Townsend's and Newell's Shearwater

Puffinus auricularis

Order PROCELLARIIFORMES – Family PROCELLARIDAE

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Introduction

Newell's Shearwater

Figure 1. Breeding range of the Townsend's Shearwater

The Townsend's Shearwater (*Puffinus auricularis townsendi*) is confined to the Revillagigedo Islands off the western coast of Mexico, where its small population is jeopardized. Also threatened, the related Newell's Shearwater (*Puffinus auricularis newelli*), once widespread in the main Hawaiian Islands, has been reduced to a few remnant breeding colonies. The taxonomy of these, and other members of the complex referred to as "Manx-type shearwaters," is unsettled and has been frequently changed. As of 1983, the American Ornithologists' Union considered Townsend's a full species and reduced Newell's to subspecific status at that time. Both forms are closely related to the Manx Shearwater (*Puffinus puffinus puffinus*) of the Atlantic. These shearwaters can be distinguished in the hand by comparison of morphology and plumage, but only the practiced eye can distinguish them on the wing at sea.

Habitat preferences and distributions of the Newell's and Townsend's shearwaters differ markedly. When not at breeding colonies, Newell's Shearwater is highly pelagic, frequenting tropical and subtropical waters overlying depths much greater than 2,000 m, mostly to the east and south of the Hawaiian Islands.

In contrast, Townsend's concentrates in cooler waters overlying the continental slope (isobaths of 200–2,000 m) of western Mexico and Central America. Both birds capture prey by pursuit-plunging, an uncommon foraging method among warm-water seabirds. Their flight is strong, with rapid wing-beats and little gliding, a style requiring predictable prey availability; thus, it is also uncommon among warm-water seabirds. These shearwaters rely heavily on tuna (*Thunnus* spp.) and other large, predatory fish that drive prey to near the surface.

The breeding phenology of these two subspecies does not overlap; Townsend's chicks fledge in late spring, Newell's chicks in late autumn. Other aspects of their breeding biology are little known, or at least much less known than for other *Puffinus* species. Predation from introduced mammals, one of the major factors affecting population trends of these birds, has confined nesting to extremely rough, heavily vegetated, and steep terrain, where access by humans is difficult at best. Pairs produce their single egg in a chamber at the end of a deep burrow. The incidence of nonbreeding among adults is high relative to that of other shearwaters. The chick-rearing period in Newell's (unknown in Townsend's) is longer than in the Manx Shearwater, owing perhaps to the low caloric content of the diet, largely squid, fed to Newell's chicks (compared to the fish that the Manx feeds its young) or to greater commuting distances between colonies and foraging areas.

Habitat loss on oceanic islands—due to clearing of forests for agriculture and urban development, mining of cinder cones, and recent volcanic eruptions—is the major factor causing decline in the populations of these two forms. Urbanization and predation from introduced mammals are other significant factors responsible for decreasing populations in these birds.

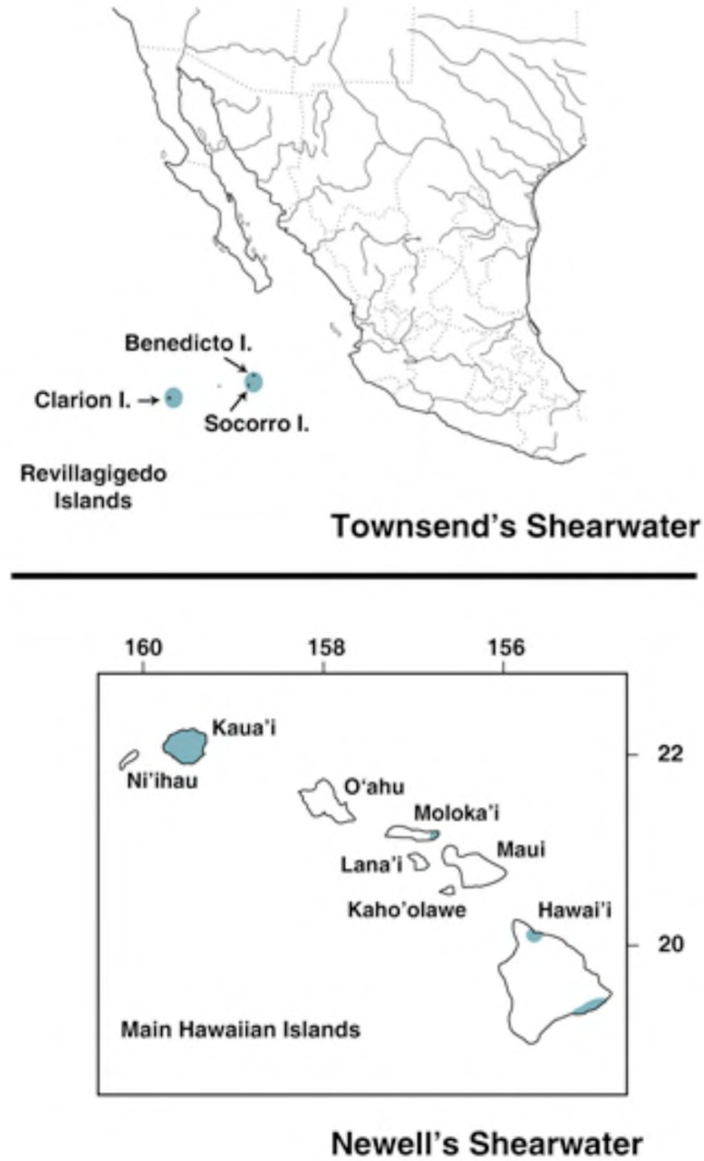

Figure 1. Breeding range of the Townsend's Shearwater

Breeding range of the Townsend's Shearwater, restricted to Benedicto, Clarion, and Socorro I. in the Revillagigedo Is., and the Newell's Shearwater, in the Hawaiian Is.

Distinguishing Characteristics

Medium-sized shearwaters; colored dark sooty brown above, with white belly, throat, and underwings. White of flanks extends upward onto back, just behind wings. Townsend's has completely dark undertail-coverts, whereas central proximal-coverts in Newell's are white (Howell et al. 1994; see below). Tail length is helpful in distinguishing the 2 species in hand: Newell's averages 83.9 mm ± 3.0 SD (range 77–89, *n* = 38), Townsend's 76.3 mm ± 3.0 (range 71–83, *n* = 41; Howell et al. 1994; see also Measurements, below).

Considering other shearwaters of similar general color pattern in e. and central Pacific, Townsend's and Newell's are larger than Audubon's (*Puffinus lherminieri*) and Little (*P. assimilis*) shearwaters; same size as Manx (and other members of Manx complex), Black-vented (*P. opisthomelas*), and Wedge-tailed (*P. pacificus*) shearwaters; and much smaller than the white-bellied Pink-footed Shearwater (*P. creatopus*). Body and limb proportions are typical of shearwaters that capture prey by plunge-diving (Ashmole 1971, Ainley 1977; see Food habits: feeding, below). These birds are sleek, have small wings relative to their body size (i.e., high wing-loading; Spear and Ainley 1997a,1997b), and have laterally flattened tarsi, in contrast to the more aerial shearwaters and gadfly petrels, which have broader wings and more rounded tarsi (see Kuroda 1954,Warham 1977). Among the "diving shearwaters," Townsend's and Newell's have shorter and broader wings (compared to, for example, Sooty Shearwater [*P. griseus*]), probably related to their less migratory character (Spear and Ainley 1997a, 1997b; see Migration, below).

At sea, Newell's and Townsend's shearwaters are difficult to distinguish from each other and from Manx Shearwater, which occurs occasionally in e. Pacific. The best criteria by which to distinguish these forms in flight, given by Howell et al. (1994; see also Howell and Webb 1995), are summarized as follows: dark undertail-coverts in Townsend's, white undertail-coverts in Manx, and intermediate pattern in Newell's. At close range, black and white of face appears to be more sharply delineated in Newell's. Some Manx have narrow, pale band on lower forehead, a pattern caused by pale feathers across the maxilla. Newell's and Townsend's tend to have much more prominent flank-patches than Manx, some individuals of which may lack them altogether. To assess these characters, clear, prolonged views of the bird are required, because effects of lighting, feather wear, and molt on perceived characters must be considered.

Distribution

Figure 1. Breeding range of the Townsend's Shearwater

The Americas

Breeding Range

Townsend’s breeds or has bred only on Clarión, San Benedicto, and Socorro Is., which with Roca Partida constitute the Revillagigedo Is. (Jehl 1982).

Marine Range

Townsend’s Shearwater mostly frequents waters of Costa Rica Current along continental slope off western coast of s. Mexico and n. Central America (Fig. 1). Overall, this shearwater ranges from s. Baja California south to El Salvador (i.e., from 24° to 12°N (Pitman 1986, Howell and Webb 1995, Spear et al. 1995). It is sparse in pelagic waters around its breeding locales in Revillagigedo Is., except for rafting birds just offshore. Marine range of this form apparently does not overlap that of Newell’s (Spear et al. 1995).

