1900–2200	insect activity moderate, with many large moths out to 800–1,000 m; high winds

crescent, First Quarter, waxing gibbous, Full Moon, waning gibbous, Third Quarter, waning crescent.

DATA COLLECTION

RADAR

Following Cooper and Day (1995), Day and Cooper (1995, 1999b, 2001), and Day et al. (2000, 2001a, 2001b, 2002, in press a, in press b), we monitored movements of Hawaiian Petrels and Newell's Shearwaters with ornithological radar. This Furuno FR-1510 surveillance radar was an X-band radar transmitting at 9,410 MHz with a peak power output of 12 kW. The range of this radar was 1.5 km, the pulse setting was 0.07 µsec, and the plotting function was set to "continuous," which meant that the screen plotting of bird locations was constantly being updated with each sweep of the radar antenna. Color plotting enhanced our ability to detect birds moving across the landscape. This radar laboratory was powered by two 12-V batteries that were linked in series. A similar radar laboratory is described in Cooper et al. (1991).

The radar scanned a 360° arc around the radar laboratory and was used to obtain information on movement rates, flight paths, and ground speeds of flying birds. At the short pulse length used in this study, echo definition is improved (giving more accurate information on target location and, hence, exact distance) over that at longer pulse lengths (in which echo detection is improved). (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 color-coded echoes (to differentiate the strength of return signals), 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). The plotting function plotted the location of a target every sweep of the antenna (2.5 sec); because time intervals are fixed, 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, using a ground-clutter reduction screen mounted to the bottom of the antenna face (described in Cooper et al. 1991), and positioning the radar so that nearby vegetation acted as a radar fence (see Eastwood 1967). We had some ground clutter at all sites (see Results).

We collected the following data on 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, or west (the four 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 2001), included targets flying <30 mi/h (<48 km/h) that we identified visually as being of either of the two species of interest, and excluded targets flying the appropriate speed but of another species. In addition, to exclude targets that were only crossing the peninsula in an east–west direction but otherwise met these criteria (see Results), we used a second target-filtering technique that required the targets to be heading inland or out to sea. We detected no targets of these species flying <30 mi/h and excluded no targets of other species flying ≥30 mi/h during this study.

VISUAL

We collected the following data on each bird or flock of birds seen:

- time;
- identification, to lowest practical taxon;
- flock size;
- ordinal flight direction (9 categories)—north, northeast, east, southeast, south, southwest, west, northwest, variable/erratic;
- flight behavior (3 categories)—straight-line, erratic, circling; and
- lowest flight altitude (estimated to the nearest 1 m agl when flying ≤25 m agl, in 5-m increments from 26 to 50 m agl, in 10-m increments from 51 to 100 m agl, and in 25-m increments above 100 m agl).

In the context of this study, our primary interests for the visual sampling were species identification, flock size, and flight altitude.

DATA ANALYSIS

We used the software Excel for all data analyses and summaries. Because overall sample sizes were so small, we did not conduct statistical tests. Instead, we simply summarized and discussed the data.

RADAR

Large numbers of moths, including large moths, sometimes caused sampling difficulties and, especially, difficulties with target identification. In addition, we had a substantial number of unidentified radar targets that were bird-like but that we do not believe were petrels or shearwaters. We discuss this problem of target identification in Results.

We tabulated counts of numbers of targets recorded during each sampling session, then converted these counts to estimates of movement rates (targets/h), based on the number of minutes actually sampled. Because rain showers sometimes obscured significant portions of the screen (Table 1, Appendix 2), we subtracted that time from the 25-min sampling period and used the resulting time in the calculation of movement rates. We used the estimated movement rate for each sampling period to calculate the mean ± 1 standard error (SE) movement rate by site and date.

We used the flight-direction data to calculate the mean flight direction ± 1 circular standard deviation of flight direction by date. To calculate flight directions, we converted flight directions to radians and calculated the mean direction, circular standard deviation, and length of directional vector r following Zar (1984). Although we do not do statistical tests for differences in flight directions here, r is necessary for such tests.

We summarized the data on flight behavior by calculating the total number of targets exhibiting each behavior. We did not conduct statistical tests on these data.

