LIGHT ATTRACTION IN ENDANGERED PROCELLARIIFORM BIRDS: REDUCTION BY SHIELDING UPWARD RADIATION

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ABSTRACT.—Autumnal attraction to man-made lighting causes heavy mortality in fledgling Hawaiian seabirds: Newell's Shearwater (*Puffinus auricularis newelli*), Dark-rumped Petrel (*Pterodroma phaeopygia sandwichensis*), and Band-rumped Storm-Petrel (*Oceanodroma castro*). These threatened, endangered, and rare species (respectively) approach and circle lights on their first flight from mountain nesting colonies on the island of Kauai to the sea. We shielded lights of the largest resort to prevent upward radiation on alternate nights during two fledgling seasons. Shielding decreased attraction by nearly 40%. Most attraction occurred 1–4 h after sunset. Full moon dramatically decreased attraction, a phenomenon that has both theoretical and management implications. *Received 11 May 1984, accepted 16 November 1984.*

EACH autumn more than a thousand individuals of threatened and endangered seabirds are found on the ground in the vicinity of bright lights near the coast on the island of Kauai, Hawaii. These birds are mainly fledglings on their first flights from their mountain nesting colonies to the ocean. These disoriented birds collide with man-made structures and, if not killed on impact, may fall to the ground injured or stunned and there be run over or preyed upon. The threatened Newell's Shearwater [now treated as a subspecies of the Townsend's Shearwater (*Puffinus auricularis newelli*, A.O.U. 1983: 25; see Jehl 1982)], the endangered Hawaiian Dark-rumped Petrel (*Pterodroma phaeopygia sandwichensis*), and the very rare Band-rumped Storm-Petrel (*Oceanodroma castro*) all suffer mortality due to their attraction to man-made lights. The general problem of light attraction is worldwide among the Procellariiformes; at least 21 species are known to be attracted to man-made lights (Ridgway 1885, Wetmore 1926, Beebe 1935, Gross 1935, Murphy 1936, Murie 1959, Wingate 1964, Swales 1965, Jouanin and Gill 1967 *in* Imber 1975, Sincock and Swedberg 1969, Imber 1975, DeSante and Ainley 1980: 11). Here we report the results of a controlled experiment shielding upward radiation of lights in an attempt to understand more thoroughly the nature of light attraction and decrease its occurrence in procellariiform birds.

Light attraction is a general problem in birds, not restricted to petrels or even to seabirds. Early authors noted the attraction of birds to fires (e.g. Murphy 1936), and lighthouses were the first man-made structures to attract birds (Clarke 1912). Ceilometer lights at airports caused heavy mortality until they were modified by shifting their spectra into the ultraviolet and turning them on only briefly (Howell et al. 1954, Laskey 1956, Terres 1956). An estimated one million migrants die at TV towers annually (Aldrich et al. 1966). Lights of a fishing vessel attracted 1.5 metric tons of Crested Auklets (*Aethia cristatella*), nearly capsizing the boat (Dick and Donaldson 1978). Birds are also attracted to gas flares on oil rigs in the ocean (Sage 1979). Such reports bear some striking parallels with light attraction in Hawaiian procellariiform birds.

The commonest mountain-nesting species on Kauai is the threatened Newell's Shearwater, which was once believed to be extinct (Peters 1931) but was rediscovered in 1954 when one flew into a lighted window on the island of Oahu (Richardson 1955). By the mid-1960's Newell's Shearwaters were being found during October and November in all inhabited coastal areas of Kauai, apparently attracted to streetlights, lighting of athletic fields, security lights around hotels and resorts, and similar areas (Hadley 1961, King and Gould 1967, Sincock and Swedberg 1969). The first breeding colony was discovered in 1967 on a steep mountainside on Kauai (Sincock and Swedberg 1969). Nest predation by the introduced lesser mongoose (*Herpestes auropunctatus*) and domes-

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tic mammals probably accounts for the extirpation or near extirpation of Newell's Shearwater on Hawaiian islands other than Kauai; the mongoose is not yet known to be established on Kauai. In 1978 a systematic study of autumnal light attraction was initiated by Sincock and T. Telfer on Kauai; in the first year of the program 867 Newell's Shearwaters, now considered a threatened subspecies, were turned in at 11 "shearwater aid stations" on Kauai. More birds were picked up in following years, with 1,451 birds recovered in 1979, 1,358 in 1980, and 1,133 in 1981. An additional 100–200 birds died on the highways each year.

