Behavior of Hawaiian Petrels and Newell's Shearwaters (Aves: Procellariiformes) Around Electrical-Transmission Lines on Kaua'i Island, Hawaiian Islands1

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Behavior of Hawaiian Petrels and Newell's Shearwaters (Aves: Procellariiformes) Around Electrical-Transmission Lines on Kaua'i Island, Hawaiian Islands[1]

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Abstract: Understanding the behavior of birds around tall structures such as electrical-transmission lines, communication towers, and wind turbines is important in assessing the potential effects of those structures on bird populations; it is especially important for threatened or endangered species. We studied responses of the mostly crepuscular/nocturnal Hawaiian Petrel (*Pterodroma sandwichensis*) and the mostly nocturnal Newell's (Townsend's) Shearwater (*Puffinus newelli*; Aves: Procellariiformes) to coastal and near-coastal transmission lines on Kaua'i Island, Hawai'i, USA, in 1992–2002. Hawaiian Petrels responded to transmission lines significantly more often (19.1% of the time; $N = 209$) than Newell's Shearwaters did (7.4%; $N = 392$), responded significantly more often with decreasing distance from a line, and responded significantly less often if a study-site was dark (i.e., unlit by ambient lights from nearby towns) than if it was light (i.e., lit by ambient lights from nearby towns), regardless of whether the sky was light (i.e., daylight or crepuscular light conditions) or dark (nocturnal light conditions). In contrast, Newell's Shearwaters showed little variation in response rates by distance or by whether the study-site or sky was light or dark. Hawaiian Petrels mostly responded to transmission lines by changing flight velocity and flight altitude, whereas Newell's Shearwaters mostly responded by changing flight direction and flight altitude. The higher response rates and more-buoyant flight characteristics of Hawaiian Petrels than Newell's Shearwaters may contribute to lower rates of fatality of Hawaiian Petrels than Newell's Shearwaters at coastal and near-coastal transmission lines on Kaua'i.

Keywords: collision, collision-avoidance behavior, conservation, Hawaii, petrel, powerline, shearwater

THE CONSTRUCTION OF TALL STRUCTURES such as electrical-transmission lines, communication towers, and wind turbines often results in the fatality of birds of various species (e.g., Anderson 1978, Avery 1978, Winkelman 1995, De Lucas et al. 2004, Desholm and

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Kahlert 2005, Manville 2005, Everaert and Stienen 2006, National Research Council 2007, Longcore et al. 2008, Gehring et al. 2009). In the Hawaiian Islands, the federally endangered Hawaiian Petrel ('Ua'u; *Pterodroma sandwichensis*) and the federally threatened Newell's Shearwater ('A'o; *Puffinus newelli*; Aves: Procellariiformes) have been killed at electrical-transmission lines (Telfer et al. 1987, Hodges 1992, Cooper and Day 1998, Podolsky et al. 1998, Travers et al. 2021) and wind turbines (Tetra Tech 2020). These two crepuscular/nocturnal seabird species nest only in the Hawaiian Islands and have undergone significant population declines in historical times; they still nest on all of the Main Islands but now are restricted primarily to scattered, small colonies in mostly inaccessible locations (Day and Cooper 1995, Cooper and Day 2003, Day et al. 2003, Raine et al. 2017, Ainley et al. 2020, Simons and Hodges 2020). The primary exceptions are Kaua'i and Lāna'i islands, which have no established Indian Mongoose (*Herpestes auropunctatus*) populations and have probably the most substantial populations of both species (Kaua'i) and of Hawaiian Petrels (Lāna'i).

Understanding the behavior of birds around structures such as electrical-transmission lines, communications towers, and wind turbines is important in assessing the potential effects of those structures on bird populations; it is especially important for threatened or endangered species. In addition, answering the question of how birds respond to structures in their airspace, and the frequency and context of such responses, is particularly difficult for species that fly during periods of low light levels because of the difficulty in collecting data. Here, we describe responses of a primarily crepuscular/nocturnal tubenose species and a primarily nocturnal tubenose species to electrical-transmission lines in the Hawaiian Islands.

METHODS

Data Collection

We collected the data at various intervals on Kaua'i Island, Hawaiian Islands, from May to October 1992–2002. The studies focused on the movements, behavior, and fatality of these tubenoses around coastal and near-coastal electrical-transmission lines, although the data-set discussed here is larger and more detailed than the 1993–1994 data-set discussed previously by Cooper and Day (1998). In addition, this data-set discusses only birds seen within 150 m of a line, whereas the data-set used by Cooper and Day (1998) discussed all birds seen, regardless of distance from a line. We visually sampled near transmission lines at various locations around the island and used optical equipment to locate and identify birds flying to and from inland nesting colonies. Study sites (Figure 1) were located near the perimeter road and varied in background levels of ambient light from nearby towns and streetlights; however, all sites differed among nights in the amount of light by time of day (i.e., daylight, crepuscular period, darkness), by lunar phase (lower during a new moon, higher during a full moon), and by lunar visibility due to the presence or absence of clouds.

We made observations with 10× binoculars and the naked eye during crepuscular periods and used night-vision optics and the naked eye during periods of darkness. The night-vision sampling was conducted with a Generation-2 hand-held scope with a 5× eyepiece (Noctron V; Special Services Company, Plano, TX). The performance of the night-vision scope was enhanced by a 2-million-Cp spotlight that was fitted with a near-infrared filter that eliminated all except a very small amount of visible light, to avoid eliciting a behavioral response to visible light by these birds.