VISUAL

For each species, we were going to tabulate the mean ± 1 SE minimal flight altitude by site and date. Because we saw only two birds, however, we simply discuss the data points individually.

RESULTS

During the five nights of data collection, the moon ranged from one night after the Full Moon (which occurred on 24 June) to shortly before the Last Quarter (which occurred on 2 July). Sunset ranged from 1912 on 25 June to 1913 on 29 June. Moonrise ranged from 2027 on 25 June to 2318 on 29 June, and moonset ranged from 0730 on 25 June (actually the morning of 26 June) to 1105 on 29 June (actually the morning of 30 June).

RADAR

We recorded 41 radar targets that we considered to be probable petrel/shearwater targets; we discuss target identification further below. We did lose some time to rain (Table 1), but that loss was minor (4.3% of all radar sampling time).

SITE CHARACTERISTICS

The various sites (Fig. 1) differed in coverage and ease of sampling. The Waialeia site had an incomplete row of "Ironwood" (*Casuarina equisetifolia*) trees to the east, so a little sea clutter was visible east of them; no trees at all were present to the northeast, so sea clutter was extensive and was particularly intense during periods of high winds. However, the mouth of the valley was visible on the radar screen, and targets clearly could be seen entering it from the ocean;

the pali was visible as ground-clutter to the southwest. This site was fairly good for visual sampling, and we saw both birds and bats here; in addition, a little light from Kalaupapa helped light the sky toward the northwest.

The Waihanau site was located in a clearing in the trees almost due south of Kauhako Crater and near the mouth of the valley. There was extensive ground-clutter to both the south (the pali) and the north (the crater). Nevertheless, the mouth of the valley could be seen clearly, and extensive areas of clear air space occurred both northeast and northwest of the site. This site was fair to poor for visual sampling, for, once a bird flew into a position where the pali was in the background, it became essentially impossible to see.

The Pali site was located in a depression in an open clearing that is used as a landfill for agricultural wastes. It had ground-clutter to the south (the pali) and perhaps 15–20 small patches of ground-clutter to the north that were caused by a few tall trees that towered above the background vegetation; otherwise, it was a good sampling site. This site also was the best of the four for visual sampling, for enough waste light escaped that one could see the air space over Kalaupapa clearly with a night-vision scope.

The Waikolu/Waialeia site was located at the same spot as the Waialeia site, except that the "screen-shift" function was turned on, allowing us to see the mouths of both the Waikolu Valley and the Waialeia Valley. This screen-shift allowed us to see just across the mouth of the entire Waikolu Valley. Unfortunately, the grove of trees along the coastline was heavier and taller in the direction of this valley (to the southeast), making the radar fence highly effective and creating a radar shadow zone extending a few hundred meters up from the ocean near the mouth of that valley. Hence, we believe that estimated movement rates of targets entering this valley are underestimates. We suggest that successive radar operators attempt to move the site slightly toward the northwest, close to the stone wall and/or slightly uphill, to see if that improves the view of the Waikolu Valley and decreases the height of the radar shadow zone.

TARGET IDENTIFICATION

Of the 72 total bird-type targets that we recorded, we considered 41 of them to be those of petrels and shearwaters. The other 31 targets were large and had flight speeds similar to those of petrels and shearwaters, but they only were seen crossing the peninsula from east to west and never entered or left the valleys or pali, which are where nesting colonies of these seabirds probably are located. Because of the uncertainty surrounding these non-petrel/shearwater targets and our opinion that they were not of either of the species of interest, we excluded these targets from the data analysis by using the additional filtering requirement that these targets must enter or leave the valleys or pali.

The timing of movements (see Day and Cooper 1995) suggested that both species were present (Table 2). We recorded targets during the period when only Hawaiian Petrels are moving at three of the four sites, recorded targets during the period of overlap in movement of the two species at three of the four sites, and recorded targets during the period when only Newell's Shearwaters are moving at three of the four sites. If our assessment of timing is correct, Hawaiian Petrels occurred at three sites (Waialeia, Waihanau, and Waikolu/Waialeia) and may have occurred at the fourth (Pali), whereas Newell's Shearwaters occurred at only three sites (Waialeia, Pali, and Waikolu/Waialeia).