Outside The Americas

Breeding Range

Newell’s Shearwater breeds only in colonies on main Hawaiian Is.; breeding currently confirmed only for Moloka‘i, Hawai‘i, and, mainly, Kaua‘i (Pratt et al. 1987, Harrison 1990, Reynolds et al. 1997a, b). Reported to breed also in small numbers on O‘ahu, Maui, and La¯na‘i, but confirmation needed, since fledgling specimens found on these islands probably were individuals attracted to shore from elsewhere by coastal lights (see Breeding: fledgling stage, below). Only about 20 colonies are known on Hawaiian Is., but others probably exist (Reynolds and Ritchotte 1997b, DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer unpubl. data).

Marine Range

Newell’s Shearwater has much more extensive marine range than Townsend’s (Fig. 1). Occurs year-round in e. tropical Pacific Ocean, especially in Equatorial Countercurrent, from near the portion of the equator lying south of Hawaiian Is. east to about 120°W and north to and around main Hawaiian islands (22°N). During breeding season especially, low densities occur short distances west and north of Hawai‘i (to about 25°N; King and Gould 1967, Spear et al. 1995). Also during that time of year, central part of marine range projects northward a bit, likely an artifact of more adults and subadults commuting to and from breeding colonies. In 1987, when Pacific Ocean was affected by a weak El Niño–Southern Oscillation event, which changed both the boundaries of current systems and the distributions of tropical seabirds (Ribic et al. 1990), Newell’s Shearwaters were seen farther east than in any other year between 1984 and 1994 (L. B. Spear and DGA unpubl. data).

Isolated records of Newell's Shearwater are known from central and s. Pacific —e.g., west to Mariana Is. (Saipan, Guam), Wake I., and Johnston Atoll (King and Gould 1967,Pratt et al. 1987), and south to Marquesas Is. and Samoa (Pratt et al. 1987, Grant et al. 1994, Spear et al. 1995).

Historical Changes

Populations of both subspecies have decreased during modern times. Townsend's was first confirmed to be breeding on Clarión I. in 1897 (Anthony 1900) and was considered to be abundant there into 1920s (Kaeding 1905, Hanna 1926). Then, a small fishing village was established and terrestrial mammals were introduced to the island (Jehl 1982). The results were devastating. For example, in 1988 "several dozen" Townsend's Shearwater carcasses were found near burrows torn apart by feral pigs (*Sus scrofa*;Howell and Webb 1989, S. Howell pers. comm.). Owing to sustained predation of this nature, numbers of breeding birds certainly must be lower now than earlier in twentieth century.

In 1897, Townsend's Shearwater was found to breed abundantly also on San Benedicto I. (Anthony 1900; see also Kaeding 1905), but may no longer do so (Jehl 1982). A cataclysmic volcanic eruption in 1952 exterminated the entire seabird fauna and the island's vegetation (Brattstrom 1963, Jehl and Parkes 1982; see Habitat: breeding range, below). Some of the seabird species have since recolonized, but apparently not Townsend's Shearwater or the vegetation (Jehl 1982). Small numbers of Townsend's Shearwaters recently have been seen rafting in the evening just offshore (Santaella and Sada 1991), so recolonization may have begun.

Numerous burrows of Townsend's Shearwater were discovered on Socorro I. in 1926 (Hanna 1926), and breeding has continued since (Jehl 1982, Jehl and Parkes 1982,Howell and Webb 1995, L. Baptista pers. comm.). The habitat, however, is being degraded in quality by sheep (*Ovis* sp.) and feral cats (*Felis catus*; S. Howell pers. comm.).

Newell's Shearwater also has been subjected to difficult times. This bird was well known to Polynesians who colonized Hawaiian Is. 1,600 yr ago. The bird apparently was abundant at time of colonization. It was used as food but also was thought to be an omen of death, owing to its departure and subsequent long absence each year (Munro 1960). Newell's was thought to be extinct in Hawaiian Is. by 1908, but was rediscovered in waters off Kaua'i in 1947

(Richardson 1955) and was confirmed to be breeding there in 1967 (King and Gould 1967, Sincock and Swedberg 1969). During last 150 yr, 75% of forest on main islands of Hawaiian Archipelago has been converted to agricultural, military, commercial, or residential land (Cuddily and Stone 1990). On smaller scale, lava flows from Kilauea Volcano within past 30 yr have covered much habitat in Puna District, HI, where species was discovered only recently to be breeding (Reynolds and Ritchotte 1997b). Recent lava flows from Mauna Loa also have covered potential nesting habitat in Kau and s. Kona (west coast of the island), where the species is currently unknown. Ironically, in the context of a longer temporal scale, volcanoes create new breeding habitat, but the recent lava flows become especially critical to a species already affected by habitat loss due to other causes. Nesting habitat for this species has been lost in twentieth century and should be considered primary cause for present jeopardy of its populations (see Conservation and management, below).

Adding to the complexity of habitat loss, mongooses (*Herpestes auropunctatus*) in the nineteenth century, and Barn Owls (*Tyto alba*) in the twentieth were intentionally introduced to most of the main Hawaiian Is. to control rats (*Rattus* spp.), introduced earlier by Polynesian and European colonists. Now, all the above species are known to prey on Newell's Shearwaters (Byrd and Telfer 1980, Harrison 1990). Predation of adults and chicks, especially by mongooses and feral cats, probably has caused further decline in availability of prime nesting habitat in the archipelago. Mongooses are absent and habitat loss less severe on Kaua'i, the stronghold of the subspecies. Analysis of the rate by which fledglings have been recovered each year since 1978 (refer to Telfer et al. 1987) indicates that the species has been declining on the heavily and long-urbanized southern shore of Kaua'i (DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer unpubl. data; see also Demography and populations: population status, below).

Fossil History

No fossils of this species known. Subfossil bones in middens and dune deposits on Kaua'i, Moloka'i, and O'ahu indicate that Newell's Shearwater has always been uncommon in lowland areas. Deposits at higher elevations are too rare for proper assessment of upland prehistoric populations (Olson and James 1982, S. Olson pers. comm.). It is apparent also from these findings, however, that subspecies' distribution was once more widespread than now.

Systematics

Geographic Variation

None is apparent within the 2 subspecies, but Newell's and Townsend's differ in color and size (see Distinguishing characteristics, above, and Measurements, below).

Subspecies; Related Species

Taxonomy of genus *Puffinus* is complex and somewhat confused among medium-sized forms having dark backs and white bellies (Warham 1990). Included are the 2 forms in question here. Townsend's Shearwater was named after C. H. Townsend, naturalist on the steamer *Albatross*, who first described the bird as a species (*P. auricularis*), having encountered it offshore of Clarión I. (Townsend 1890). Newell's Shearwater was named as a species (*P. newelli*) by H. W. Henshaw after Brother Matthais Newell, who had received specimens from local residents on Maui (Henshaw 1900). A half century later, after a detailed review, Murphy (1952) considered Townsend's and Newell's to be part of the Manx Shearwater superspecies, which is composed of 8 allopatric subspecies. Murphy proposed to reclassify the 2 forms in question as *P. p. townsendi* and *P. p. newelli* . Bourne (in Palmer 1962) placed *P. p. newelli* in a subgroup with *P. p. puffinus*,*P. p. huttoni*, and *P. p. auricularis*, all of which are dark-backed, cool-water members of the complex. Brooke (1990) noted also that these dark-backed shearwaters tended to breed more in mountainous terrain and forage farther offshore than the brown-backed forms that are part of the other *P. puffinus* subgroup: *P. opisthomelas* (Black-vented Shearwater), *P. gavia* (Fluttering Shearwater), *P. yelkouan* (Yelkouan Shearwater).

Species rank was extended to *P. auricularis* by Am. Ornithol. Union (1957) and Voous (1973), and subsequently Jehl (1982) proposed that *newelli* be considered a well-marked race of *auricularis* (hence, *P. a. newelli* and *P. a. auricularis*). This classification, which is the one currently recognized by Am. Ornithol. Union (1983), is problematic because Newell's and Townsend's, which can be distinguished on morphological basis (see Distinguishing characteristics, above, and Measurements, below), possess nonoverlapping breeding seasons (see Breeding: phenology, below), as well as separate breeding and marine ranges (see Distribution, above). Further, Newell's is highly pelagic, whereas Townsend's is semi-neritic (and not pelagic) in marine habitat preference (see Habitat: marine range, below).

Migration

At present, evidence incomplete. Townsend's Shearwater occurs year-round east of its breeding grounds; Newell's occurs year-round within area of eastern tropical Pacific (see Distribution, above). Estimates of total population size made during breeding and nonbreeding season on basis of at-sea densities and ocean area occupied showed no difference (Spear et al. 1995). For Newell's Shearwater, ocean area occupied during autumn, the nonbreeding season, was slightly larger than that of spring. During breeding season, some Newell's can be found within a few hundred kilometers of Hawaiian Is. breeding colonies, but most individuals occur in waters as far as 3,000 km to the east. During nonbreeding season, Newell's appears to be absent from waters around Hawai'i (*cf.* King and Gould 1967, Spear et al. 1995). Adult Newell's begin to visit breeding colonies during last week of Apr and cease visits a week or so before last chick fledges in early Nov (Ainley et al. 1995); analogous dates for Townsend's Shearwater are not known. Status of Newell's found near Hawaiian Is. during breeding season, and whether that status differs from birds found farther east and south, remain to be determined. A postbreeding dispersal of Hawaiian Is. breeders to east and south may be involved, and birds that occur close to the islands during summer may be breeders on their commute between breeding colonies and feeding areas.