The visual sampling usually was conducted in conjunction with radar-based studies of these birds and was conducted to locate and confirm the identification of birds, obtain information on flight-altitudes and distances at which birds approached or crossed transmission lines, and determine behavioral reactions to lines (Day and Cooper 1995, Cooper and Day 1998, Day et al. 2003). We collected data primarily during the evening and/or morning peaks of movement in the summer (19:00–22:00; 04:00–06:00) and fall

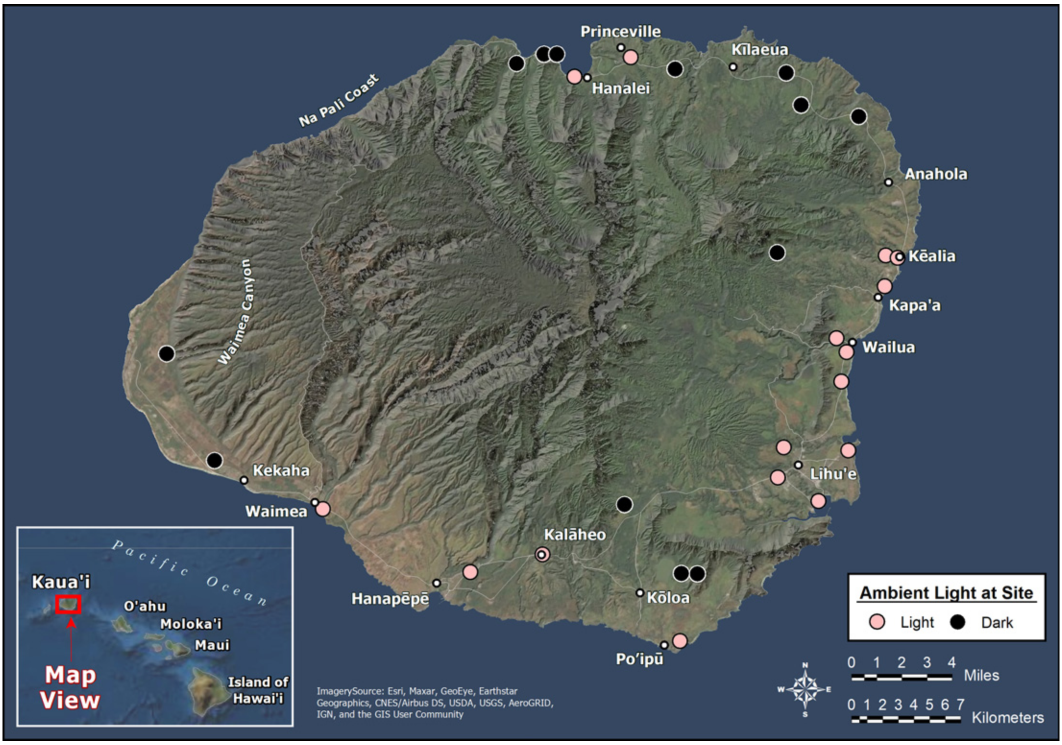

FIGURE 1. Locations of study areas on Kaua'i Island, Hawai'i, in 1992–2002.

(18:00–21:00; 04:00–06:30) because that was when most petrels and shearwaters fly inland toward (evening) and seaward from (morning) the nesting colonies (Day and Cooper 1995). We also did opportunistic sampling when visiting the island.

For each bird seen during sampling, we recorded the species to the lowest possible taxonomic unit (Hawaiian Petrel, Newell's Shearwater, unidentified petrel/shearwater, unidentified shearwater); number of birds in the group; estimated flight altitude (m above ground level [agl]; in 1-m units to 25 m agl, in 5-m units 26–50 m agl, in 10-m units 51–100 m agl, in 25-m units 101–200 m agl, in 50-m units 201–500 m agl, and in 100-m units above 500 m agl); line-crossing behavior (no response [normal behavior—do not change original flight direction, altitude, or flight speed]; change direction and/or altitude and cross line; change direction and/or altitude but do not cross line; flare [change direction and/or altitude in an extreme manner as a last resort to avoid hitting the line]; slow flight speed significantly); and the closest crossing distance (in meters) above or below the nearest part of the line. The coastal and near-coastal transmission lines along the perimeter road of Kaua'i ranged from ~10 m to ~25 m high and varied in power from local distribution lines to low interties; these lines and nearby towers and structures provided scale for estimating flight altitudes. In the context of this study, we define here a "change" to be any noticeable change in any aspect of behavior observed (e.g., a bird flying in a straight, level flight vector suddenly changes flight direction and/or flight altitude and/or flight speed as it approaches or crosses the line).

Weather conditions encountered during these surveys were representative of weather on Kaua'i in general. Across 637 survey sessions, wind speed averaged 10.1 ± SD

6.4 km/h (range 0–32 km/h); 6.1% of all sessions were conducted during calm winds, 91.2% were conducted during light to moderate winds (1–24 km/h), and 2.7% were conducted during high winds (≥25 km/h). Cloud cover averaged 50.5 ± SD 31.0%, with 1.7% of the sessions conducted during completely clear skies (0% cloud cover), 90.1% conducted during partially cloudy skies (1–99% cloud cover), and 8.2% conducted during completely-overcast skies (100% cloud cover). Precipitation was light and had little impact on our ability to see birds, with 80.1% of the sessions conducted during periods without precipitation, 0.3% conducted during fog, and 19.6% conducted during rain. Minimal visibility ranged from 500 m to >5,000 m, with 2.2% of the sessions conducted during periods with visibility ≤5,000 m and 97.8% conducted during periods with visibility >5,000 m; hence, these excellent levels of visibility reflected a negligible effect of precipitation and fog on our ability to see a broad area.

