Condor 85:292–296
© The Cooper Ornithological Society 1983

BREEDING BIOLOGY OF WEDGE-TAILED SHEARWATERS AT KILAUEA POINT, HAWAII

G. VERNON BYRD
DANIEL I. MORIARTY
AND
BARRY G. BRADY

ABSTRACT.—We studied the breeding biology of Wedge-tailed Shearwaters (*Puffinus pacificus*) at a colony of about 700 pairs on the north shore of Kauai Island, Hawaii, between 1978 and 1981. Most birds nested in earthen burrows, but they also readily used artificial ones. The nesting chronology at the study area was similar among years and nearly identical to that recorded elsewhere in Hawaii. Shearwaters began to arrive in March, and spent considerable time rehabilitating burrows before laying eggs synchronously in June. Most eggs hatched between 1 and 12 August. Chicks fledged more than 100 days later during November. Approximately 80% of the eggs produced fledglings in 1978 and 1979, but success dropped in 1980 and 1981, probably because of predation and human disturbance.

The Wedge-tailed Shearwater (*Puffinus pacificus*) breeds widely in the tropical and subtropical Pacific and Indian oceans (A.O.U. 1957). The northern edge of its breeding range includes the northwestern Hawaiian Islands and offshore islets near the main Hawaiian Islands of Oahu, Maui, and Kauai (Richardson 1957). This species does not usually nest on the main Hawaiian Islands, probably because of introduced mammalian predators, particularly the mongoose (*Herpestris auropunctatus*). However, scattered colonies, like the one to be described here, occur on Kauai Island where this predator is absent (Byrd and Boynton 1979).

Our study was conducted to provide baseline data with which to manage a seabird refuge that was recently established at Kilauea Point, Hawaii. The objectives of the study were to (1) determine the size of the breeding population at Kilauea Point, (2) describe nest sites and evaluate the persistence of nesting burrows, (3) determine the timing, duration, and synchrony of different phases of the breeding cycle, (4) determine nesting and fledging success, and (5) identify major mortality factors. This paper summarizes our findings and compares them with those from other studies.

Several annotated faunal lists, especially that of Woodward (1972), include anecdotal information about the Wedge-tailed Shearwater (e.g., Richardson 1957, Amerson 1971, Ely and Clapp 1973). A few longer studies describe the natural history of this species on selected islands, specifically on Heron Island, Australia (Gross et al. 1963), the Kermedec Islands near New Zealand (Crockett 1975), and Manana Island, Hawaii (Shallenberger 1973).

STUDY AREA AND METHODS

Kilauea Point is the tip of a 50-m high, flat-topped peninsula on the north shore of Kauai Island, Hawaii. It is the site of a U.S. Coast Guard lighthouse station and since 1974 the U.S. Fish and Wildlife Service has managed the area as a seabird refuge. The site is open to the public and over 75,000 people visited annually from 1978 to 1979; by 1981, visitors exceeded 100,000 per year (U.S. Fish and Wildlife Service records). The refuge is protected by live-trapping of cats and a fence that excludes dogs.

Nesting seabirds at Kilauea Point, other than the Wedge-tailed Shearwater, include Red-tailed Tropicbird (*Phaethon rubricauda*), White-tailed Tropicbird (*P. lepturus*), and Red-footed Booby (*Sula sula*; Byrd and Zeillemaker 1981).

Our study area was along the upper edge of the steep hillside surrounding the lighthouse. The dominant vegetation included the introduced shrubs *Lantana camara, Leucaena latisiliqua,* and *Schinus terebinthifolius,* and the native shrubs *Scaevola taccada* and *Euphorbia atococca. Portulaca oleracea* and *Cynodon* sp. provided most of the ground cover.

In October 1977, 108 shearwater burrows were marked with wooden stakes and numbered metal tags. They were checked every 3–5 days thereafter to determine fledging dates. From 1978 to 1981, the burrows were checked every 3–7 days during the incubation and chick-rearing periods, and every 1–3 days during laying, hatching, and fledging. Many of the original burrows did not persist throughout the study, so we marked an additional 38 during the incubation period in 1981.

In 1978, 18 wooden structures, similar in size to earthen burrows, were placed in the study area to determine whether shearwaters would use them for nesting. We wanted to determine if artificial burrows would enhance the birds' nesting success in areas where natural burrows regularly collapsed because of erosion. The wooden structures were replaced in 1979 by 30 pieces of plastic pipe 15 cm in diameter and 46 cm long.

From 1979 to 1980 we tried to band every nestling in the colony so that we could census successful burrows, measure total annual production, and have a large sample of known-aged birds at the site for future studies.