A few individuals of two rarer procellariiform species were also picked up. One of these, the endangered Hawaiian Dark-rumped Petrel, breeds in a small remnant colony on the inner slopes of Haleakala "crater" on the island of Maui and possibly rarely in a few other sites in the Hawaiian Islands, but no nest has yet been found on Kauai. Three fledglings were turned in on Kauai during the 1978 season, 5 in 1979, 3 in 1980, and 6 in 1981.

The third species, the Band-rumped Storm-Petrel (formerly known as Harcourt's or Madeiran Storm-Petrel), is so rare in Hawaii that its nesting has not yet been confirmed. During a helicopter survey in 1980, we located the nest burrow of some species on a sheer cliff face in a valley where Sincock had heard Band-rumped Storm-Petrels calling during the breeding season. As our survey was made after nesting, no birds were at the burrow so we cannot say with certainty that the nest site belonged to this species. One individual was turned in during the 1978 fallout, 2 each in 1979 and 1980, but none in 1981.

METHODS

A technical survey recommended that shielding of upward radiation was the least expensive modification of lights likely to decrease attraction (Hailman 1979). The Kauai Surf Resort, a seaside hotel located in Lihue, was selected as the study site because approximately one-third of the island-wide downing of birds occurred there in 1978–1979, and because the management was sympathetic to the plight of the birds and offered complete cooperation.

Design.—If average attraction was constant through the fledging season, it would be possible to use a random experimental design in which the lights are shielded for half the nights scattered randomly through the autumn. However, analysis of island-wide data for previous years (T. Telfer pers. comm.) revealed two forms of systematic variability: (1) a seasonal peak, with the average number of downed birds increasing each night up to late October and decreasing each night thereafter; and (2) a "moon effect," with the average number of downed birds decreasing each night as the moon became fuller and increasing each night after full moon until the next new moon. These two effects constrain effective experiments to an alternating design, in which nights with shielded lights can be compared with adjacent control nights.

A problem arises with an alternating design if there is natural alternation in attraction. We tested for natural alternation in the island-wide data using a method inspired by MacArthur's (1958) evaluation of whether animal populations rise and fall in successive years. The data were first tabulated in a 3 × 3 contingency table (increase, no change, and decrease on night x vs. the same categories for night $x + 1$). The 1978 data showed no interaction ($\chi^2 = 7.72$, df = 4, $P = 0.102$), but a significant interaction was found in the 1979 data ($\chi^2 = 23.63$, df = 4, $P < 0.001$). This latter result occurred because of large numbers of zero-bird nights in the "no-change" columns and rows. Therefore, the contingency tables were reanalyzed after elimination of the zero-laden no-change columns and rows, interactive effects being tested by Fisher's exact probability method. No sign of natural alternation was found in the 1978 data ($P = 0.368$), the 1979 data ($P = 0.644$), or the two years combined ($P = 0.417$). Further tests on the restricted period around the seasonal peak also failed to show any natural night-to-night alternation. In fact, combining the years showed that increases were more often followed by further increases, and vice versa. Therefore, on the first night of a given experimental season the light condition (shielded or unshielded) was chosen randomly and alternated on subsequent nights.

Procedure.—Experiments began in 1980, with 12 of the brightest security lights shielded on alternate nights from 1 October to 15 November; the 1981 season (21 October to 6 November) began later due to funding delays. Most of these experimental lights were on top of two 11-story buildings, the two largest buildings on the island. Most other bright lights were permanently shielded during the study because they were too difficult to reach for daily changing. Two special-event lights were lighted on rare occasions, and one of these could not be shielded; a full record was kept of evenings on which these lights burned. In addition, there were hundreds of smaller lights in the vicinity of the resort, including room lights and walk lights. There was no experimental control over such illumination, which varied little from night to night.

Shielding consisted of a hood, the top of which projected outward from the obliquely down-pointing lights in a horizontal line with the bottom of the