These targets included both birds that circled over the ocean, sometimes repeatedly, on their way inland (visible at the coastal Walaleia and Waikolu/Waialeia sites) and birds that flew more directly, without any circling. The circling birds were seen between 1939 and 2013, or 27–60 min after sunset, whereas the directly flying birds were seen between 2010 and 2156, or 58–164 min after sunset; we also had a few other targets of unrecorded characteristics that could have been of either species. Of targets for which we recorded detailed flight characteristics, 1 circling target and no directly flying targets were seen during the period when only Hawaiian Petrels are believed to be moving, 10 circling targets and 1 directly flying target were seen during the period of overlap between the two species (and the one directly flying target occurred almost at the end of this period), and 0 circling targets and 6 directly flying targets were seen during the period when only Newell's Shearwaters are believed to be moving (Table 2). Because of their early movement time

Table 2. Estimated numbers of Hawaiian Petrels and Newell's Shearwaters as determined by timing of movements on ornithological radar near Kalaupapa, Molokai, June 2002, by site, date, and (when possible) flight characteristics. Data are expressed as number of targets (number circling/number directly flying, when the flight characteristics were identified).

		Species[1]		
Site	Date	Hawaiian Petrel	Overlap (either species)	Newell's Shearwater
Waialeia	26 June	1 (0/0)	6 (1/0)	5 (0/0)
Waihanau	27 June	2 (0/0)	0 (0/0)	0 (0/0)
Pali	28 June	0 (0/0)	1 (0/0)	2 (0/0)
Waikolu/Waialeia[2]	29 June	1 (1/0)	10 (9/1)	13 (0/6)

[1] Hawaiian Petrels are assumed to be the only species flying between sunset and ~30 min later; both Hawaiian Petrels and Newell's Shearwaters (i.e., there may be an overlap between the two species) may be flying 31–60 min after sunset; and Newell's Shearwaters are assumed to be the only species flying >60 min after sunset (see Day and Cooper 1995).

[2] This site included targets moving into both the Waialeia Valley and the Waikolu Valley.

(they began moving between sunset and complete darkness and ended within 60 min after sunset; Day and Cooper 1995) and their flight characteristics, we believe that the early and circling targets were those of Hawaiian Petrels. Because of their late movement time (they began moving about 60 min after sunset and, hence, after the period of complete darkness) and their flight characteristics, we believe that the late and directly flying targets were those of Newell's Shearwaters.

MOVEMENT RATES

Movement rates varied considerably among sites and nights (Table 3) and among sampling sessions (Appendix 2). Variation between time periods and among nights reflected among-night variability in numbers of birds heading inland and seaward at particular times on different nights. Variation among sampling sessions reflected the temporal variation in numbers and species-composition of birds heading into or leaving the colonies. Movement rates peaked overall between 1930 and 2130 in the evening, when the birds are returning to their nests on land (Day and Cooper 1995).

Mean nightly movement rates ranged between 0.8 and 9.6 targets/h (Table 3). For individual sampling sessions, movement rates varied between 0 and 33.6 targets/h (Appendix 2). Overall, the highest mean nightly movement rates occurred at the Waialeia and Waikolu/Waialeia sites, which lie on the eastern side of the peninsula. The lowest mean nightly movement rates were at the Waihanau site and were only slightly higher at the Pali site; rates at these two inland sites, however, were essentially 10% of the rates at the two coastal sites. At the two coastal sites, the mean movement rate into the Waialeia Valley and the pali/unspecified location was 5.1 and 8.0 targets/h on 26 and 29 June, respectively.

FLIGHT PATHS

We examined specific movements of targets more closely at the Waialeia site on 26 June and at the Waikolu/Waialeia site on 29 June. On 26 June, we saw 1–2 probable Hawaiian Petrel targets circling over the water, then flying into the Waialeia Valley between 1943 and 1947 and saw 3 targets of unidentified characteristics flying into the valley between 1939 and 1953. We also saw 8 unidentified targets flying to unidentified locations (some moving west along the pali, toward the Waihanau Valley) between 1925 and 2149; unfortunately, we did not consistently record locations where the targets were heading on this first evening of sampling.