Habitat

Breeding Range

Breeds in burrows or deep rock crevices at higher elevations. Townsend's breeds at top of Clarión I. at 244 m, above 161 m on San Benedicto I., and above 500 m (to 900 m) on Socorro I. (Jehl 1982). On Kaua'i, Newell's breeds between 160 and 1,200 m (mean 460 m ± 120 SD, *n* = 17; DGA), and in Puna District on Hawai'i, at 189 and 330 m (Reynolds and Ritchotte 1997b). Neither form breeds in lowlands, either in Revillagigedo Is. or Hawaiian Is., where Wedge-tailed Shearwaters are confined—a species that does not breed at higher elevations (Brattstrom and Howell 1956, Harrison 1990; see Distribution: fossil history, above).

Whether competitive exclusion is involved in apparent habitat segregation between Newell's and Wedge-tailed shearwaters remains to be determined. Fossil and subfossil bones of Wedge-tailed Shearwaters, abundant near sea level, have not been found at higher elevations (S. Olson pers. comm.), and

Newell's bones are rare at low elevations (see Distribution: fossil history, above). Pertinent to the question of competitive exclusion, Byrd et al. (1984) transferred eggs of Newell's Shearwaters to nests of Wedge-tailed Shearwaters breeding on lowland coast at Kilauea Point, Kaua'i, and Wedge-tailed Shearwaters successfully fledged Newell's chicks. In subsequent years, a few Newell's Shearwaters were heard calling over the Wedge-tailed colony, and a few subadult Newell's, banded as fostered chicks, were recovered (having collided with utility wires) along nearby roads. A few Newell's have recruited to the colony, but little else is known of their well being (TCT). In nw. Hawaiian Is., where Newell's is absent, Wedge-tailed and Christmas Island (*Puffinus nativitatus*) shearwaters breed abundantly, but all these islands are low, with sparse vegetation—not typical Newell's habitat. Curiously, Christmas Island Shearwater is absent from most of the main Hawaiian Is.—the stronghold of Newell's—although it breeds on small islets off O'ahu, Moloka'i, and Ni'ihau, where Newell's is absent (see Pratt et al. 1987, Harrison 1990). These islets, too, are low in elevation. Thus, if competitive exclusion is at play, it may be facilitated by elevation of suitable breeding habitat.

Owing to presence of pigs, mongooses, and cats in Hawaiian Is., Newell's now nests on steep slopes, most of which exceed 65°. The experience of Howell and Webb (1989, pers. comm.) on Clarión I., where several dozen carcasses of Townsend's Shearwater were found at burrows excavated by pigs, explains why such steep terrain is optimal for these shearwaters. Newell's Shearwater usually nests where terrain is vegetated by open canopy of trees and understory of densely matted *uluhe* ferns (*Dicranopteris linearis*). Some exceptions exist, as on walls of Waimea Canyon, Kaua'i, where forest canopy is absent. Townsend's nests among tussocks of densely matted grass and bracken (plate 16 in Bent 1922, S. Howell pers. comm.) and possibly within forested areas (L. Baptista pers. comm.). These birds climb nearby trees or rock outcrops to take wing, for they are incapable of taking off from flat ground unless there are no obstructions and winds are strong (DGA). Their difficulties on flat ground may explain their need to nest on elevated terrain.

Nesting colonies can be situated far inland (as much as 14 km on Kaua'i). Preliminary information suggests that inland-breeding Newell's Shearwaters repeatedly use same routes when flying between colonies and sea, especially where river valleys provide openings through coastal mountains (*cf.* Day and Cooper 1995, DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer unpubl. data). However, flight corridors (or at least consistent flight directions) also appear to exist in Puna District, HI, where coastal topography is gentle (radar detections at adjacent localities by Cooper and David 1995,Reynolds et al. 1997b). Waipi‘o Valley, which is undeveloped (Breeden 1996), also appears to be a breeding site having a flight corridor (Reynolds et al. 1997a). On the other hand, during clear weather many Newell’s Shearwaters also fly to and from colonies passing over ridges and outside of river valleys on Kaua‘i (Day and Cooper 1995). Flight corridors may or may not be the rule, depending on conditions; this requires further study (see Priorities for future research, below).

Meteorological conditions at breeding grounds for Townsend’s and Newell’s shearwaters are very different. Skies over Revillagigedo Is. usually are clear, but those over Hawaiian mountains usually are cloudy. Townsend’s breeding grounds are xeric (Brattstrom 1963), but rainfall in Kaua‘i mountains, where Newell’s nest, is among the heaviest anywhere on Earth; rainfall in Puna District and Waipi‘o Valley, HI, is also heavy (Carlquist 1980).

Spring And Fall Migration

None.

Marine Range

Spend most of their time at sea, visiting land only to court and to tend eggs and chicks. These shearwaters avoid inshore waters, except when rafting in evening before flying inland to breeding colonies after sundown. Rafting birds have been seen offshore of various of the Revillagigedo Is. (Jehl 1982, Howell and Webb 1990, pers. comm.,Santaella and Sada 1991) and Kaua‘i (Ainley et al. 1997).

Occur at sea only over warm subtropical (>18°C) and tropical (>22°C year-round) waters. Off west coast of Mexico, Townsend’s Shearwater occurs and feeds in surface upwelling fronts overlying continental slope of deep oceanic trench (isobaths of 200–2,000 m; Howell and Engel 1993, Spear et al. 1995). Apparently does not feed near Revillagigedos, which are well offshore of frontal area. In contrast, Newell’s Shearwater feeds only over deep, oceanic waters (much greater than 2,000 m). In particular, Newell’s frequents oceanic fronts, especially those of Equatorial Countercurrent, which are particularly rich in food resources (Spear et al. 1995).

Characteristics of marine habitat frequented by Newell's and Townsend's shearwaters, respectively, are distinct as defined by oceanic variables (mean ± SE): sea surface temperature (°C), 26.8 ± 0.07 versus 24.9 ± 0.26; sea-surface salinity (ppt), 34.52 ± 0.01 versus 34.34 ± 0.02; thermocline depth (m), 76 ± 0.05 versus 45 ± 1.8; and thermocline intensity (°C change/ 20 m depth change), 7.2 ± 0.19 versus 2.6 ± 0.15 (Spear et al. 1995). These factors indicate clear preference of Newell's for oceanic water and that of Townsend's for water influenced by coastal upwelling. Average meteorological conditions at sea are also distinctly different for Newell's and Townsend's shearwaters, respectively: wind speed (km/h), 33 ± 0.29 versus 19 ± 0.44; and cloud cover (oktas [= celestial hemisphere divided by eighths]), 4.9 ± 0.15 versus 2.6 ± 0.2. These factors indicate preference of Newell's for waters within intertropical convergence zone (frequent clouds and rain squalls) and of Townsend's for waters with clear skies.

Food Habits

Feeding

Main Foods Taken

Not well known, but squid was the only prey regurgitated by adult Newell's Shearwaters trapped at entrances of their burrows on Kaua'i (*n* = 9; DGA).

Food Capture And Consumption

Townsend's and Newell's shearwaters are members of aquatic shearwaters (seeKuroda 1954), which feed by pursuit-plunging (Ashmole 1971, Ainley 1977). Upon spotting prey or other foraging birds, and without interrupting wing-beats, they plunge at a low angle into water and continue swimming, using their partly folded wings for propulsion. At times, they flutter toward water's surface, as if aiming, before they plunge. Can reach depths of at least 10 m (at least, the slightly larger Sooty Shearwater does so using the same technique; A. Baldridge pers. comm.). Swallow prey whole; beneath water's surface can swallow >1 prey item on a given plunge. These shearwaters do not normally scavenge dead prey.

Newell's Shearwater takes part in multispecies feeding flocks associated with tuna (Au and Pitman 1986, L. B. Spear and DGA unpubl. data) and is considered by fishermen to be one of the "tuna birds," which indicate the presence of these fish. In oceanic waters, where thermocline is very deep (see Habitat, above), foraging tuna drive prey to surface within reach of the birds. Townsend's Shearwater, too, often joins multispecies feeding flocks

(Howell and Engel 1993, Howell and Webb 1995), but in waters that have shallow thermocline. There, prey normally occur closer to surface, and the birds are not necessarily dependent on tuna to facilitate access to prey. Nevertheless, Townsend's does associate with porpoises of various kinds (Au and Pitman 1986, Howell and Engel 1993, Spear et al. 1995).

Diet

Not well known (see Main foods taken, above).

Food Selection And Storage

Does not store food.

Nutrition And Energetics

Not studied.

Metabolism And Temperature Regulation

Not studied.

Drinking, Pellet-Casting, And Defecation

Seabirds drink seawater, and excrete excess salt though supraorbital glands. Shearwaters are not known to cast pellets.

Sounds

Figure 2. Sonograms of Aerial/Burrow Call

Vocalizations

Development

Chicks in burrows, when disturbed, give squeaky versions of adult aerial calls, as early as downy stage. As chicks age, voice deepens and call becomes more braylike (DGA).

Vocal Array

Known repertoire incomplete.