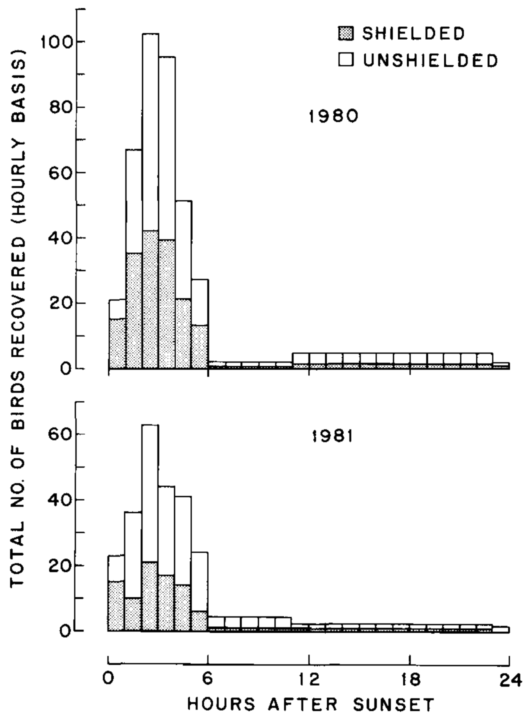

Fig. 1. Hourly distribution of Newell's Shearwaters recovered at the Kauai Surf Resort during shielding experiments in 1980 and 1981. Shielded nights are represented by dark bars and unshielded (control) nights by open bars. Multihour bars (i.e. 6–11 and 11–23 h after sunset) reflect the average number of birds recovered per hour. Birds recovered during the first hour following sunset are believed to have come down the previous night and hidden during the day (see text).

light; the sides were triangular. The shaded lights projected nearly their full radiation downward but could not be seen anywhere above the elevation of the light itself. The effectiveness of shielding was assessed by systematic photographic surveys by helicopter on 22 October (unshielded) and 25 October 1980 (shielded) at 33-m increments from 33 to 167 m above Nawiliwili Bay in front of the resort. No shielded light was visible from 33 m or higher above the water.

Each night at least two persons searched the grounds and rooftops for downed shearwaters; additional birds were recovered by security guards and other resort personnel. Searches usually began shortly before sunset and terminated either approximately 6 h after sunset or after two consecutive hours during which no birds were found. On nights of exceptionally large numbers of birds, searches continued until 0200–0300 AHST the following morning. A data form

TABLE 1. Times that the first Newell's Shearwaters were observed flying at the Kauai Surf Resort during fall 1981. Times are expressed in hours and minutes after sunset.

Date	Order of birds seen 1	2	3	4	5
27 Oct.	1:22	—	—	—	—
28 Oct.	0:49	1:17	1:17	1:18	1:18
29 Oct.	1:21	1:41	1:45	1:53	1:54
30 Oct.	1:31	1:35	1:35	1:35	1:36
1 Nov.	1:06	1:08	1:14	1:17	1:20
3 Nov.	1:00	1:28	1:30	1:31	1:31

was completed giving the date, time, observer, condition of the bird, and a map on which the bird's location was recorded. The grounds and rooftops were searched the following morning for any further birds.

Timing.—Field studies by Sincock revealed that Newell's Shearwaters begin activity at the nesting burrows at about sunset but are not flying around overhead until about an hour later. To determine how these observations relate to light attraction at the coast, the number of birds found at the experimental site was tallied for the first 6 h following sunset (0–6 h), the late evening (6–11 h following sunset), daylight hours up to 1 h before sunset (11–23 h), and the hour preceding sunset (23–0 h).

RESULTS

Daily timing.—Figure 1 shows that the number of birds recovered reached a peak 2–3 h following sunset (probably closer to 3 h), then decreased steadily until 6 h following sunset, when almost no new birds were found. One aspect of the data seems to contradict observations at the mountain colonies: some birds were found at the resort within the first hour after sunset, which is before adults are flying in the colonies. A few early-flying birds would be possible, but we believe that most of these birds came down the previous night and crawled into hiding places where they were overlooked by searchers. Then, with the fall in ambient illumination the following evening, these birds began crawling out of hiding and were discovered. This interpretation is supported by Reed's observations of at least 6 shearwaters crawling out of heavily vegetated areas onto lawns during the hour following sunset.

To test the foregoing hypothesis, an assistant was stationed on the roof of the resort before sunset on 6 nights during 1981, where she re-

TABLE 2. Pair-wise comparisons of numbers of Newell's Shearwaters recovered on consecutive nights when lights were shielded and unshielded (control).[a] See text for statistical comparison between shielding reduction in 1980 and 1981.

	Total birds found		Percent	Control precedes			Control follows		
Data set	Control	Shielded	reduction	*n*	T^b	*P*	*n*	T^b	*P*
1980	252	180	28.6	20	69	0.090	20	48	0.017
1981	192	92	52.1	8	0	0.006	7	6	0.089
Total	444	272	38.7	28	83.5	0.003	27	87	0.007

[a] Comparisons by the Wilcoxon matched-pairs, signed-ranks test, where *n* is the number of non-tie, pair-wise comparisons.
[b] One-tailed probability levels calculated by the formula for z (Siegel 1956: 81, Eq. 5.5).

corded the times that shearwaters were sighted in flight. Only the first observation is crucial because subsequent sightings could have been of the same bird circling the grounds. These data showed that the vast majority of birds did not begin arriving until an hour or more after sunset (Table 1) and hence confirmed observations made at the colonies. We therefore concluded that all birds found in the first hour after sunset probably fell the previous night. It is possible that a few birds found later than 1 h after sunset also fell the previous night, but as some cutoff time was needed, we defined the experimental day as beginning 1 h after sunset.