On 29 June, we saw 5 probable Hawaiian Petrel targets circling over the water, then flying

Table 3. Movement rates (targets/h) of Hawaiian Petrels and Newell's Shearwaters as determined by ornithological radar near Kalaupapa, Molokai, June 2002, by site, date, and target type. Data are expressed as the mean movement rate ± 1 SE (*n*). Sample sizes for individual dates represent number of sampling sessions.

Site	Date	Movement rate
Waialeia	26 June	5.1 ± 1.9 (6)
Waihanau	27 June	0.8 ± 0.8 (6)
Pali	28 June	1.2 ± 0.5 (6)
Waikolu/Waialeia [1]	29 June	9.6 ± 5.3 (6)[1]

[1]This site included targets moving into both the Waialeia Valley and the Waikolu Valley. The movement rate into the Waialeia Valley and elsewhere along the pali (similar to the sample on 26 June) was 8.0 ± 4.8 targets/h; the movement rate into the Waikolu Valley was 1.6 ± 1.2 targets/h.

into the Waialeia Valley between 1939 and 2008 and saw 9 probable Newell's Shearwater targets directly flying into the valley between 2010 and 2156. We also saw 4 probable Hawaiian Petrel targets circling over the water, then flying into the Waikolu Valley between 1947 and 2006 and saw no probable Newell's Shearwater targets directly flying into that valley. In addition, we saw 1 probable (i.e., circling) Hawaiian Petrel target and 5 probable (i.e., directly flying) Newell's Shearwater targets flying to unidentified locations (some along the pali and toward the Waihanau Valley) at 2013 and 2015–2048, respectively.

FLIGHT DIRECTION

Mean overall flight directions varied, both among nights and among sites; the moderately-sized circular standard deviations reflected variation in flight directions and, occasionally, the effects of small sample sizes (Table 4). Mean flight directions ranged between 216° and 257°; the latter mean direction, however, was caused by two targets heading into the pali and one flying almost due north, away from it. Otherwise, mean target directions were into the valleys and the pali in general.

At three of the four sites, the circular standard deviation was small–moderate and the length of the directional vector *r* was moderate–large (i.e., it approached 1.0000), indicating moderate–strong directionality. As indicated above, however, the shorter vector length for petrel/shearwater-type targets at the Pali site was caused by nearly-opposing flight directions and small sample sizes.

BEHAVIOR

Flight behaviors were predominantly directional, with 38 of 42 targets exhibiting straight-line (directional) behavior, 2 exhibiting circling behavior, and 2 exhibiting erratic behavior. As discussed above, what we believe were Hawaiian Petrels alternated periods of circling over the ocean (to gain altitude) with periods of straight-line flight, and what we believe were Newell's Shearwaters were flying only with a straight-line flight.

VISUAL

We recorded two unidentified petrels/shearwaters visually during the five nights of sampling. Both of these were seen at the Waialeia site on 25 June, and they were flying at altitudes of 40 m and 500 m above ground level (agl). Unfortunately, they were too far away for positive identification. On the same night, we saw a Hawaiian Hoary Bat (*Lasiurus cinereus semotus*) foraging off the pali at an estimated flight altitude of 500 m agl.

DISCUSSION

TARGET IDENTIFICATION

The timing of the movement data suggests that both Hawaiian Petrels and Newell's Shearwaters still occur, and presumably still nest,

Table 4. Mean flight directions of Hawaiian Petrels and Newell's Shearwaters as determined by ornithological radar near Kalaupapa, Molokai, June 2002, by site, date, and targets type. Data are expressed as the mean flight direction ± 1 circular standard deviation (*n*), and length of directional vector *r*. Sample sizes represent numbers of radar targets with directional measurements.