Data Analysis

We used the software Microsoft Excel (Microsoft Corporation, Redmond, WA) for data summary and analysis. For data summaries, frequencies are presented as number *n* (% of *N*). In all statistical tests, the level of significance (α) is 0.05. We used data from all light conditions because we wanted to compare the avoidance rates of these birds under the range of light conditions experienced by both species during their daily cycle.

We started with data-sets of 1,224 total visual observations of Hawaiian Petrels and 741 total visual observations of Newell's Shearwaters across all years and sites. We then screened the data to create a subset of birds seen near transmission lines, seen crossing or attempting to cross within 150 m of a transmission line, and for which we had information on both behavioral responses and crossing distances (i.e., distances above, between, or below the lines at which birds crossed); this screening resulted in sample sizes (*N*) of 209 Hawaiian Petrels and 392 Newell's Shearwaters for analysis. We used this subset for analysis because it both provided a substantial sample size and included all except one bird that we recorded exhibiting behavioral responses. We subtracted the height of the transmission line from the estimated flight altitude to get the closest vertical crossing distance over/under the transmission lines; for birds passing through lines (i.e., between lines that are oriented vertically), we recorded that distance as the crossing distance. We tallied the data as the total number of birds, the closest crossing distance from the line (in meters), and the behavioral response (as detailed in descriptions of behavior). We assumed that any change in flight behavior was a response to the line; although this assumption may inflate the percentage of birds that actually are responding to the structure, there was no way to determine a bird's true intent when it exhibited a response.

We recoded the detailed behavioral information into six main categories: no response; change flight direction; change flight altitude; change velocity to slow noticeably; change both flight direction and flight altitude; and flare at the last second to avoid collision. We summarized the data as the frequencies of responses by species, and then tested for differences in frequencies of response with Chi-square tests for row-by-column independence with a Yates correction. We summarized the data as the frequencies of responses by 25-m distance categories (as above) from 0 to 150 m for each species, and then tested by species for differences in frequencies of response by distance category with Chi-square tests for row-by-column independence with a Yates correction. We also summarized the response-frequency data for the closest 25-m category as 0–10 m versus 11–25 m from the transmission line, then tested by species for differences in frequencies of response by distance category with Chi-square tests for row-by-column independence with a Yates correction. In addition, we tested for differences between the two species in the frequency of responses by distance category with a Chi-square $2 \times 2 \times 6$ test for row-by-column independence with a Yates correction.

We also examined the effects of the environment on responses to transmission lines by summarizing for each species the frequency of response by whether the study-site was lighted by ambient light from nearby towns (light) or was unlighted (dark) and whether the light in the sky at the time of that observation occurred during the daylight/crepuscular period (light) or after dark (dark). Locations of light and dark study sites are shown in Figure 1. To determine whether a bird was flying in a light or dark sky, we classified evening records as occurring with a light sky if the bird was seen before or <30 min after civil sunset and as with a dark sky if the bird was seen ≥30 min after civil sunset; we classified morning records as occurring with a dark sky if the bird was seen ≥30 min before civil sunrise and as a light sky if the bird was seen <30 min before civil sunrise or after civil sunrise. These points 30 min after sunset in the evening and 30 min before sunrise in the morning correspond closely with the point of complete darkness described in Day and Cooper (1995). Sunset and sunrise times were taken from the website sunrisesunset.com for Lihue, Kaua'i. After summarizing for each species the frequencies of response by light levels for study-site and sky, we tested for differences between species with a Chi-square 2 × 4 test for row-by-column independence with a Yates correction.

RESULTS

Behavioral Responses

Hawaiian Petrels exhibited behavioral responses to transmission lines 19.1% of the time (40 of 209 observations; Table 1). Of the responses, the most common one was changing velocity to slow noticeably (26 observations; 65.0% of all birds responding and 12.4% of all birds), followed in decreasing order by changing flight altitude (8; 20.0% of all birds responding and 3.9% of all birds), flaring (3; 7.5% of all birds responding and 1.4% of all birds), changing flight direction (2; 5.0% of all birds responding and 1.0% of all birds), and changing both direction and altitude (1; 2.5% of all birds responding and 0.5% of all birds). Of those birds changing flight altitude, 75% increased and 25% decreased it as they crossed the line.

Newell's Shearwaters exhibited behavioral responses to transmission lines only 7.4% of the time (29 of 392 observations; Table 1). Of the responses, the most common one was changing flight direction (16 observations; 55.2% of all birds responding and 4.1% of all birds), followed in decreasing order by changing flight altitude (9; 31.0% of all birds responding and 2.3% of all birds), flaring (3; 10.3% of all birds responding and 0.8% of all birds), and changing flight velocity (1; 3.4% of all birds responding and 0.3% of all birds);

TABLE 1

Behavioral Responses of Hawaiian Petrels and Newell's Shearwaters Observed Within 150 m of Transmission Lines on Kaua'i Island, Hawai'i, in 1992–2002, by Species

	Species[a]			
	Hawaiian Petrel		Newell's Shearwater	
Behavioral Response	Number	Percent	Number	Percent
No response	169	80.9	363	92.6
Change flight direction	2	1.0	16	4.1
Change flight altitude	8	3.9	9	2.3
Change both direction and altitude	1	0.5	0	0
Change flight velocity	26	12.4	1	0.3
Flare	3	1.4	3	0.8
N	209	100.0	392	100.0

[a] Data are presented as number and percent of *N*.

none (0% of all birds) changed both flight direction and altitude as they crossed the line.