Aerial/Burrow Call. Given in flight or on the ground in the colony. (Fig. 2). Howell and Webb (1995: 112), from tapes recorded by L. Baptista, describe Aerial/Burrow Call of Townsend's Shearwater as "slightly intensifying series of 2–6 gruff, throaty, slightly braying 2–3-syllable phrases: *ahr eh ahr eh* ... or *ahr ah-ah ahr ah-ah* . " Former is similar to call of Newell's (DGA), in both forms, with the *ahr* given by exhalation and the *eh* by inhalation. The Hawaiian name of Newell's Shearwater, ʻAʻo, refers to its Aerial/Burrow Call (*Ao-ao-ao*). Call is similar to that of Manx Shearwater (see Brooke 1990: 190–192). On the basis of the appreciable extent of individual variation in the calls of Manx Shearwater, comparison of sonograms of Newell's and Townsend's (Fig. 2) provide no clues as to any species-level differences in calls. No other recordings of Townsend's exist at present.

The Aerial/Burrow Call probably functions as "song" of these shearwaters, warning members of same sex to keep away and beckoning those of opposite sex to approach. When both members of a pair are in the burrow together, they sing duets using this call. Calls given by adults in burrows are answered sometimes by other adults in nearby burrows (DGA).

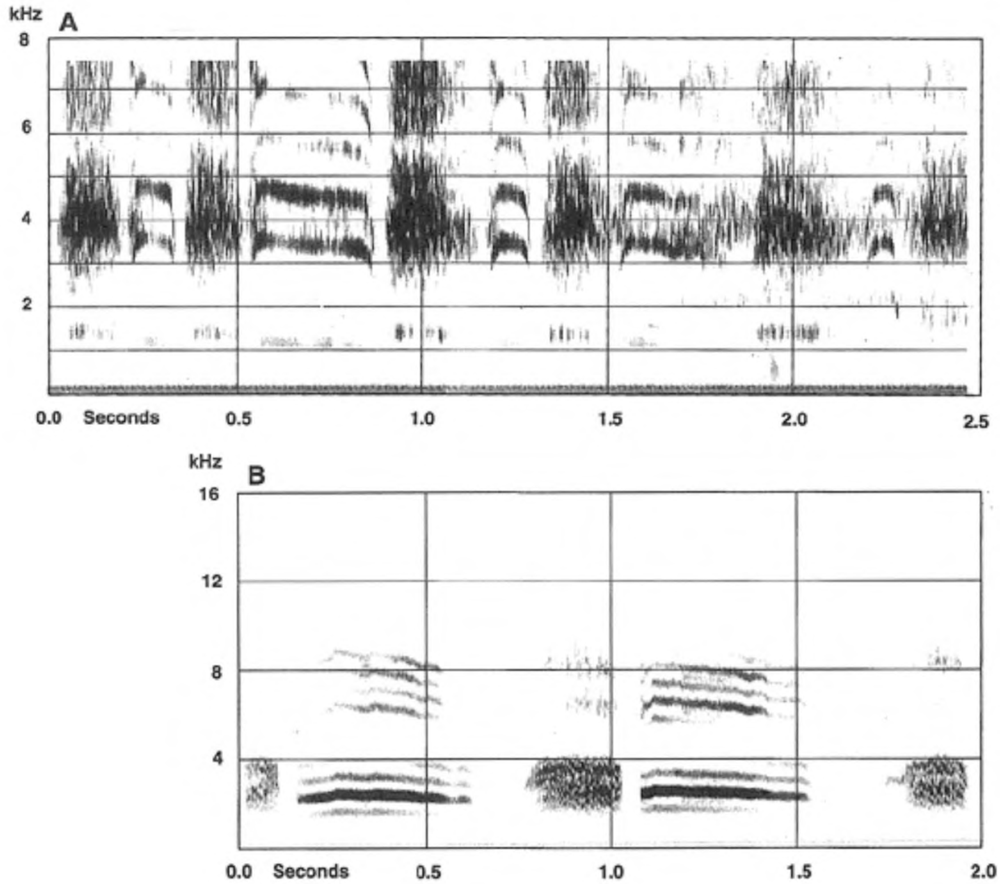

Figure 2. Sonograms of Aerial/Burrow Call

A. Townsend's Shearwater (recorded by L. F. Baptista, Socorro I., 29 Mar 1995; sonogram prepared at California Academy of Sciences, San Francisco). B. Newell's Shearwater (recorded by M. Reynolds and B. Neilsen, Pu'u Lena Crater, 10 Sep 1993; recording provided by Library of Nat-ural Sounds, Cornell University, Laboratory of Ornithology; sonogram prepared by Borror Laboratory of Bioacoustics, Ohio State University). Sonograms were prepared on a Kay Elemetrics DSP 5500 Sona-graph with an effective band width of 600 Hz (100 pt. transform size).

In Manx Shearwater (which has a call similar to that of Newell's and Townsend's; Jehl 1982), calls follow the same pattern for either sex, but pitch of female's call is lower (Brooke 1978, Warham 1990). Female's call is also harsher, noisier, and can be located less easily than that of male. Males call more from the ground and females more from the air.

Daily Pattern Of Vocalizing

Calls by adults and subadults generally heard only at night. In the colonies themselves, birds vocalize primarily just after arrival and just before departure (DGA). Unpaired subadults or newly paired birds in their burrow call more frequently than others.

Places Of Vocalizing

Calling can be heard frequently in vicinity of colony. Individuals flying to and from colonies call rarely when flying over land.

Nonvocal Sounds

These shearwaters fly quickly over land when flying to or from colonies; thus, in still air, a "whooshing" noise can be heard as they pass closely. They also make noise as they crash-land in vegetation near their burrow entrances. While these sounds likely are not used for communication, they have become maladaptive: Introduced mammalian and avian predators use these sounds to locate the birds (see Behavior: predation, below).

Behavior

Locomotion

Walking, Hopping, Climbing, Etc

Legs of shearwaters are placed well back on their bodies, making it difficult for them to walk. They shuffle along on their feet, flapping their wings to raise their bodies slightly, thereby to lighten the load. When pursued, they can move very quickly through underbrush (Warham 1990). They are very good at climbing, which is facilitated by their sharp claws and beak. Trees in vicinity of Newell's Shearwater nests are well worn by repeated ascents, because the birds use them to launch forth, away from the tangle of ground vegetation. They can climb vertical lava rock walls, using feet, tail, and beak, almost like a woodpecker (TLT). Conceivably, in the absence of trees Townsend's uses rocky outcrops in the same way.

Flight

Fast, directional, and low to water, owing to high wing-loading (Newell's: 60 N [newtons]/m^2 ± 5.3 SD) and low aspect ratio (Newell's: 10.3 ± 0.45 SD; n = 18), compared to the more aerial shearwaters (see Warham 1977, Spear et al. 1995, Spear and Ainley 1997a). Rapid beats on stiffly held wings are interspersed with glides. This type of flight is among the most energy-demanding of those used by seabirds, particularly tropical seabirds (Ballance 1993). The higher wing-loading results from greater body density and reduced wing area needed for swimming underwater. To conserve or restore energy, these shearwaters rest often, especially when winds are calm (Spear et al. 1995).

In high winds, wing-beats are fewer, glides are longer, and birds bank several meters high in a type of dynamic soaring off wave crests. These and other petrel species avoid flying with tailwinds (Spear et al. 1995), perhaps because they have minimal control or move too quickly to spot prey. Both Newell's and particularly Townsend's fly much more often into wind than do other large petrels or shearwaters, which they are able to do probably because of their higher wing-loading and rapid wing-beats.

The average flight speed of Newell's and Townsend's shearwaters has been measured at sea, as a function of relative wind direction, by Spear and Ainley (1997b; measured by stopwatch over known distances). With tailwinds (n = 16) and headwinds (n = 19), respectively, ground speed (m/s ± SD) was 16.2 ± 2.5 and 12.3 ± 1.3, and air speed (ground speed minus apparent wind speed) was 11.1 ± 2.0 and 17.6 ± 1.7. Across wind (n = 14), ground speed was 14.4 ± 1.3. Over land on Hawai'i, without corrections for wind direction and speed, ground speed of Newell's averaged 38 mph ± 4 SD (16.8 m/s ± 1.9; Reynolds et al. 1997a, measured by radar).

Owing to high wing-loading, landings in breeding colonies are noisy, as birds crash into vegetation, especially when winds are light. In open areas or on sea, landings are smooth, as birds fly upwind and stall just before touchdown.

Swimming And Diving
Webbed feet aid movement on surface of ocean. Adept divers, using technique called pursuit-plunging, in which momentum of aerial dive and, thereafter, movement of wings provide propulsion underwater (see Food habits: feeding, above).

Self-Maintenance
Preening, Head-Scratching, Stretching, Bathing, Anting, Etc
No information available. As with other petrels, individuals at rest on sea spend much time preening (DGA).

Sleeping, Roosting, Sunbathing
Do not roost on land. Form flocks of resting birds at sea, called rafts.

Daily Time Budget
Fly to and from colonies only at night. On Kaua'i, Newell's Shearwaters begin to arrive at colonies well after sunset and just before sky becomes completely dark (i.e., a light meter reads 0 lux; Day and Cooper 1995). After 30 min,

markedly fewer birds arrive, although some continue to arrive throughout night. In morning, departure is even more synchronous and is centered about 15 min on either side of completely dark sky. On basis of Jehl's (1982) observations, Townsend's Shearwater appears to have similar schedule of arrival and departure.

Agonistic Behavior

No information available.