Site	Date	Direction	*r*
Waialeia	26 June	222 ± 15 (12)	0.9655
Waihanau	27 June	216 ± 1 (2)	0.9998
Pali	28 June	257 ± 64 (3)	0.5311
Waikolu/Waialeia [1]	29 June	239 ± 36 (22)	0.8187

[1]This site included targets moving into both the Waialeia Valley and the Waikolu Valley.

on Molokai; the flight behavior of the targets on the radar display screen reinforce this view. Day and Cooper (1995) showed that there was a dramatic difference in the timing of movements of these two species into and out of colonies on Kauai. Further, in the evening, this timing was oriented to the timing of sunset and the "point of complete darkness," which is the end of twilight. In essence, Hawaiian Petrels begin moving inland between sunset and the point of complete darkness and finish that movement ~60 minutes after sunset, or about 30 min after the point of complete darkness (Day and Cooper 1995, unpubl. data). In contrast, Newell's Shearwaters begin moving at the point of complete darkness and continue moving thereafter, Hence, there is a period of perhaps 30 min (from the point of complete darkness to ~60 min after sunset [~30 min after the point of complete darkness]) when the movements of both species overlap. In this study, targets that clearly were circling repeatedly over the ocean on their way inland (i.e., what almost certainly were Hawaiian Petrels) were seen between 1939 and 2013, or 27–60 min after sunset. In contrast, targets that flew without any circling and flew directly inland (i.e., what almost certainly were Newell's Shearwaters) were seen between 2010 and 2156, or 58–164 min after sunset. Hence, the behavior of targets that we believe were of each species matches well the timing of movements of the two species that we have seen visually on Kauai. Similarly, Cooper and Day (in press) found that movements of Hawaiian Petrels inland on Maui ends ~60 min after sunset.

Perhaps the most problematical of the issues involving target identification on Molokai involves the identity of the unidentified targets that we do not believe were those of petrels or shearwaters. These unidentified targets were large and had flight speeds similar to those of petrels and shearwaters, but they only were seen crossing the peninsula from east to west (i.e., with the wind). The fact that they were traveling only with the wind suggests that at least some were large moths (sphinx moths) or very large moths, such as the noctuid species that is called "Black Witch" (*Ascalapha odorata*). The strong winds seen during this sampling (up to 30 mi/h [~50 km/h]), which would have provided a substantial tailwind to moths already flying ~20–25 mi/h (~32–40 km/h), could have increased the overall ground speed of moths to the speeds recorded in this study. These targets, however, were so large that they were seen at distances out to 1,000 m, or considerably farther than the maximal distance at which we usually see moths (~500–600 m; Day and Cooper, pers. obs.). Some of these unidentified targets also may have been Hawaiian Hoary Bats, since we recorded one visually and saw several radar targets that probably were those of bats (up to 5 bat-like targets in a night). In addition, at least two of these unidentified targets probably were frigatebirds that were crossing the peninsula at a high rate of speed. We also heard Wedge-tailed Shearwaters (*Puffinus pacificus*) calling off the eastern side of the peninsula one night, and they occasionally do come inland for short distances (Day and Cooper, pers. obs.), so some of these targets may have been of this

species. Further, it is possible that some were Sooty Terns (*Sterna fuscata*) or Black Noddies (*Anous minutus*), which occasionally come inland at night. Hence, these unidentified targets may have been composed of a variety of species but clearly were large; however, the fact that we could not see any, even though we had excellent viewing conditions on some nights, suggests that they either were flying very high in the sky or were large moths, rather than birds.

DISTRIBUTION AND ABUNDANCE

Movement rates of petrel/shearwater targets at all sites were small, with mean nightly rates at the Waialeia and Waikolu/Waialeia sites comparable to the lowest rates on Kauai (Day and Cooper 1995) and rates at the other two sites much lower than any sites on Kauai but comparable to rates along most of the shoreline of Hawaii (Day et al., in press a) and southwestern Maui (Cooper and Day, in press). We emphasize, however, that the number of birds entering the Waikolu Valley (~15–20% of the number entering the Waialeia Valley) is an underestimate because of partial shielding of the radar's view into that valley by Ironwood trees—we caught only that part of the movement that was flying above the radar shadow. Movements into/out of the Waihanau Valley and the pali were extremely low. Although we could not see into the Waihanau Valley well enough to see how much potential nesting habitat occurred there, the pali itself consists primarily of numerous layers of hard volcanic basalt that are unsuitable for nesting; no crevices or talus slides in which petrels could nest and no soil in which shearwaters could nest were evident from visual inspection. Hence, it is possible that the very few targets seen entering/leaving the Pali site actually were circling over the southern side of the island and entering other valleys.