Hawaiian Petrels responded significantly more often overall to transmission lines than Newell's Shearwaters did ($\chi_1^2 = 17.353$; $P < .001$). In addition, petrels that responded did so by noticeably slowing flight velocity much more often than shearwaters did (65.0% vs. 3.4% of all birds responding; Table 1). In contrast, frequencies of the other behaviors were rare and generally similar between the two species.

Effects of Distance on Behavioral Response

The type and frequency of behavioral responses seen in Hawaiian Petrels varied with crossing distance—that is, distance from the nearest transmission line as the bird crossed it (Table 2). For example, changes in both flight direction and altitude at the same time and in flaring, both of which are extreme types of response, were recorded only in petrels flying within 25 m of a line. Changes in flight direction also were seen only within 25 m of a line. All changes in flight altitude occurred within 50 m of a line, with nearly all changes occurring within 25 m of a line. Changes in flight velocity were seen as far away as 125 m from a line, although nearly 90% of all responses occurred within 50 m of a line.

The type and frequency of behavioral responses seen in Newell's Shearwaters also varied with crossing distance (Table 2). For example, both changing flight velocity and flaring were recorded only within 25 m of a line. In contrast, changes in flight direction and in flight altitude were recorded in shearwaters as far away as 125 m, with no pattern by distance from the line being apparent.

Effect of Distance on Frequency of Response

Of 209 Hawaiian Petrels that crossed within 150 m of a transmission line, response rates clearly increased dramatically as the crossing distance decreased (Figure 2). Response rates also increased quickly within 25 m from the line, in that petrels passing 26–50 m from a line responded 17.9% of the time, whereas petrels passing 0–25 m from one responded 44.4% of the time—a 148% relative increase in response rates. Indeed, response rates differed significantly with distance ($\chi_5^2 = 49.705$; $P < .001$). About 60% of that Chi-square value came from the innermost distance category, indicating that the frequency of response near the transmission lines was much higher than expected, based on frequencies seen at greater distances.

Examination of only those Hawaiian Petrel data in the closest 25 m from a transmission

TABLE 2

Behavioral Responses (Number, Percent) of Hawaiian Petrels and Newell's Shearwaters near Transmission Lines on Kaua'i Island, Hawai'i, in 1992–2002, by Species and Nearest Distance from the Structure

		Distance (m)[a]						
Species	Behavioral Change	0–25	26–50	51–75	76–100	101–125	126–150	*N*
Hawaiian Petrel	Flight direction	2 (100.0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2
	Flight altitude	7 (87.5)	1 (12.5)	0 (0)	0 (0)	0 (0)	0 (0)	8
	Direction and altitude	1 (100.0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1
	Flight velocity	19 (73.1)	4 (15.4)	2 (7.7)	0 (0)	1 (3.8)	0 (0)	26
	Flare	3 (100.0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	3
Newell's Shearwater	Flight direction	5 (31.3)	2 (12.5)	2 (12.5)	4 (25.0)	3 (18.8)	0 (0)	16
	Flight altitude	2 (22.2)	2 (22.2)	4 (44.4)	1 (11.1)	0	0 (0)	9
	Direction and altitude	–	–	–	–	–	–	0
	Flight velocity	1 (100.0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1
	Flare	3 (100.0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	3

[a] Data are presented as number (percent of *N*) and are listed only for behavioral responses to structures.

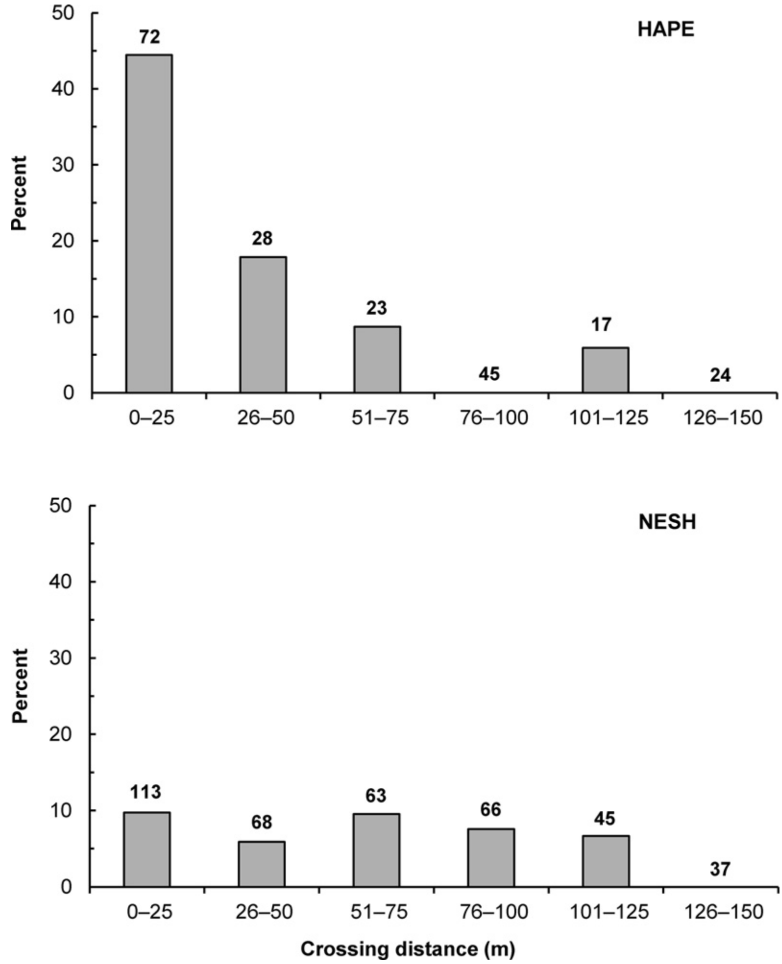

FIGURE 2. Percentage of Hawaiian Petrels (HAPE) and Newell's Shearwaters (NESH) exhibiting behavioral responses to transmission lines on Kaua'i Island, Hawai'i, in 1992–2002, by 25-m nearest crossing-distance categories. Sample sizes for each category are shown above bars.