Spacing

Territoriality

On Clarión I., Townsend's nests are 3–10 m apart (S. Howell pers. comm.). On Kaua'i, Newell's nests are 20–50 m apart (TCT, DGA), and the spacing may be determined by that of *ohia* trees (*Metrosideros collina*), the major tree species present. Large roots of this tree apparently exist where digging is easier, or they may facilitate burrowing.

Individual Distance

Large numbers collect in rafts during evening, resting on surface of sea just offshore of breeding colonies. Birds are spaced 1 to a few body distances apart (DGA).

Sexual Behavior

Mating System And Sex Ratio

Presumably monogamous, as is Manx Shearwater (Brooke 1990). In sample of 35 adult and subadult Newell's Shearwaters collected randomly on Kaua'i (victims of collisions with power lines), sex ratio was 1 male: 1.1 female (DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer unpubl. data).

Pair Bond

Nothing known about process or criteria used in mate choice. Vocalizations are frequent and given as duet among paired birds in burrow (see Sounds: vocalizations, above).

Pairs presumably mate in burrows. Courting pairs remain in burrow sometimes during day, rather than departing for sea (as free members of breeding pairs do, thus, leaving mate to incubate egg).

Extra-Pair Copulations

Not studied.

Social And Interspecific Behavior

Degree Of Sociality

Colonial breeder. Nocturnal at breeding colonies, so little has been observed of social interactions (see Breeding: phenology, below).

Play

None observed.

Nonpredatory Interspecific Interactions

Forages in multispecies flocks (see Food habits: feeding, above).

Predation

Kinds Of Predators

Worldwide, mammals introduced to islands have wreaked havoc on insular avian populations, particularly ground-nesting species such as shearwaters (including Newell's and Townsend's) and petrels (Croxall et al. 1983, Nettleship et al. 1994, Flint in press). Predation by humans for food has also had significant negative effects on populations of shearwaters and petrels, including Newell's Shearwater, and is well documented for Hawaiian and South Pacific islands (Munro 1960, Olson and James 1982, Steadman 1995).

Introductions of mammals to Hawaiian and Revillagigedo Is. has resulted in population declines and extirpation of Newell's and Townsend's shearwaters in large parts of formerly occupied habitat (see Distribution: historical changes, above). DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer (unpubl. data) present evidence that predation by feral cats on Newell's Shearwaters in breeding colonies on Kaua'i accounts for an annual 5% mortality of breeders or, because predation may be greater on the more socially active and more vocal prebreeders, an average 2.5% of all burrow occupants. These researchers thought that additional mortality, perhaps mainly among eggs and chicks, could be caused by rats, which are prevalent, but insufficient data precluded assessment of impact.

Newell's Shearwaters are preyed on also by Barn Owls, which were intentionally introduced to Kaua'i and other Hawaiian islands to control rats (Byrd and Telfer 1980). Now, Barn Owls are attracted to Newell's Shearwater vocalizations played at night from a tape recorder (Ainley et al. 1995), suggesting that they are keying on calling birds. No evidence exists that the owl endemic to Hawaiʻi, the Pueo (a subspecies of Short-eared Owl [*Asio flammeus*]), preys on Newell's Shearwater; and none indicate that the owl endemic to Clarión I.—Burrowing Owl (*Speotyto cunicularia* .)—preys on Townsend's.

At sea, Newell's and Townsend's shearwaters are kleptoparasitized by jaegers (*Stercorarius* spp.) and South Polar Skuas (*Catharacta maccormicki*), both of which are prevalent in ocean areas frequented by these 2 shearwaters (Spear and Ainley 1993).

Response To Predators

Nocturnal activity and cavity-nesting in seabirds have evolved to reduce predation by diurnal avian predators. Otherwise, these shearwaters have no defense against mammalian predators. Burrow-nesting has become maladaptive in the face of mammals introduced to breeding habitat.

Breeding

Figure 3. Phenology of reproduction and molt in Townsend's and Newell's shearwaters.

Phenology

Pair Formation

Pairs form in years before first year of breeding together. Pairs reunite in burrow at start of each breeding season. Following weeks of prebreeding courtship and synchronization of schedules, during the 2 wk before the highly synchronous egg-laying period, few adults visit the colonies (DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer unpubl. data)—a characteristic procellariiform event called "pre-laying exodus" (see Warham 1990). At this time, females are developing their eggs and males are refurbishing fat reserves to take the first incubation stint.

On basis of recovery of individuals banded as fledglings on Kauaʻi (DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer unpubl. data), 1-yr-olds do not visit breeding islands and 2- and 3-yr-olds do so only after others have completed egg-laying, ceasing their visits by the time the eggs hatch. Older nonbreeders, particularly 4- and 5-yr-olds, visit colonies from pre-egg stage until early chick stage of reproduction. The latter represent the age classes and the period in which pair bonds are formed.

Nest-Building

Burrows are deepened during period when pairs reunite.

First/Only Brood Per Season

Newell's Shearwaters on Kaua'i lay their eggs during first 2 wk of Jun (Telfer 1986,Ainley et al. 1995; see Fig. 3). This short period indicates that laying is well synchronized. Pairs skip breeding in some years (DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer unpubl. data). Replacement eggs are not known.

Timing of laying in Townsend's Shearwater differs from that of Newell's, but has not been studied directly; in fact, only 1 egg specimen (addled) exists in museum collections (see Eggs, below). Timing of egg-laying, however, can be estimated on basis of other data (Fig. 3). "Large" young have been reported by several persons who have visited Revillagigedos Is. from late Apr to end of May (Anthony 1900, Kaeding 1905, Hanna 1926). On this basis, assuming an incubation period and chick growth rate similar to those of Manx Shearwater, Jehl (1982) reasoned that egg-laying in Townsend's Shearwater must begin in Jan. Laying phenology, however, may differ slightly among Townsend's Shearwaters nesting on different islands. For example, in late Apr and early May 1897, on San Benedicto I., Anthony (1900) and Kaeding (1905) found both "large" and "very small" young; but in late May 1897, on Clarión I., Anthony (1900) found only "large" young. These data suggest that older young may have fledged by the time of Anthony's visit.

Nest Site

Selection Process

Not known.

Microhabitat

Not studied.

Site Characteristics

Nesting terrain is usually very steep and well vegetated, with open canopy and dense ground cover (see Habitat: breeding range, and Behavior: spacing, above).

Nest

Construction Process

These shearwaters dig burrows or further excavate crevices in rocky volcanic soil, especially (at least in the case of Newell's) at base of trees (see Behavior: spacing, above).

Structure And Composition Matter

May drag a few sprigs into egg chamber, but nests generally are not lined with vegetation (see also Byrd et al. 1984).

Dimensions

Burrows on Kauaʻi averaged 87.7 cm ± 22.2 SD long (range 46–175), and had entrances 9.9 ± 1.8 cm high by 13.8 ± 3.1 cm wide (Telfer 1986; *n* = 19).

Maintenance And Reuse Of Nests

Not studied directly, but same burrows are used over and over. Among 35–40 burrows studied by Telfer (1986) in early 1980s, at least 10 were known to be occupied still in 1993–1994. Those of Telfer's tags that could be found in the dense vegetation were disintegrated (Ainley et al. 1995), leaving open the possibility that reuse probably is even more prevalent.

Nonbreeding Nests

Prebreeders dig and occupy burrows. Pairs do not use >1 in a given year.

Eggs

Shape

Elliptical to short subelliptical.

Size

In Newell's Shearwater, average length 60.7 mm ± 2.4 SD, breadth 41.9 ± 1.4 (*n* = 34;Byrd et al. 1984). Egg size in Townsend's is known from only a few eggs, in museum collections. One egg, in U.S. National Museum, measured 57.3 x 40.4 mm (Bent 1922). The only other eggs in a collection, 2 at the California Academy of Sciences, have not been measured.

Mass

Not known.

Color

White (Bent 1922).

Surface Texture
Smooth.

Eggshell Thickness
Not known.

Clutch Size
Only 1 egg is laid by a female in a given year.

Egg-Laying
Not observed.

Incubation
Onset Of Broodiness And Incubation In Relation To Laying
Not known.

Incubation Patch
Each member of pair develops 1 incubation patch on lower abdomen.

Incubation Period
Probably similar to that of Manx Shearwater (average 51 d, range 47–66, *n* = 193;Brooke 1990). Telfer (1986), however, noted incubation period of 62 d for Newell's Shearwater on Kaua'i.

Parental Behavior
As far as known, both members of pair incubate egg equally. Normally, male incubates first, having returned from the prelaying exodus (see Phenology, above) on the same day as or within a day of the female, who lays her egg and departs (Warham 1990). For both Newell's and Townsend's shearwaters, length of incubation stints for individual birds is not known.

Hardiness Of Eggs Against Temperature Stress; Effect Of Egg Neglect
Not studied directly. The long incubation period compared to that of Manx Shearwater is one indication that egg neglect may be common in Newell's. Significant neglect of eggs would be consistent, too, with the extremely long commute distances undertaken by breeding Newell's compared to Manx Shearwater (Spear et al. 1995; see Parental care, below).

Hatching
Preliminary Events And Vocalizations

Not known.

Shell-Breaking And Emergence

Egg hatches within day or 2 of being pipped (Telfer 1981).

Parental Assistance And Disposal Of Eggshells

Probably none, as in other procellariiforms (DGA).