Flight directions and behaviors suggested that the targets that we believe were petrels and shearwaters were birds entering/leaving nesting colonies in the valleys. We even watched some targets flying toward the south-southwest from the ocean, then turn and enter the valley mouths. In addition, the overall high degree of directionality matches that seen for these species on Kauai (Day and Cooper 1995), Maui, and Hawaii (Day and Cooper, unpubl. data).

Little information is available on the Hawaiian Petrel on Molokai, with the species apparently becoming quite rare there sometime in the Twentieth Century. Bryan (1908; also 1914, cited in Banko 1980b) extensively discussed the distribution and abundance of Hawaiian Petrels on this island. He recorded and/or collected birds in the Pelekunu Valley (where they appeared to be common to abundant), at Olokui (a mountain ridge between the southeastern Pelekunu Valley and the Wailau Valley), and near the Moanui sugar mill (on the southeastern coast of the island, south of the Halawa Valley) and the Wailau Valley. Surprisingly, he did not record the species in the Halawa Valley, even though he searched there. Munro (1941, 1960) stated that mongooses had exterminated this species that formerly nested in "immense numbers" on Molokai and indicated that it was questionable whether nesting populations of petrels still survived here. The only recent record that we can find of this species on Molokai is of a few seen at sea off the northern and western coasts of Molokai on 2–4 July 1988 (Pratt 1988b). Our data suggest that this species still nests in the Waikolu, Waialeia, and (probably) Waihanau valleys.

Little information is available on the Newell's Shearwater on Molokai, with the species apparently being quite rare there even a century ago. Bryan (1908) discussed little about the Newell's Shearwater other than that it tended to nest at lower elevations than the Hawaiian Petrel and that he heard a few birds calling over the Waikolu and Peleknunu valleys; his opinion was that it was much rarer than the petrel. In addition, Perkins (1903, cited in Banko 1980a) mentioned seeing several dead Newell's Shearwaters at the head of one of the valleys in northeastern Molokai a few days after a severe storm. Although Munro (1960) stated that mongooses (*Herpestes auropunctatus*) probably had exterminated this species on Molokai, at least two colonies are still suspected to occur, as indicated by (1) recent records of birds heard calling near the rims of the Pelekunu and Wailau valleys during forest-bird surveys in 1979–1980, and (2) the recent record of two Newell's Shearwaters heard calling as they flew up Kamalo Gulch near Ka'apahu Cone in May

1988 (Pratt 1988a). (NOTE: There is no "Ka'apahu Cone" on the *Reference Maps of the Islands of Hawai'i*, but there is a "Ka'apahu [dome]" on it, SW of Kamakou. Birds flying north up this gulch would enter the upper Pelekunu Valley.) In addition to these records, our data suggest that the species still nests in the Waikolu and Waialeia valleys but that it may not nest in the Waihanau Valley.

FLIGHT ALTITUDES

Because we saw only two birds visually, we did not analyze the flight-altitude data; these birds were flying at altitudes of 40 and 500 m agl. From our experience, we usually detect visually only 1–2% of all targets seen on radar (Day and Cooper, unpubl. data); thus, we would have expected to have detected <1 bird with visual means during the entire 5-day study.

The high flight altitude of the one bird seen visually, plus the circling behavior of some Hawaiian Petrels that were trying to gain altitude before entering the valleys, suggests that many were flying at substantial altitudes. We also saw some targets entering the Waikolu and Waialeia valleys in locations where they would have had to been flying at least a few hundred meters above sea level for our radar to detect them above the tall trees that were forming a radar shadow in that direction. Further, the location of what appeared to be suitable nesting habitat (soil, rather than bedrock, on very steep hillsides) occurred high in the Waialeia Valley, from what we could see. We were unable to examine each valley visually, however.