line again indicates increasing response rates with decreasing distance from the line (Figure 3). Petrels passing 11–25 m from a line responded 33.3% of the time, whereas petrels passing 0–10 m from a line responded 53.8% of the time—a 62% relative increase in response rates. Surprisingly, this substantial increase in response rates did not differ significantly with distance ($\chi^2_1 = 2.272$; $P = .132$), perhaps because of decreased statistical power resulting from the small sample sizes ($N = 72$).

Of 392 Newell's Shearwaters that passed within 150 m of a transmission line, response rates did not increase dramatically as the crossing distance decreased: 5.9–9.7% of birds exhibited responses in the various crossing-distance categories (Figure 2). The response rate actually was highest in the 0–25-m category (9.7%), but the second-highest rate was in the 51–75-m category (9.5%), followed in decreasing order by 76–100 m (7.6%) and 101–125 m (6.7%); the lowest response rates were seen in the 26–50-m (5.9%) and 126–150-m (0%) categories, indicating that these birds did not consistently exhibit behavioral avoidance of transmission lines as they neared

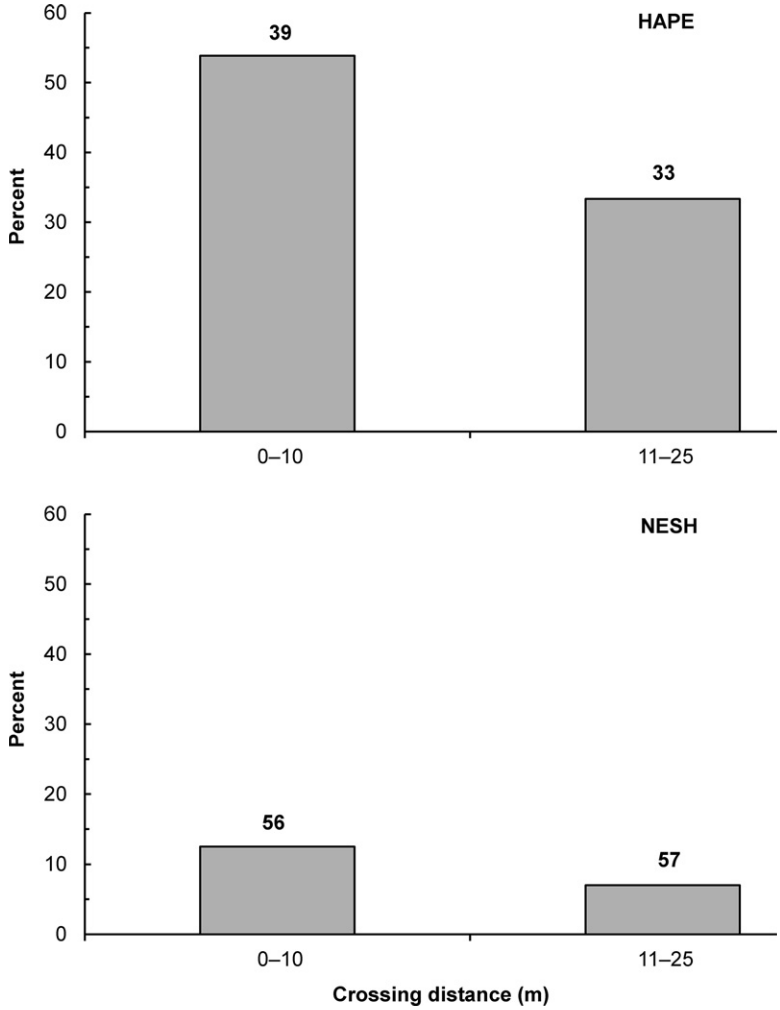

FIGURE 3. Percentage of Hawaiian Petrels (HAPE) and Newell's Shearwaters (NESH) exhibiting behavioral responses to transmission lines on Kaua'i Island, Hawai'i, in 1992–2002, within the innermost-25-m crossing-distance category shown in Figure 2. Sample sizes for each category are shown above bars.

them. Not surprisingly, response rates did not differ significantly with distance ($\chi^2_5 = 4.538$; $P = .475$).

Examination of only those Newell's Shearwater data in the closest 25 m from a transmission line also indicates an increase in response rates with decreasing distance from transmission lines (Figure 3), similar to that seen for Hawaiian Petrels. Shearwaters passing 11–25 m from a transmission line responded 7.0% of the time, whereas shearwaters passing 0–10 m from a line responded 12.5% of the time—a relative increase of 78.6%. However, the frequencies of avoidance behavior did not differ significantly with distance ($\chi^2_1 = 0.443$; $P = .506$); because sample sizes appeared to be large enough for adequate statistical power ($N = 113$), there appears to be no significant difference in frequencies between distance categories.