Effect of shielding.—More birds were found during control (unshielded) nights than nights when lights were shielded (Fig. 1). This difference holds for both years as a whole and for all individual periods during the daily cycle, except during the first hour after sunset in both 1980 and 1981 and the second hour after sunset in 1980. As noted above, birds found in the hour after sunset had fallen the previous night and hidden, to emerge the next evening. Hence, each data-bar for the hour following sunset in Fig. 1 actually belongs to the previous experimental day, in which the opposite condition (shielded or normal lights) occurred. In sum, during every time period for seasonal totals in both 1980 and 1981, with the one exception mentioned above, as many or more birds were found on control nights than were found on experimental (shielded) nights.

In 1980 the full moon occurred just when the peak of fledging was expected, and almost no birds were found (Fig. 2). For this reason the experiment was run again in 1981 around the time of the expected peak (with no full moon) to see differences in the effectiveness of shielding when attraction was low and high. Attraction in 1981 was also smaller on experimental nights than on the control nights (Fig. 2). Pair-wise comparisons (data from shielded nights vs. the previous and succeeding night) show one of them to be significant for each year (Table 2), and the combined data from both years clearly demonstrate a significant reduction in attraction for both comparisons. The data in Fig. 2 and Table 2 use the division of experimental days at 1 h following sunset, as noted above. To determine whether including birds found in the first hour after sunset in the previous night's totals affected the conclusions, these birds were removed from the tallies and all the statistical comparisons recalculated. In all cases the resulting probability values were very close to those in Table 2.

The overall reduction in attraction resulting from the shielding of lights was nearly 40% (Table 2), but the two experimental years differed. During the lower levels of nightly recovery in 1980 the reduction was only about 30%, whereas reduction during the seasonal peak in 1981 was more than 50%. The totals of Table 2 were cast into a 2×2 contingency table (year vs. experimental condition) and subjected to Chi-square analysis ($\chi^2 = 6.26$, df $= 1$, $P = 0.012$). Although the experiment was not designed to test for differences in reduction at different magnitudes of attraction, it does appear that shielding is significantly more effective when attraction is greater.

DISCUSSION

Three major conclusions can be drawn from the results. First, the full moon decreases attraction to lights. We cannot say if (1) full moon inhibits young shearwaters from fledging, (2) greater ambient light causes a visual diminu-