Young Birds

Condition At Hatching

Altricial; weak and unable to thermoregulate.

Growth And Development

At hatching, 4 chicks on Kaua'i weighed 45 (2), 49, and 53 g (Telfer 1981); linear measurements averaged (in mm): culmen 9.2, tarsus 23.0 (Telfer 1986). Development of temperature control not studied. Townsend's chicks are dark smoke gray, becom-ing white on lower parts (Loomis 1918). Same is true of Newell's (DGA).

Parental Care

Brooding

Newell's chicks probably are attended for their first several days by a parent, as in Manx Shearwater (all to age 5 d and a few to age 10 d; Bech et al. 1982).

Feeding

Chicks are fed irregularly. Frequency of feeding is not known and likely differs markedly between Newell's and Townsend's shearwaters, owing to different commute distances, which average 1,200 and 450–600 km, respectively, between feeding grounds and colony (Spear et al. 1995). Because Townsend's and Manx shearwaters commute similar distances, feeding frequency of each may be similar. In Manx, each parent commutes to visit the chick, on average, every 1.6–2.0 nights. Chicks thus are fed, on average, every 1.2–1.3 d (Thompson 1987). Given that the fledging period is 23% longer in Newell's than in Manx (see Fledgling stage, below), feeding frequency and/or caloric value of food are much lower in Newell's. This would be consistent, too, with the longer commute distances of this subspecies.

Nest Sanitation

Chicks defecate in one corner of nest chamber (DGA).

Cooperative Breeding

None.

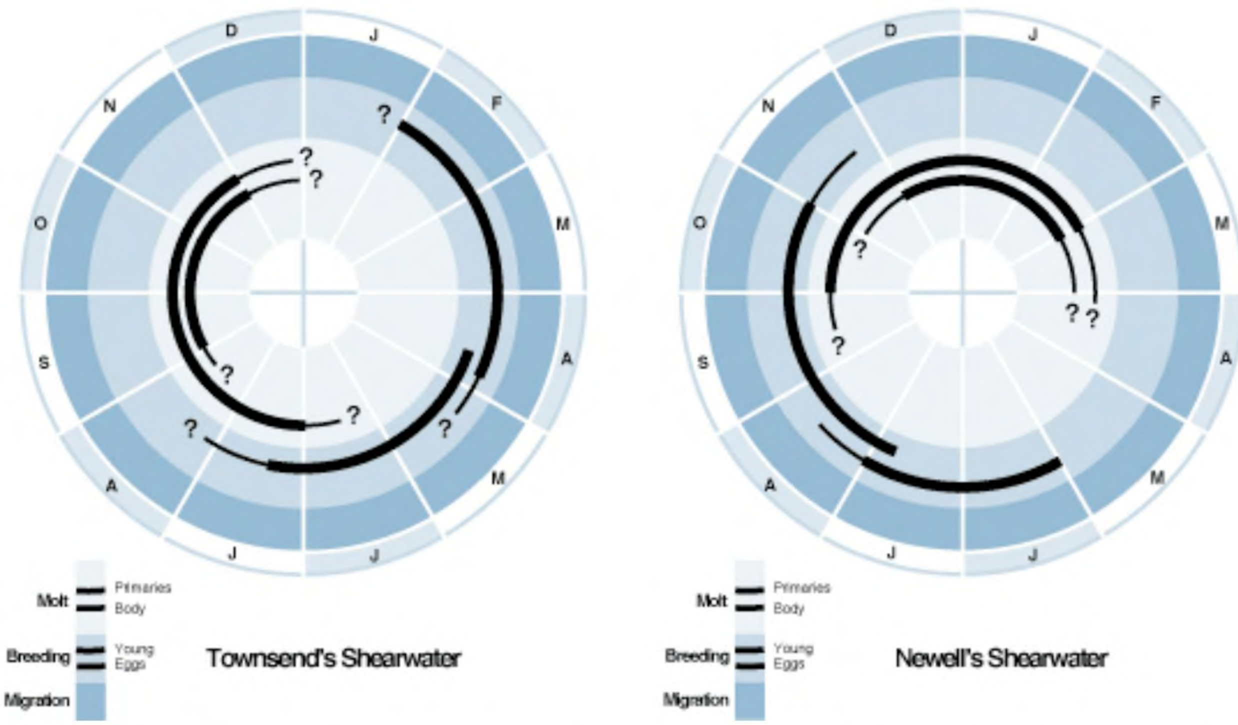

Figure 3. Phenology of reproduction and molt in Townsend's and Newell's shearwaters.

Thick lines show peak activity; thin lines, off-peak.

Brood Parasitism

None.

Fledgling Stage

Departure From Nest

Fledglings depart nest at night, usually just after sundown. Fledglings are independent of parents as soon as they depart.

Newell's Shearwater fledges in Oct (Telfer et al. 1987; Fig. 3). On initial flight to sea, Newell's fledglings are strongly attracted to lights, a behavior less characteristic of adults. Reason for this attraction is not known (Reed et al. 1985, Telfer et al. 1987). The fact that fewer fledglings are attracted to urban lights when moon is full may be due to the fact that the moon, on the horizon at sundown, is the brightest light around (Reed et al. 1985, DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer unpubl. data). Light attraction leads to phenomenon known as fallout (see Conservation and management, below), which in turn has led to a program called Save Our Shearwaters (SOS; Rauzon 1991).

Strong attraction to lights by fledglings means that occurrence of a fledgling in an urban setting does not indicate that Newell's Shearwater necessarily breeds on the island where the bird was recovered. For example, a stray bird found on O'ahu (Richardson 1955) likely is the source of suppositions that the species still breeds on that island (e.g., Harrison 1990; see Distribution: breeding range, above). DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer (unpubl. data) hypothesized that most fledglings that fall out on Kaua'i are attracted back to shore by coastal lights after successfully reaching the sea. Some fledglings also have been attracted to brightly lighted ships steaming among Hawaiian Is. (TCT).

Growth

Newell's Shearwater chicks fledge at age averaging 92.4 d ± about 3.1 SD (range 88–100, *n* = 44; Byrd et al. 1984). Growth constant (*k* = kg/d) averages 0.061. A few hours before fledging, chicks average 364.6 g ± 55.2 (*n* = 44), but on morning of release by SOS (after several hours of struggling in boxes; see Conservation and management, below), average 339.4 ± 44.7 g. Average mensural characteristics of fledglings are (mm ± SD): culmen length, 32.8 ± 1.1 (*n* = 853); tarsus length, 46.9 ± 1.6 (*n* = 860); wing length, 232.7 ± 7.0 (*n* = 859); and tail length, 81.7 ± 3.3 (*n* = 855).

Immature Stage

Not studied.

Figure 3. Phenology of reproduction and molt in Townsend's and Newell's shearwaters.
Thick lines show peak activity; thin lines, off-peak.

Demography and Populations

Measures Of Breeding Activity

Age At First Breeding

Estimated by DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer (unpubl. data) to be similar to that of Manx Shearwater (6 yr; Brooke 1990). Supporting this estimate are recoveries of known-age birds on Kauaʻi (from Telfer 1984–1994). As summarized in DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer (unpubl. data), among 15 banded known-age birds recovered, all the ones <5 yr old were found during period after egg-laying had begun. Of 2 birds 6–7 yr old, 1 was recovered during prelaying period, consistent with a bird that would breed.

Annual And Lifetime Reproductive Success

For Newell's Shearwater on Kauaʻi, on basis of estimates made by Telfer (1986, as summarized in DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer unpubl. data), incidence of nonbreeding is high: only 46% of pairs that actively use a burrow actually breed in a given year (range 30–62%, n = 5 yr, 36–47 burrows monitored/yr). Among nests in which eggs are laid, 66.0% ± 6.4 SD (range 49–75) fledge young. This fledging rate is similar to that of stable Manx Shearwater populations (Brooke 1990). Hatching success not known.

Number Of Broods Normally Reared Per Season

Not >1/pair; averaged over several seasons, certainly <1 (DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer unpubl. data).

Life Span And Survivorship

On basis of allometric equation relating survivorship to body mass in procellariiforms, annual adult survivorship of Newell's Shearwater was estimated to be 0.904 ± 0.017 SE (95% confidence interval, range 0.870–0.934; DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer unpubl. data). This figure is close to that estimated for Manx Shearwater by more conventional means (Brooke 1990).

Disease And Body Parasites

Diseases

A few Newell's Shearwater fledglings picked up by Save Our Shearwaters (SOS) have exhibited mild symptoms (lesions) of poxvirus (TCT). *Plasmodium* sp. has been found in Newell's Shearwater (Van Riper and Van Riper 1985), but symptomatic avian malaria (the scourge of many endemic, lowland nesting Hawaiian birds) has not. The facts that Wedge-tailed Shearwaters breed in large numbers on islands where Newell's nest, and at the low altitudes suitable for mosquitoes carrying malaria, indicate that this disease is not likely a factor in the natural history of Hawaiian shearwaters. Newell's chicks cross-fostered by Wedge-tailed Shearwaters in a lowland colony in 3 separate years showed no sign of malaria. In fact, the fostering parents raised more Newell's chicks than did Newell's raising their own in their mountain colony (see Byrd et al. 1984).