As might be expected from the preceding comparison for response rates of Hawaiian

Petrels and Newell's Shearwaters flying within 150 m of a transmission line, species-specific responses differed quite dramatically (Figure 2). Response rates of the two species differed significantly with distance ($\chi^2_{16} = 116.182$; $P < .001$), reflecting the significant effect of distance from a line on response rates of Hawaiian Petrels but not on those of Newell's Shearwaters. Again, response rates in the 0–25-m category were so much higher than expected, based on all data, that they contributed ~70% to the total Chi-square value, with the response rates of petrels much higher than those of shearwaters.

Effects of Environmental Light on Frequency of Response

Hawaiian Petrels exhibited an effect of environmental light on response rates (Table 3). At least 16.7%, and as many as 25.5%, of the birds crossing a transmission line exhibited a response when the study-site had ambient light (i.e., light), whereas no birds responded at any time if the study-site was unlighted (i.e., dark). Thus, they reacted significantly less often than expected if the study-site was dark than if it was light, regardless of whether the sky was light or dark ($\chi^2_3 = 9.510$; $P = .023$).

In contrast to the pattern seen for Hawaiian Petrels, Newell's Shearwaters exhibited no effect of ambient light or light in the sky on response rates (Table 3). Although there is a suggestion of a lower response rate when the study-site was dark, sample sizes in the fourth category are small, percentages in that category were equal, and the overall test was nonsignificant ($\chi^2_3 = 6.331$; $P = .097$).

Collisions and Near-Collisions

Of 209 Hawaiian Petrels and 392 Newell's Shearwaters that passed within 150 m of a transmission line, none collided with a line. However, an unidentified shearwater/petrel collided with a line near Kēalia 30 min before civil sunrise one morning in summer 1993. It collided with a line in a section that had been marked with aircraft marker balls, then wobbled in flight on its way out to sea. We do not know the fate of this bird. Hence, of visual data on 2,106 Hawaiian Petrels, Newell's Shearwaters, unidentified shearwaters, and unidentified petrels/shearwaters seen near transmission lines, this is the only collision that we ever witnessed.

Although we saw no Hawaiian Petrels collide with lines, we saw one nearly hit lines near Kēalia one morning in summer 1993, as the bird was flying out to sea 31 min before civil sunrise. The bird appeared not to notice the lines, and then suddenly reacted as it approached more closely. It slowed noticeably in flight and almost stopped in mid-air, then slipped between the lines and continued out to sea.

Although we saw no Newell's Shearwaters collide with lines, we saw one bird nearly hit lines near the Wailua River one evening in fall 1993, as the bird was flying seaward 83 min

TABLE 3

Behavioral Responses (Number, Percent) of Hawaiian Petrels and Newell's Shearwaters near Transmission Lines on Kaua'i Island, Hawai'i, in 1992–2002, by Species, Ambient Light at Study Sites, and Light in the Sky

Species	Behavioral Response	Study-Site: Light/Sky Dark	Study-Site: Dark/Sky Dark	Study-Site: Light/Sky Light	Study-Site: Dark/Sky Light	*N*
Hawaiian Petrel	Response	12 (16.7)	0 (0.0)	28 (25.5)	0 (0.0)	40
	No response	60 (83.3)	17 (100.0)	82 (74.5)	10 (100.0)	167
	Total	72	17	110	10	209
Newell's Shearwater	Response	24 (7.3)	1 (3.1)	2 (6.9)	1 (50.0)	28
	No response	305 (92.7)	31 (96.9)	27 (93.1)	1 (50.0)	364
	Total	329	32	29	2	392

after civil sunset. There was no apparent change in flight altitude or flight speed, and the bird flew between lines and continued flying out to sea.

We also recorded birds flaring—exhibiting extreme avoidance behavior—on several occasions. We saw Hawaiian Petrels exhibit flaring three times, with all three birds eventually crossing 1 m from the nearest line. The first bird was seen at Wailua one morning in summer 1993, as it was flying out to sea 32 min before civil sunrise. The second bird was seen at the same location on the same morning, as it was flying out to sea 30 min before civil sunrise. The third bird was seen at Kēalia one morning in summer 1993, as it was flying out to sea 10 min before civil sunrise.

We saw Newell's Shearwaters exhibit flaring three times. The first bird was seen at Kēalia one morning in summer 1993, as it was flying out to sea 27 min before civil sunrise; it crossed 1 m from the nearest line. The second bird was seen at the same location on the same morning, as it was flying out to sea 26 min before civil sunrise; it also crossed 1 m from the nearest line. The third bird was seen at the Kalihiwai airport one evening in summer 1994, as it was flying inland 39 min after civil sunset; it crossed 3 m from the nearest line.

In addition to flaring, we saw a Hawaiian Petrel change both flight altitude and flight behavior one time; we consider this behavioral response to be less intense than flaring behavior but more intense than simply changing flight altitude, flight direction, or flight speed. This bird was seen at Wailua one morning in summer 1993, as it was flying out to sea 7 min before civil sunrise; it crossed 3 m from the nearest line.