RESULTS AND DISCUSSION

DISTRIBUTION AND ABUNDANCE OF SHEARWATERS AT KILAUEA POINT

Nesting density at Kilauea Point was highest on the 15- to 45-degree slopes that extended from the edge of a flat plateau to the top of nearly vertical cliffs (Fig. 1). In 1978, 1,344 Wedge-tailed Shearwater burrows were counted near Kilauea Point (Byrd and Boynton 1979); 994 were in our study area. If the percentage of burrows that contained a chick at our site was similar to that of the overall area censused (53%), 520 chicks were present. We did not determine the number of active burrows again after 1978, but annual censuses of chicks just prior to fledging (495 in 1979, 536 in 1980) were similar to our 1978 estimate.

By using the approximate average production (520 fledglings) and the average reproductive success (75% is used because success in the colony was doubtless higher than in the study area in 1980 and 1981—see Production below), we estimated that approximately 700 pairs of Wedge-tailed Shearwaters laid eggs in burrows at our study area each year.

NEST SITES

Most of the shearwaters at Kilauea Point nested in earthen burrows, the dimensions of which were 19.4 ± 3.4, 11.8 ± 2.3, and 50.0 ± 10.8 cm ($\bar{x}$ ± SD for the diameter and height of the nest's entrance and nest depth, respectively; $n = 64$). The size of these burrow entrances is similar to that recorded for the same species in Australia (17.2 × 12.4 cm; Gross et al. 1963).

Erosion destroyed many burrows, particularly during winter, when shearwaters were absent. Of 69 burrows marked in October 1977, 94% remained in 1978, 73% in 1979, 52% in 1980, and 44% in 1981. The net loss, however, was less than 10% in the study area since new burrows were constructed each year, often within 1 m of an old one.

Wedge-tailed Shearwaters readily used ar-

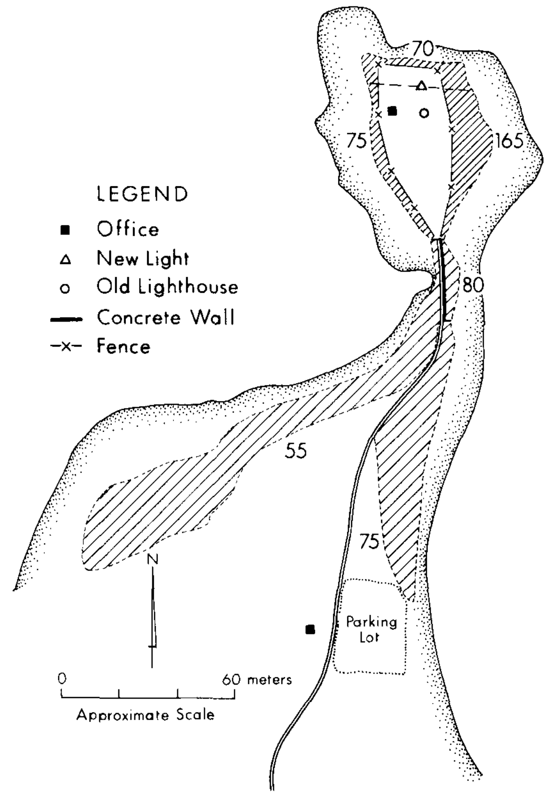

FIGURE 1. Map of Kilauea Point showing the distribution of nesting shearwaters (hatched areas). Numbers indicate the approximate average number of chicks that fledged from each area. Study area boundaries are indicated by solid (near concrete wall) or dashed (across peninsula) lines.

tificial burrows (Byrd 1979b), and those that did had higher than average nesting success. Consequently, artificial burrows may prove important for maintaining shearwaters in areas that are particularly subject to erosion at Kilauea Point.

NESTING CHRONOLOGY

Between 1977 and 1981, Wedge-tailed Shearwaters began to arrive at Kilauea Point during early March (first sightings ranged from 28 February to 12 March), as they do elsewhere in Hawaii (Richardson 1957). Within two weeks after the arrival of the first bird, hundreds of them were present nightly.

The first eggs were laid at Kilauea Point between 6 and 10 June each year. In 1978, 1979, and 1981 the peak of laying was 12–18 June; it was probably the same in 1980 although burrow checks were less frequent and timed differently in that year (Table 1). Most laying in burrows was completed by 25 June, but each year 20–30 eggs were laid later on the lawn around the lighthouse or elsewhere in the colony on the surface of the ground. Most of these late eggs were never incubated. Synchronous

TABLE 1. Egg laying dates of Wedge-tailed Shearwaters at Kilauea Point, Hawaii.