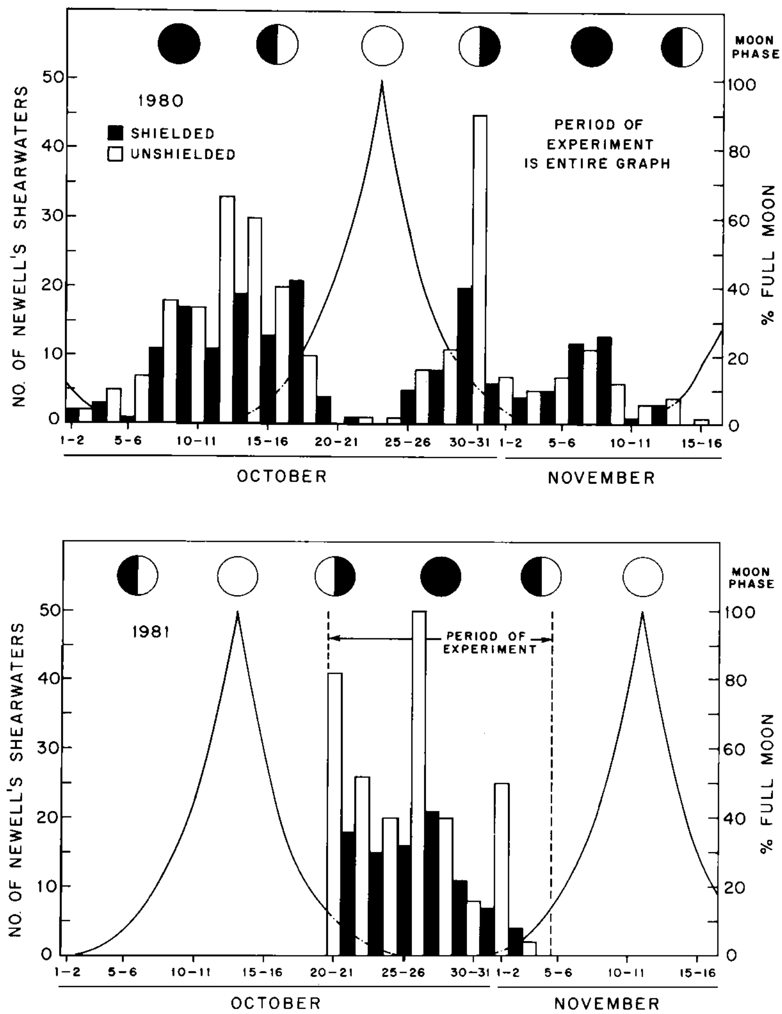

Fig. 2. Numbers of Newell's Shearwaters recovered at the Kauai Surf Resort during the shielding experiments in 1980 and 1981. Nights when lights were shielded are represented by dark bars, and unshielded (control) nights by open bars. Associated moon phases are diagrammed, and intensity of moonlight measured in relation to full-moonlight intensity is plotted. Full moons occurred at 1052 AHST on 23 October and 0839 on 21 November 1980, and at 0049 on 13 October and 2226 on 11 November 1981.

tion of point-sources of light, or (3) fledging birds orient toward the moon and hence do not come down to man's lights. Verheijen (1980, 1981) found no reports of attraction during the 4 nights around the time of the full moon for 62 nights with reported bird kills in the U.S. between 1935 and 1973. He also found no kills during the full moon in the 4-yr daily records of bird kills at a Dutch lighthouse, during which time approximately 1,500 birds of 62 species were recovered. However, Crawford (1981) notes that the full-moon effect does not hold for TV tower kills in the Florida panhandle. Tower kills may not be due to light-attraction; birds may simply strike the tower and support wires because they cannot see the structures in the dark.

The effect of the full moon in depressing shearwater attraction necessitated running the experiment a second year. The effectiveness of shielding was most clearly demonstrated during 1981, when the waning and new-moon phases produced early, moonless evenings of high recovery yielding 52% reduction on shielded nights. The waxing crescent moon is always present in at least the early evening sky, whereas the full moon is above the horizon for nearly the entire evening. The waning crescent moon, which rises after sunset and sets after sunrise, leaves the first part of the night without moonlight. Lunar periodicity, coupled with maximum recovery between 1–4 h after sunset, may explain the asymmetry in the distribution about the full moon of 23 October 1980. Only 6 birds fell during the 4 nights preceding the full moon, whereas 22 fell on the succeeding 4 nights. The moon was either low in the night sky or below the horizon during the peak recovery hours of 24–27 October 1980. In both of Verheijen's (1981) figures attraction was also lower for the four nights preceding the full moon than those following it.

A second conclusion is that light shielding decreases attraction and hence has management potential. In areas where other light sources are rare, shielding of principal bright lights (street lighting, athletic stadiums) would probably have an even larger effect in decreasing attraction than found in this study, where many lights were not under experimental control.

Finally, because the sides of large buildings and the entire grounds were fully lit in the shielded condition, the decrease indicates that the fledglings were attracted primarily to the light sources themselves rather than to the areas they illuminated. Therefore, one need not reduce the effectiveness of lighting for human purposes in order to decrease avian attraction. (In fact, shields may reflect additional light downward, increasing the efficiency of lighting for human purposes.) Furthermore, the attraction of birds to bright point sources may mean that fledglings have a predilection to fly toward certain star patterns. Man's lights could be "supernormal" starlike stimuli that unwittingly convert an adaptive response into a disaster that may threaten the existence of rare species. Sincock estimates that over 50% of Newell's Shearwater fledglings are involved in the autumnal attraction on Kauai.

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Joint meetings of the **Herpetologists' League and The Society for the Study of Amphibians and Reptiles** will be held at the University of South Florida, Tampa, Florida, **3-9 August 1985**. For further information write: **Henry R. Mushinsky, Department of Biology, University of South Florida, Tampa, Florida 33620 USA.**

The **Pacific Seabird Group and Colonial Waterbird Group** will hold a **joint meeting 4-8 December 1985** at the San Francisco Hotel in San Francisco, California. Two symposia will be held: "Recent advances in gull research" and "The use of man-modified vs. natural wetlands by waterbirds and shorebirds." Scientific paper sessions will be held 5-7 December, with field trips on the 8th. For information contact the program chairpersons: **Ms. Lora Leschner** (PSG), **Washington Department of Game, 16018 Mill Creek Boulevard, Mill Creek, Washington 98012 (206-774-8812)**; or **Dr. William Southern** (CWG), **Department of Biological Sciences, Northern Illinois University, DeKalb, Illinois 60115 (815-753-7140).**