DISCUSSION

Electrical-transmission lines, communication towers, and wind-energy developments continue to be built in Hawai'i. For example, a state goal in which 40% of Hawai'i's energy is to come from "clean" energy sources by 2030 (HB 1464, passed in 2009) undoubtedly will lead to more wind-energy developments in the state. Because even small errors in avoidance rates for these types of structures can have a very large effect on predicted fatality rates from preconstruction studies (Chamberlain et al. 2006, Fox et al. 2006), understanding the avoidance behavior of birds around these structures will be especially important in assessing the potential effects of those structures on birds, especially on endangered species such as Hawaiian Petrels and Newell's Shearwaters. Although it is clear from several studies that both Hawaiian Petrels and Newell's Shearwaters collide with transmission lines on Kaua'i (Cooper and Day 1998, Podolsky et al. 1998, Travers et al. 2021), we found that, during the peak evening and morning activity periods, a substantial proportion of petrels and a small proportion of shearwaters detect and respond to coastal and near-coastal transmission lines under normal ranges of weather conditions and visibility. We agree with others (Chamberlain et al. 2006, Fox et al. 2006), however, that detailed avoidance data are needed to understand and model fatality risk with confidence. Further, we suspect that there are structure-specific differences in avoidance rates within a species, in that response rates at spinning wind turbines almost certainly are different from avoidance rates at transmission lines or communication towers. Thus, we recognize that there is a need to collect further behavioral-avoidance data for Hawaiian Petrels and Newell's Shearwaters at other types of structures to understand and minimize the risk of collisions with other proposed structures.

Collision-Avoidance in Petrels and Shearwaters

It is clear that collision rates are low, both at these coastal and near-coastal transmission lines and at the mostly inland lines studied by Travers et al. (2021). We recorded only one collision in 2,106 total Hawaiian Petrels, Newell's Shearwaters, unidentified shearwaters, and unidentified petrels/shearwaters seen flying near lines on 637 sampling sessions during ~300 h of sampling, suggesting that collisions may be on the order of ~0.0005 collisions/bird seen near a coastal or near-coastal transmission line and ~0.003 collisions/h of sampling effort. In all cases, collisions clearly are a rare event, making estimates of collision rates difficult to quantify with accuracy. On the other hand, such small numbers can become large numbers when calculated across the entire island over a year (Travers et al. 2021).

Although Newell's Shearwaters are well known for colliding with structures, Hawaiian Petrels sometimes hit structures too, even though they are less well-known at doing it than Newell's Shearwaters are. Occasional fatalities have been recorded at electrical-transmission lines near the summit of Haleakalā, Maui Island (Hodges 1992), at wind turbines on Maui Island (Tetra Tech 2020), at fences high on Mauna Loa on Hawai'i Island (Swift 2004), and at a fence high on Lāna'i Island (anonymous reviewer of this paper, *in litt.*). In contrast, fatality rates at inland transmission lines on Kaua'i Island appear to be high (Travers et al. 2021). Weather conditions during these occasional fatality events often are not known, so it is unclear how often poor visibility is involved in such fatalities; however, the fairly frequent occurrence of fog near the summit of Haleakalā at night (RHD, pers. obs.), but apparently infrequent fatality of petrels there, implies that they are able to avoid colliding under most conditions. However, Swift (2004) also recorded a collision of a Hawaiian Petrel at a fence during foggy conditions. On the other hand, shearwater collisions along at and near the coast on Kaua'i occur during periods ranging from clear, dry conditions to overcast, dry conditions to rain (RHD and BAC, pers. obs.).

The data presented here indicate that 19.1% of the Hawaiian Petrels flying within 150 m of a coastal or near-coastal transmission line on Kaua'i Island responded to lines and that the frequency of responses increased with decreasing distance, especially within 25 m of a line. These results suggest that many Hawaiian Petrels avoid transmission lines by exhibiting behavioral responses consistent with collision-avoidance behavior, even if the birds may not have been flying exactly at the height of the transmission lines.

Newell's Shearwaters flying within 150 m of coastal and near-coastal transmission lines exhibited a substantially lower response rate (~7.4% of all birds) than Hawaiian Petrels did, and there was not a strongly-increasing response rate with decreasing distance. None of the shearwaters exhibiting a response collided with a line, although one flew between lines that were in a vertical orientation. It is possible, however, that some of the birds that we observed changed flight altitudes long before they approached the transmission lines, although the substantial collision-caused fatality rate of this species at coastal and near-coastal lines (Cooper and Day 1998, Podolsky et al. 1998) and visual observations of actual collisions with inland lines on Kaua'i Island (26 Hawaiian Petrel and 62 Newell's Shearwater collisions; Travers et al. 2021) implies that some Newell's Shearwaters (and Hawaiian Petrels) truly do not. Unfortunately, our study indicates that Newell's Shearwaters show little response to coastal and near-coastal transmission lines, regardless of distance from lines or the presence or absence of ambient light from nearby towns or light in the sky, so the fact that Newell's Shearwaters represent the preponderance of collisions recorded both at or near the coast (Cooper and Day 1998, Podolsky et al. 1998) and inland (Travers et al. 2021) is not surprising.

The results of our study support those of Travers et al. (2021), in that Hawaiian Petrels are good at responding to electrical-transmission lines if the general study-site is light (i.e., lighted by ambient light) but show little response if the study-site is dark (i.e., unlighted). Because much of Travers et al.'s sampling occurred at remote inland sites that were dark (i.e., with no nearby communities to provide ambient light to the area and lines), it is not surprising that Hawaiian Petrels collided with lines at those inland locations, whereas collisions of that species appear to occur rarely at the coastal and near-coastal lines that we studied. However, it should be noted that inland collisions recorded by Travers et al. were nonrandom spatially, suggesting that other factors besides ambient lighting also are important in causing collisions. The biggest difference between these two studies is that Travers et al. showed that both species, and not just Newell's Shearwaters, regularly collide with transmission lines at these inland sites.