Although data from Molokai are limited, data from Kauai also suggest that birds here probably are flying quite high. In locations on Kauai where steep cliffs or mountains also lie just inland from the coastline (e.g., Hanalei, Lumahai, Wainiha), the mean flight altitude of petrels and shearwaters combined is 308 ± SE 8 m agl (n = 493; Day and Cooper, unpubl. data). On Maui, where the topography also is steep, the mean flight altitude of Hawaiian Petrels is 191 ± SE 25 m agl (n = 20), and birds there were seen flying inland at altitudes of 25–500 m agl.

BEHAVIOR

The limited data collected by the radar suggested that essentially all targets were flying in a straight-line direction; two targets flew erratically, and two were circling. These frequencies are similar to those seen on Kauai in 1992–2002 (Day and Cooper, unpubl. data).

CONCLUSIONS AND RECOMMENDATIONS

Our preliminary survey of just three of the eight valleys on the northeastern part of Molokai suggests that both Hawaiian Petrels and Newell's Shearwaters still nest there. Because the historical information on Molokai is so sketchy (Bryan 1908 is the most-recent thorough information), it is unclear whether either species nested in these valleys in historical times and, if they did, in what numbers they nested. This discovery of these species in these valleys today is important, for it suggests that both species occur/nest on at least four of the six Main Islands, with the two other islands not yet having been examined with ornithological radar. We suspect that one or both species still nests today in probably most or all of the eight major valleys on Molokai, with the Pelekunu and Wailau valleys having the greatest potential for nesting birds, based on Bryan's (1908) extensive surveys and the recent records. Because of the presence of Mongooses, nesting habitat probably consists primarily of very steep soil and/or rock crevices (Bryan 1908); indeed, the recent records of Newell's Shearwaters were near the steep upper edges of the rims of the Pelekunu and Wailau valleys (Pratt 1988a). Given the limited amount of this habitat in the one valley we were able to examine visually, this steep, protected habitat may be limited in several of these valleys.

We recommend that further surveys on Molokai be conducted to delineate better the distribution and abundance of these species there. We recommend that this survey include several days of sampling along the southeastern shore of the island, where one could count birds flying inland from the ocean, and a few days in which the radar unit is carried by helicopter into the mouths of some of the more remote valleys that show great potential for nesting birds of either species; however, we could survey the Halawa Valley from

the road system. Clearly, the Pelekunu and Wailau valleys are large and, hence, may contain most of the birds, whereas the Waiaho'okalo and Kawainui valleys are small and, hence, may contain few birds. We believe that these radar data may provide resource managers with information on the level of protective measures that must be instituted to save these colonies (by determining some estimate of abundance of these species on the island as a whole) and that they will provide these managers with information on locations (valleys) where ground-based searches must be conducted to locate nesting colonies themselves.

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Appendix 1. Locations of sampling sites during surveys near Kalaupapa, Molokai, June 2002.

Site	Coordinates	Description
Waialeia	21°10.585'N 156°56.808'W	in open field to southeast of St. Philomenas Church, near crypts next to stone fence
Waihanau	21°10.967'N 156°57.990'W	in open field just to southeast of turnoff to Kauhako Crater, south of Damien Road and just west of cemetery
Pali	21°11.053'N 156°58.899'W	in depression in agricultural landfill
Waikolu/Waialeia	21°10.585'N 156°56.808'W	same location as Waialeia site with "screen-shift" function turned on, so that entire mouth of both valleys is visible

Appendix 2. Movement rates (targets/h) of petrel/shearwater targets on ornithological radar during the evening near Kalaupapa, Molokai, June2002, by site and date. Actual lengths of sessions shortened by rain showers or other reasons are listed in parentheses after the movement rate; otherwise, session length is 25 minutes.

		Sampling session (time of day)					
Site	Date	1905–1929	1935–1959	2005–2029	2035–2059	2105–2129	2135–2159
Waialeia	26 June	4.0 (15)	12.0	9.6	2.4	0	2.4
Waihanau	27 June	4.8	0 (19)	0	0 (15)	0	0
Pali	28 June	0	2.4	2.4	0	0	2.4
Waikolu/Waialeia	29 June	0	14.4	33.6	2.4	0	7.2