Year	Dates in June						After June
	6–11	6–14	12–18	15–24	19–24	25–30	
1978	21[a]		47 (68)[b]		18 (86)	7 (93)	7 (100)
1979	23		56 (79)		18 (97)	3 (100)	0
1980		32		63 (95)		3 (98)	2 (100)
1981	18		40 (58)		22 (80)	15 (95)	5 (100)

[a] Percentage of total eggs laid in marked burrows.
[b] Cumulative percentage in parentheses.

laying has been reported for most species of *Puffinus* that have been studied (e.g., Rowan 1952, Marshall and Serventy 1956, Richdale 1963, Harris 1966, Serventy 1966, Harrow 1976). In most reports nearly all laying, except "late" eggs, occurred within a two- to three-week period. The timing of laying at Kilauea Point was remarkably similar to that at Manana Island where Shallenberger (1973) recorded a peak between 13 and 26 June and Munro (1960) observed it between 15 and 18 June. The laying period is similar in the northwestern Hawaiian Islands (Amerson 1971, Amerson et al. 1974, Clapp and Wirtz 1975), although the peak may occur slightly later at the western end of the chain (Woodward 1972).

The average incubation period of Wedge-tailed Shearwaters at Kilauea Point was 53 days (range: 51–55 days, $n = 6$). Similar periods have been recorded for this (Shallenberger 1973, Amerson and Shelton 1976) and other species (e.g., Richdale 1963, Harris 1966, Serventy 1966) in the genus *Puffinus.*

At Kilauea Point, chicks began to hatch during late July, and most had hatched by mid-August (Table 2). The overall hatching period here and elsewhere is more restricted than the egg-laying period because eggs laid late frequently do not hatch.

The nestling periods of chicks at Kilauea Point ranged from 103 to 115 days and averaged 109.2 days in 1978, 107.1 days in 1979, and 106.2 days in 1980 (see Pettit et al., in press). This is slightly longer than the 103 days (range: 99–111 days) reported for chicks at Kure Island, Hawaii (Woodward 1972). The period required for a chick to reach fledging size is presumably influenced by the availability of food (Lack 1968), so that annual and geographical variation such as this would be expected. Nestling periods of other species of *Puffinus* range between 75 and 109 days (Burger 1979).

Chicks began to fledge in early November, always peaking between 13 and 27 November, though varying among years (Table 3). Fledging dates varied more than laying, and also particularly hatching, dates because of the variation in the length of the nestling periods of individual chicks.

PRODUCTION

The probability that an egg laid in a natural burrow at Kilauea Point would produce a fledgling was nearly 80% in 1978 and 1979, but considerably lower in 1980 and 1981 (Table 4). Eggs laid in artificial burrows were more likely to produce fledglings than those laid in natural burrows in 1978 and 1980, but not in 1979 (Table 4). Surprisingly few data on nesting success have been reported for shearwaters. However, 80% of the eggs laid by Wedge-tailed Shearwaters at Kure Island in 1964 produced fledglings. Harris (1966) found that hatching success was 78% for *P. puffinus* at a colony in Wales, but only averaged 59% with considerable annual variation for Audubon's Shearwater (*P. lherminieri*) in the Galapagos Islands (Harris 1969). In contrast, Richdale (1963) reported 93% hatching success for a group of Sooty Shearwaters (*P. griseus*).

Most of the loss of potential production at Kilauea Point involved egg mortality, since over 85% of the eggs that hatched in natural and artificial burrows produced fledglings, except in 1980 (Table 4). The major cause of egg

TABLE 2. Hatching dates for Wedge-tailed Shearwaters at Kilauea Point, Hawaii.

Year	27–31 July	1–6 Aug.	7–12 Aug.	13–18 Aug.	Later
1978	13[a]	35 (48)[b]	41 (89)	10 (99)	1 (100)
1979	15	34 (49)	33 (82)	15 (97)	2 (99)
1980	7	35 (42)	49 (91)	9 (99)	0

[a] Percentage of total.
[b] Cumulative percentage in parentheses.

TABLE 3. Fledging dates of Wedge-tailed Shearwaters at Kilauea Point, Hawaii.

Year	10–12 Nov.	13–20 Nov.	21–27 Nov.	28 Nov.–4 Dec.	4 Dec.
1977	13[a]	42 (55)[b]	40 (95)	4 (99)	1 (100)
1978	11	28 (39)	44 (83)	16 (99)	1 (100)
1979	10	42 (52)	34 (86)	11 (97)	3 (100)
1980	8	29 (37)	55 (92)	8 (100)	
1981	8	48 (56)	38 (94)	6 (100)	

[a] Percentage of total.
[b] Cumulative percentage in parentheses.