The difference in response rates between the two species could help explain the greater collision rate of Newell's Shearwaters with coastal and near-coastal transmission lines on Kaua'i than is seen in Hawaiian Petrels (Cooper and Day 1998). One alternative hypothesis is simply that Newell's Shearwaters are much more abundant than Hawaiian Petrels on Kaua'i and that fatality is directly proportional to the number of birds crossing the transmission line; however, there does not appear to be a relationship between these numbers and the fatality rate of Newell's Shearwaters on Kaua'i (Cooper and Day 1998), so there is little support for this hypothesis.

Another alternative hypothesis is that weather plays a strong role in causing fatalities of Newell's Shearwaters but not Hawaiian Petrels. For example, Telfer et al. (1987) speculated that they sometimes found higher fallout of young Newell's Shearwaters during rainy periods because the sky was obscured by clouds and light reflected off of wet surfaces, possibly making the birds think they were landing on water. However, moon phase and proximity to lights (Telfer et al. 1987), proximity of the transmission line to the coast (Cooper and Day 1998), and line height and complexity (Podolsky et al. 1998)—not weather—have been found to be significantly associated with fatalities and downing of Newell's Shearwaters. In addition, weather conditions during the 637 visual surveys in this study were representative of weather conditions that commonly occur at lower elevations on Kaua'i and of conditions under which these birds collide with transmission lines; that is, these birds are downed during a variety of weather conditions, but those conditions commonly are seen here. Finally, we cannot explain why weather would affect only one of the two species negatively.

Thus, the simplest explanation for the lower fatality rates of Hawaiian Petrel is that they simply are more responsive to structures in their airspace than Newell's Shearwaters are. From what we can determine, Newell's Shearwaters show little alteration of behavior, regardless of distance from lines, ambient light at a study-site, or the amount of light in the sky. Further, collision rates of Newell's Shearwaters at inland sites studied by Travers et al. (2021) were about 200% higher than those of Hawaiian Petrels, again suggesting a lower response rate of Newell's Shearwaters at those inland sites.

Why is there such a strong difference between the two species in the frequency of responses to transmission lines? Hawaiian Petrels have two primary characteristics that enable them to avoid collisions, whereas Newell's Shearwaters have two that make them poorly able to avoid collisions. Hawaiian Petrels tend to be highly-maneuverable birds that are able to fly at a variety of speeds and change direction easily, whereas Newell's Shearwaters tend to be direct fliers that fly at a high velocity and with less ability to maneuver (RHD and BAC, pers. obs.). Indeed, wing-loading for gadfly petrels tends to be about half of that for Newell's Shearwaters (Spear and Ainley 1997), which gives the petrels a more buoyant flight. As a result, Hawaiian Petrels can slow their speeds dramatically and, hence, can maneuver around and through transmission lines and other structures (what Travers et al. 2021 call a "stall"), whereas Newell's Shearwaters have little time to react to structures because they are flying so quickly and have little maneuverability.

The results of this study differ from those of Cooper and Day (1998), who suggested that reaction frequencies to coastal and near-coastal transmission lines on Kaua'i were small and not different between these two species. That paper suggested that the overall reaction rate to transmission lines by all Hawaiian Petrels was only 4.8% of all birds, whereas the overall rate within 150 m of lines in this study was 19.3%. Likewise, that paper suggested that the overall reaction rate to transmission lines by all Newell's Shearwaters was only 4.9% of all birds, whereas the overall rate within 150 m of lines in this study was 7.4%. There are three reasons for these differences in results between the two studies. First, the current study includes additional data collected in 1999–2002 that increased sample sizes substantially. Second, the substantially larger data-set used in this study allowed us to focus only on those birds flying near lines, whereas the earlier paper used all data, regardless of distance; in reality, the probability that a bird flying 500–1,000 m above a transmission line will respond to it is low. Third, we recoded behavioral responses and included slowing the flight speed as an additional type of avoidance response; that response had not been considered in the original study, although we recorded observations of slowing in comments during data collection. We believe, however, that these new data and focused analyses allow us to discern avoidance reactions of these species to transmission lines better than previously was possible and at a more relevant scale.

Collision-Avoidance in Birds

We agree with others (Chamberlain et al. 2006, Fox et al. 2006) that detailed collision-avoidance data are needed to understand and model fatality risk at proposed tall structures such as electrical-transmission lines, communication towers, and wind turbines. The response data presented here are consistent with the hypothesis that most petrels and shearwaters detect and avoid transmission lines (and presumably other structures, such as trees) near the coast under normal ranges of weather conditions and light levels experienced by both species.

Ameliorating factors and mitigation efforts during construction may increase collision-avoidance rates and, hence, reduce fatality rates of petrels and shearwaters. Small structures such as guy wires on meteorological towers are difficult for nocturnal birds to see (Longcore et al. 2008), so marking of the wires and fences should increase their visibility, especially to diurnal birds (e.g., Alonso et al. 1994, Baines and Andrew 2003). Indeed, marking of metal fences with white flagging has been shown to reduce the collision rate of Hawaiian Petrels at night near inland nesting colonies on Hawai‘i (Swift 2004) and Lāna‘i (anonymous reviewer of this study, in *litt*.). Alternatively, unguyed meteorological towers may reduce fatality rates (Longcore et al. 2008, Gehring et al. 2009). Finally, towers and transmission lines may be located against hillsides (if feasible) that will shield much of the height of the structures and may be mostly or entirely hidden behind natural structures such as trees to reduce the amount of those structures that is exposed to flying birds, especially nocturnally-flying ones (see also APLIC 2006).

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