Body Parasites

Mallophaga present but not studied. Nest mites (*Ornithodosis capensis*) reported for Newell's Shearwater (Van Riper and Van Riper 1985).

Causes Of Mortality

Large numbers of Townsend's Shearwaters likely were killed by eruption of Barenca Volcano on San Benedicto in 1952 (Brattstrom 1963). Lava flows and noxious gases from various eruptions of Kilauea in Puna District, HI, could have killed Newell's Shearwaters, especially chicks, as well.

Hurricanes, such as ʻIniki in 1992, which passed over Kauaʻi in the midst of chick-rearing period, could have killed some Newell's Shearwaters, especially chicks in burrows on slopes where mudslides occurred or where uprooted trees destroyed the burrows. However, no direct observations of hurricane-caused mortality are available. Hurricanes are common within the experience of these shearwaters. Revillagigedos Is. are subject to hurricanes. Newell's (and Townsend's) Shearwaters experience hurricanes annually in their foraging area of the eastern tropical Pacific. Adults likely would vacate nesting areas as an intense low pressure system approached, much as various tropical petrels must do to escape hurricanes battering islands in the w. Atlantic during summer and early autumn (e.g., Black-capped [*Pterodroma hasitata*] and Bermuda [*P. cahow*] petrel).

At sea, diving into school of tuna, which are large creatures that forage at high speed, could be hazardous for a shearwater and may be one reason that most tropical seabirds resort to aerial forms of foraging (Ainley 1977).

Population Status

Numbers

Surveys of colonies never will be adequate to estimate population size of these shearwaters, because terrain in nesting areas is too difficult for proper study.

On basis of at-sea densities (multiplied by surface area of ocean occupied by the species), Spear et al. (1995) estimated total populations (adults, subadults, and juveniles) of 46,400 Townsend's Shearwaters (95% confidence interval, range 17,500–89,000) and 84,000 Newell's Shearwaters (range 57,000–115,000). On basis of demographic parameters (see above) and Spear et al.'s estimates, DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer (unpubl. data) estimated breeding population of 14,600 pairs, almost all of which nest on Kaua'i. Using radar, Cooper and Day (1994) estimated that 63,000 (range 37,000–89,000) adults and older subadult Newell's Shearwaters visited colonies on Kaua'i in 1993, a figure that would extrapolate to a breeding population within the same order of magnitude as that estimated by DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer (unpubl. data). Size of shearwater population on Hawai'i I., the only other island where colonies of Newell's Shearwaters have been found in modern times, has not been estimated (MHR). On basis of radar data (Reynolds et al. 1997a), compared to those from Kaua'i (Cooper and Day 1994), however, the breeding population on that island can not exceed a few thousand birds (see below).

Radar studies by Cooper and Day (1994) indicated detection rate (shearwaters/h passing through 1.4-km-diameter radar beam) of 250–875 during height of breeding season at 5 sites on northern shore of Kaua'i. There, about 80% of the world's population of Newell's Shearwater nests (DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer unpubl. data). At 6 sites on eastern shore, rates ranged from 65 to 360, and at 4 sites on southern shore, 35–150. In comparison, radar studies by Reynolds et al. (1997a) and Cooper and David (1995) on Hawai‘i indicate smaller population than on Kaua‘i. Shearwaters/h ranged 0–135 at 6 sites in Puna District and, on the northern shore, 230 at Waipi‘o Valley. In Puna District, Reynolds and Ritchotte (1997) discovered 3 cinder cones/pit crater where Newell's Shearwaters nest. Population size at each is <100 pairs, an estimate consistent with results of the radar studies.

Trends

The historic pattern of population decline may be continuing for Townsend's Shearwater (see Distribution: historical changes, above). Visits to Revillagigedo Is. by naturalists, however, are too infrequent to reveal any but the most dramatic changes.

In the case of Newell's Shearwater, numbers of fledglings obtained each autumn on Kaua‘i by SOS, during the period 1980–1997, indicate a declining population on the southern shore, assuming that number of fledglings found is related to number of breeding pairs (DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer unpubl. data; SOS, TCT; see Effects of human activity: urbanization, below). Numbers of fledglings found on eastern shore have shown no change, and on northern shore have increased. On eastern and especially northern shore, however, rapidly expanding urbanization, with much more coastal lighting to attract fledglings and more people to find downed birds, perhaps better explains the SOS trends there. If so, urbanization increasingly is affecting colonies on Kaua‘i's eastern and northern shores through mortality associated with fallout (see Conservation and management, below).

A Leslie model (Leslie 1945) constructed to estimate growth patterns of Kaua‘i population of Newell's Shearwater indicates negative growth rate on southern and eastern shores (DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer unpubl. data). Because of predation by introduced predators (especially cats), collisions by adults and subadults with power lines, and mortality of fledglings as result of fallout (collisions, being run over by cars, etc.), the model projected that the population is decreasing 30–60% every 10 yr. The range of rates depends on which values of demographic parameters are used in the model, but nevertheless project the rate of decrease in fledglings recovered over the past 10 yr (see above).

Muddling the situation is the fact that Hurricane ʻIniki hit Kauaʻi in autumn 1992, which was also the year when fallout rates (as an index to breeding population size and fecundity) peaked. Since then, numbers of fledglings processed by SOS have declined progressively (through 1996). Iniki was a major hurricane and could have led to major mortality, but no direct evidence was found.

Population Regulation

In Revillagigedo Is., population size is limited by availability of nesting sites to which feral mammals have no access. Thus, recolonization of San Benedicto I. (following the volcanic eruption in 1952)—a process that may first require reestablishment of vegetation—may be the key to the continued existence of Townsend's Shearwater. San Benedicto currently is mammal-free, much of the island is now covered by bunchgrass (*Eragrostis variabilis*), and Wedged-tailed Shearwaters, at the least, have recovered (S. Howell pers. comm.).

In Hawaiian Is., assuming idealistically that no more native forest will be claimed by urban or agricultural sprawl, population size of Newell's, too, is a function of habitat free of introduced predators. In addition, however, urban factors that lead to mortality must be managed effectively (e.g., power lines, coastal lighting, roads developed into new areas, etc.; see Conservation and management, below). On the other hand, until all the main Hawaiian islands are searched for nesting colonies of Newell's Shearwater, the degree to which available habitat is affecting population size will remain unclear.

Factors that regulated populations of Townsend's and Newell's shearwaters during prehistoric times are a subject of conjecture only. Ashmole (1963) thought that food supply during chick-provisioning period of reproduction regulated population size of tropical seabirds nesting on oceanic islands. Limited availability of oceanic islands for predator-free nesting, however, must play role in regulation as well.

Conservation and Management

Effects Of Human Activity

Degradation Of Nesting Habitat

Having to cope with lava flows on Hawaiʻi I. and volcanic eruptions on San Benedicto I. in the Revillagigedos, these shearwaters can withstand little more loss of nesting habitat from other causes. Among the main Hawaiian islands, 75% of native forest has already been lost to agriculture and the growth of cities and towns (Cuddily and Stone 1990). Much, but not all of the remaining forest habitat has been set aside as federal or state preserves and parks. Now, however, degradation of habitat by noxious weeds, even in wildlife preserves, is becoming an important problem. How this might affect Newell's Shearwater is not known.

Predation From Introduced Animals

Assuming no more degradation of habitat, predation from introduced mammals (and owls) remains the major factor requiring management. The introduction to Kaua'i of mongooses from the other Hawaiian islands or brown tree snakes (*Boiga irregularus*) from w. Pacific islands would be devastating to remaining colonies of Newell's Shearwater. Appropriately, wildlife agencies are well aware of the potential for introductions, and guard measures are in place.

More problematic is the presence of pigs and cats in Revillagigedo Is. (except San Benedicto) and Hawaiian Is., as well as presence of mongooses in the latter (except Kaua'i). At present, not one pair of Newell's Shearwater nests in a preserve where feral animals are managed.

Urbanization

Urbanization is not a problem for Townsend's Shearwater in the Revillagigedos, but is critical for Newell's Shearwater in Hawaiian Is. There, attraction to lights and collisions with power lines and other structures exact a significant mortality on fledgling and breeding adult Newell's Shearwaters, respectively.

Each autumn on Kaua'i, citizens find an average of 1,500 fledglings that have circled lights until exhausted or have collided with cars, power lines, or other urban structures—a phenomenon known as fallout. These birds are taken to SOS (Save Our Shearwaters) stations, where they are collected in the morning by wildlife officials and taken to be banded and released. The program has operated every fall since 1978, and to date about 25,000 fledglings have been banded and released (TCT). DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer (unpubl. data) estimated that, of 9,600 juveniles fledging each autumn, on average, about 15% are involved in fallout and about 10% of those are killed. Without SOS, most of the fledglings falling out would perish immediately (Telfer et al. 1987, DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer unpubl. data).

Adult Newell's Shearwaters suffer significant mortality related to urbanization, as a result of collisions with power lines as they fly to and from breeding colonies in darkness. DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer (unpubl. data) estimated that 0.6–2.1% of nest occupants (both adults and subadults) are killed each year throughout s. and e. Kauaʻi as result of such collisions. Mortality rate likely is higher still when considering specific colonies that may use flyways that cross power lines unintentionally constructed across the flyway.