TABLE 4. Productivity of Wedge-tailed Shearwaters at Kilauea Point, Hawaii.

Year	Eggs laid	Eggs hatched	Hatching success	Chicks fledged	Fledglings per eggs hatched	Fledglings per eggs laid
Natural burrows						
1978	93	77	82.8	74	96.1	79.6
1979	83	71	85.5	65	91.5	78.3
1980	62	36	58.1	29	81.0	46.8
1981	36	24	66.7	21	87.5	58.3
		29[a]		25	86.2	
Artificial burrows						
1978	15	15	100.0	14	93.3	93.3
1979	25	17	69.0	15	88.2	60.8
1980	28	27	96.4	23	85.2	82.1

[a] To increase sample size, 38 new burrows with eggs were marked after incubation was well underway (14 July); 29 of these eggs hatched.

mortality differed among years. In 1978, nearly all of it was due to predation by the Common Myna (*Acridotheres tristis*; Byrd 1979a). [That year birds using artificial burrows fared particularly well (Byrd 1979b).] In 1979, such predation was greatly reduced (Byrd and Moriarty 1980), but the number of eggs incubated full-term or nearly so that failed to hatch was unaccountably high, especially in artificial burrows (Table 4).

The lowest hatching success during our study was recorded for eggs in natural burrows in 1980. We attribute most of the mortality to disturbance by humans and their pets. Before 1980, refuge personnel were present at the shearwater colony during the period each day when it was open to visitors. A cord separated people from the colony, and pets were prohibited. Nevertheless, enforcement was constantly necessary to ensure compliance. Before the nesting season began in 1980, the refuge office was moved away from the colony, and for the first time, personnel were frequently absent. Evidence of disturbance to nesting shearwaters that year included crushed burrows, adults and chicks that had been killed by dogs, smashed or displaced eggs, obvious attempts to feed the birds (e.g., bread in burrow entrances), and footprints (human and canine) in the colony. Eggs in artificial burrows fared much better than those in natural burrows (Table 4), probably because they were deeper than natural ones; hence, birds were neither as visible to visitors nor as vulnerable to dogs. Disturbance was particularly severe in the area with marked burrows because it adjoined the main visitor-use area; nesting success was therefore probably lower there than elsewhere in the colony.

During the 1981 breeding season, a barrier fence was built around the visitor-use area during mid- to late incubation, and the shearwaters were disturbed less, at least late in the season. Nevertheless, predation by Common Mynas was as severe in 1981 as it had been in 1978, probably because it was impossible to repel these birds (Byrd and Moriarty 1980) at the proper time.

Chick mortality resulted from several factors. A few chicks died of unknown causes within one week after hatching. However, the major cause of mortality among older chicks was the destruction of burrows, owing to either human intrusion in the colony (1980) or heavy rainfall (other years of our study). Several chicks were buried by mud after burrows collapsed, but more commonly death resulted from predation by owls (Byrd and Telfer 1980), exposure to high temperatures, or starvation after chicks wandered away from burrow sites and adults failed to find them. Similar consequences of heavy rainfall have been reported at a shearwater colony on Manana Island, Hawaii (Whittow 1979).

Dogs and cats were significant predators at Kilauea Point (Titcomb 1960) until control measures were instituted there in 1975. They are still serious predators in shearwater colonies elsewhere on Kauai where such protection is lacking (Byrd and Boynton 1979).

ACKNOWLEDGMENTS

F. Zeillemaker kindly provided his field notes concerning shearwaters at Kilauea Point between 1974 and 1977 for use in setting up our study. Field assistance was provided by J. Andre, D. Boersma, D. Boynton, V. Byrd, J. Gravning, R. Ittner, R. Schulmeister, S. Schulmeister, and H. Seshiki. Helpful suggestions on preparing the manuscript were offered by C. Kepler, A. Newman, M. Naughton, C. J. Ralph, R. Shallenberger, and F. Zeillemaker.

LITERATURE CITED

AMERICAN ORNITHOLOGISTS' UNION. 1957. Check-list of North American birds. 5th ed. American Ornithologists' Union, Baltimore.

AMERSON, A. B., JR. 1971. The natural history of French Frigate Shoals, Northwestern Hawaiian Islands. Atoll Res. Bull. 150.

AMERSON, A. B., JR., R. B. CLAPP, AND W. O. WIRTZ III. 1974. The natural history of Pearl and Hermes Reef, Northwestern Hawaiian Islands. Atoll Res. Bull. 174.

AMERSON, A. B., JR., AND P. C. SHELTON. 1976. The natural history of Johnston Atoll, Central Pacific Ocean. Atoll Res. Bull. 102.

BURGER, J. 1979. The "desertion period" in seabirds. Proc. Colonial Waterbird Group 3:16–26.

BYRD, G. V. 1979a. Common Myna predation on Wedge-tailed Shearwater eggs. Elepaio 39:69–70.

BYRD, G. V. 1979b. Artificial nest structures used by Wedge-tailed Shearwaters at Kilauea Point, Kauai. Elepaio 40:10–12.

BYRD, G. V., AND D. S. BOYNTON. 1979. The distribution and status of Wedge-tailed Shearwaters at Kilauea Point, Kauai. Elepaio 39:129–131.

BYRD, G. V., AND D. MORIARTY. 1980. Treated chicken eggs reduce predation on shearwater eggs. Elepaio 41: 13–15.

BYRD, G. V., AND T. C. TELFER. 1980. Barn Owls prey on birds in Hawaii. Elepaio 41:35–36.

BYRD, G. V., AND C. F. ZEILLEMAKER. 1981. Seabirds of Kilauea Point, Kauai Island, Hawaii. Elepaio 41:67–70.

CLAPP, R. B., AND W. O. WIRTZ III. 1975. The natural history of Lisianski Island, Northwestern Hawaiian Islands. Atoll Res. Bull. 186.

CROCKETT, D. E. 1975. Kermadec Islands expedition reports: the Wedge-tailed Shearwater (*Puffinus pacificus pacificus*) in the northern Kermadecs. Notornis 22:1–9.

ELY, C. A., AND R. B. CLAPP. 1973. The natural history of Laysan Island, Northwestern Hawaiian Islands. Atoll Res. Bull. 171.

GROSS, A. O., J. M. MOULTON, AND C. E. HUNTINGTON. 1963. Notes on the Wedge-tailed Shearwater at Heron Island, Great Barrier Reef, Australia. Atoll Res. Bull. 99.

HARRIS, M. P. 1966. Breeding biology of Manx Shearwater (*Puffinus puffinus*). Ibis 108:17–33.

HARRIS, M. P. 1969. Food as a factor controlling the breeding of *Puffinus lherminieri*. Ibis 111:139–156.

HARROW, G. 1976. Some observations of Hutton's Shearwater. Notornis 23:269–288.

LACK, D. 1968. Ecological adaptations for breeding in birds. Methuen, London.

MARSHALL, A. J., AND D. L. SERVENTY. 1956. The breeding cycle of the Short-tailed Shearwater *Puffinus tenuirostris* (Temminck), in relation to trans-equatorial migration and its environment. Proc. Zool. Soc. Lond. 127:489–509.

MUNRO, G. C. 1960. Birds of Hawaii. Rev. ed. Tuttle, Tokyo.

PETTIT, T. N., G. V. BYRD, G. C. WHITTOW, AND M. P. SEKI. Growth of the Wedge-tailed Shearwater in the Hawaiian Islands. Auk, in press.

RICHARDSON, R. 1957. The breeding cycles of Hawaiian seabirds. Bernice P. Bishop Mus. Bull. 218.

RICHDALE, L. E. 1963. Biology of the Sooty Shearwater *Puffinus griseus*. Proc. Zool. Soc. Lond. 141:1–117.

ROWAN, M. K. 1952. The Greater Shearwater *Puffinus gravis* at its breeding grounds. Ibis 94:97–121.

SERVENTY, D. L. 1967. Aspects of the population ecology of the Short-tailed Shearwater, *Puffinus tenuirostris*. Proc. XIV Int. Ornithol. Congr. (1966):165–191.

SHALLENBERGER, R. J. 1973. Breeding biology, homing behavior, and communication patterns of the Wedge-tailed Shearwater *Puffinus pacificus chlororhynchus*. Ph.D. diss., Univ. of California, Los Angeles.

TITCOMB, M. 1960. Dinner with Frank Richardson and John Bowles. Elepaio 21:24.

WHITTOW, G. C. 1979. The effects of heavy rain on nestling Wedge-tailed Shearwaters (Rabbit Island). Elepaio 39:138–139.

WOODWARD, P. W. 1972. The natural history of Kure Atoll, Northwestern Hawaiian Islands. Atoll Res. Bull. 164.

U.S. Fish and Wildlife Service, P.O. Box 87, Kilauea, Kauai, Hawaii 96754. Present address of first author: Aladdin Route, Box 160 E, Colville, Washington 99114.
Received 2 April 1982. Final acceptance 30 October 1982.