Availability Of Tuna

Newell's Shearwater depends on high-seas tuna to force prey within reach. Tuna schools in e. Pacific, however, are target of widespread and efficient commercial fishery, and several tuna species now are considered to be in jeopardy (IUCN 1996). Unknown is the effect on these shearwaters of losing to fishermen a tuna school and having to find another. Certainly, this would increase the energetic costs of foraging to a species that already uses an energetically costly means of flight (see Food habits: feeding, above). Repeated losses of foraging tuna schools could reduce the feeding frequency of chicks.

Management

Conservation Status

Both Townsend's and Newell's shearwaters are considered by IUCN (International Union for the Conservation of Nature) to be in great jeopardy because of the small size and isolated nature of their breeding populations, as well as the numerous factors affecting them. Newell's Shearwater is listed as "threatened" on the U.S. Endangered Species List (Dept. of the Interior 1982).

Measures Proposed And Taken

Solutions to reducing mortality of Newell's Shearwater related to urbanization are difficult. Control of lighting is possible, as indicated by isolated successes on the part of Hawaiʻi Department of Land and Natural Resources in convincing architects to plan building projects with shearwaters in mind (e.g., Kauaʻi Surf Hotel and Poipu Hyatt Regency Hotel on Kauaʻi), and the influence of the astronomical observatories in the planning of urban lighting on Hawaiʻi (A. Peanut pers. comm.). Control of power lines also is possible (burying of lines in critical areas), but costs are high and the process has yet to be implemented (except in some neighborhoods on O‘ahu, which have no shearwaters).

The SOS program helps mitigate the collision problem for fledglings (DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer unpubl. data). However, the fact that <30 of 25,000 banded birds have been found, dead or alive, by SOS indicates that effectiveness of “rehabilitation” may be less than hoped (DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer unpubl. data; see Priorities for future research, below).

Mammalian predators in Revillagigedos Is. probably can be controlled and extirpated through education of members of a small military installation. Control in Hawaiian Is., however, may be an illusion, because pigs and cats are well established and are of great value to some segments of Hawaiian society. Fencing and use of toxicants to exclude predators from colonies may be the only option, as is done on Maui to exclude predators from nesting habitat of Hawaiian Petrel (*Pterodroma sandwichensis*; Hodges 1994) and from forest bird reserves. Surveys to locate Newell’s Shearwater colonies, however, have yet to become a priority among wildlife managers; only the few pairs nesting at Ki¯lauea Pt. NWR are in a reserve where feral mammals are controlled.

Perhaps a major problem for Newell’s Shearwater at present is that, although listed as threatened, it is far more abundant than dozens of other Hawaiian species also in jeopardy. These latter species thus command all of the limited management resources available.

Appearance

Molts And Plumages

Hatchlings

Both Townsend’s and Newell’s shearwater chicks are initially covered with pale gray down, except for bare areas on head (lores, forehead, chin). According to Berger (1981: 47), a Newell’s chick 8 d old was “medium gray on the head, back, and rump; white on the chin, throat, and abdomen; and whitish to very pale gray on the breast. The bill was slate gray; the eyes were black; the inner surface of each leg was pink, but the outer surface was gray.”

Juvenal Plumage

Prejuvenal molt and Juvenal molt not studied specifically in either Townsend's or Newell's shearwater. Subadults and fledglings appear to be indistinguishable from adults, except seasonally on basis of feather wear.

Basic I Plumage

Number of Prebasic molts between Juvenal and Definitive Basic not known in Newell's or Townsend's. In other shearwaters, different age classes molt at different times of year, but good data are lacking for any species (Warham 1990).

One molt per year in adults for both Newell's and Townsend's. Definitive Prebasic molt complete in both; occurs away from breeding area, although some contour feathers may be lost toward end of chick-rearing period (Jehl 1982, DGA). Molt of primaries proceeds distally and in secondaries both distally and proximally from central feathers in other shearwaters, and thus presumably in Townsend's and Newell's (literature summarized for genus *Puffinus* by Warham 1990). Townsend's Shearwaters that were collected at sea from Sep to Nov (i.e., nonbreeding season) were molting flight-feathers (Jehl 1982).

These shearwaters, colored dark sooty brown above, have white belly, throat, and underwings. White of flanks extends upward onto back, just behind wings. Townsend's has completely dark undertail-coverts, whereas central proximal-coverts in Newell's are white (Howell et al. 1994; see below). At close range, black and white of face appear to be more sharply delineated in Newell's. Otherwise, Townsend's and Newell's are indistinguishable (see also Distinguishing characteristics, above).

Bare Parts

Bill And Gape

In both subspecies, bill dark gray to brown, sharply hooked at tip; nostrils in tube at base of culmen.

Iris

Iris brown.

Legs And Feet

Legs pale whitish pink, with black stripe running up back; feet whitish pink, except for black on outer surface of each outer toe, connecting to black of hind tarsus (Howell and Engel 1993). Nails sharp.

Measurements

Linear

Newell'S Shearwater

Mean linear measurements (mm ± SD): wing, 237.4 ± 6.19 (range 223–249, *n* = 37); tail, 84.3 ± 2.75 (78.9–88.8, *n* = 36); exposed culmen, 33.2 ± 0.21 (30.2–35.5, *n* = 39); tarsus, 45.8 ± 0.31 (43.3–48.3, *n* = 39); middle toe with claw, 49.1 ± 2.18 (45.6–54.3, *n* = 37; King and Gould 1967).

Townsend'S Shearwater

From Murphy 1952 (*n* = 13), mean linear measurements (mm): wing, 227.7 (range 220238); tail, 74.9 (67.5–77.6); exposed culmen, 31.7 (28.9–34.4); tarsus, 44.8 (42.9–46.4). From Bourne et al. 1988 (*n* = 10): wing, 230 ± 4.8 (range 225–237); tail, 76.3 ± 1.9 (74–79); exposed culmen, 32.7± 1.9 (30–35); tarsus, 45.4 ± 1.3 (43–48).

See Howell et al. 1994 and Distinguishing characteristics, above, for further discussion and measurements of tail length.

Mass

Newell'S Shearwater

Body mass as determined by King and Gould (1967), without specification of season, averaged 391.2 g ± 29.6 SD (range 342.5–425); as determined by DGA, R. Podolsky, L. Deforest, N. Nur, and G. Spencer (unpubl. data) for spring-summer (Jun–Jul) specimens (with empty stomachs), averaged 381 g ± 45 SD (range 340–411, *n* = 35).

Townsend'S Shearwater

Body mass obtained by Jehl (1982) of 5 specimens collected in Sep, Oct, and Apr, at sea, averaged 337 g (range 315–358); 5 measured on Socorro I. in Apr averaged 303 g (range 290–315; Jehl 1982).

Priorities for Future Research

Broad but limited surveys of Hawai'i Island and Kaua'i Island, made by the use of radar at a few coastal sites, have produced some tantalizing information on the natural history of Newell's Shearwater (Cooper and David 1995, Cooper and Day 1994, Day and Cooper 1995, Reynolds et al. 1997a). To understand better what these data mean, intensive radar-based sampling is now required to elucidate (1) nightly and seasonal variability in shearwater movement rates, (2) the effect of topography on flight routes between colonies and the sea, (3) the effect of altitude of the terrain on flight altitude (along the coast and well inland), and (4) in conjunction with help by direct visual means, the effect of rain on routes and altitudes flown. Concurrently, data are needed on the length of incubation stints and visitation rates of individual birds, both breeders and nonbreeders, in the colonies. These data could be acquired by telemetry. Together, all these data would immensely improve our understanding of interactions between Newell's Shearwaters and urban factors. A radar study (aboard ship) could be made, as well, of Townsend's Shearwaters in the Revillagigedo Islands and of Newell's Shearwater flying inland along the Na Pali coast of Kauaʻi, as well as around other Hawaiian islands.

The coastal areas offshore of all the main Hawaiian islands easily could be searched in the evening during summer to find rafting areas. Results would indicate the approximate location of breeding colonies.

It is not clear why fallout rates are decreasing on the southern shore but increasing on the northern shore of Kauaʻi. Because of long-established urban development on the southern shore, the population could be decreasing; new but increasing development on the northern shore, with more lights, may be attracting more birds. Also, the shearwater population may be shifting to the northern shore. However, as demonstrated by the extremely low rate of recolonization of San Benedicto I. since 1952 (Brattstrom 1963, Howell and Webb 1990, Santaella and Sada 1991), the apparent high degree of philopatry in this species argues against the latter mechanism. The shift of fallout from southern Kauaʻi to northern Kauaʻi possibly is related to better suvival of breeders and less damage to breeding habitat on the northern shore than on the southern shore as a result of Hurricane ʻIniki (TCT). Searches for breeding colonies on the northern shore of Kauaʻi for birds banded as fledglings in the SOS program (>25,000 banded to date) would help resolve the reasons behind the curious trends in SOS data. If urban development is the cause, then the stability of the largest remaining population of this species is in jeopardy.

Finally, knowing the degree to which predation by cats constrains Newell's Shearwaters to the wettest parts of the Hawaiian Islands would be helpful in planning the protection of remaining colonies. So far, most of our information on the breeding biology of Newell's Shearwater and the effect of predation is based on studies conducted in one colony in the mountains on the southern shore of Kaua'i (with supplemental information from a few other colonies). More intensive work in other colonies, especially on the northern shore and elsewhere in the Hawaiian Islands, would provide instructive information.

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