THE PREY OF NEWELL'S SHEARWATER *PUFFINUS NEWELLI* IN HAWAIIAN WATERS

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While diet and foraging behavior are known fairly well for many temperate and polar seabirds, information is scant for subtropical and tropical species (see summary in Shealer 2002). For the dramatically decreasing Newell's Shearwater *Puffinus newelli* (classified as "threatened" under the US Endangered Species Act) virtually nothing is known of its diet. Ainley *et al.* (1997) reported they preyed on squid, but Spear *et al.* (2007: 49) stated the following:

> Although not included in the present analysis owing to low population size, but definitely occurring in the study area (Spear *et al*. 1995), two endangered seabird species, the Hawaiian Petrel [*Pterodroma sandwichensis*]… and Newell's Shearwater…, are both members of the flocking-feeding group of the [eastern tropical Pacific]. The recovery plans for these species dwell only on colony-related impacts to populations (US Fish and Wildlife Service 1983), but given the state of the depleted tuna fisheries and the importance of tuna to these seabirds, further investigation about the relationship between bird population trends and tuna availability is warranted. At the least, a changed food-web structure may require re-definition of how much future growth is possible in these seabird populations. Further monitoring of all ETP seabird populations is important in this regard.

That being said, we should expect the diet of Newell's Shearwater to be similar to that of the other subtopical/tropical seabirds that frequent schools of subsurface predators (i.e. tuna). Such information is important to the future recovery of this rapidly decreasing species. Here, we report for the first time information on the diet of Newell's Shearwater, derived from individuals in the Kaua'i, Hawaiian Islands, nesting population.

During two periods, 1993–94 (n = 19) and 2001–09 (n = 79), the stomachs were taken from birds found beneath powerlines along Kaua'i roadways (see Podolsky *et al.* 1998). Almost all individuals had recently fledged, and, thus, stomach contents reflected what was fed to them by parents. The 1993–94 specimens were picked up by us (GCS, DGA) during concerted searches, and the stomach was removed right away (included are two regurgitations collected in a nesting colony and the nine squid samples mentioned in Ainley *et al.* 1997); the 2001–09 sampling was derived from birds turned in to the Save Our Shearwaters program by Kaua'i citizens. Stomachs from this sample were removed long after the carcass had been frozen for storage, sometimes years after finding. In addition, many of the stomachs in the 2001–09 sample series were from birds that were recovered alive and spent at least several days in the rehabilitation facility before it was deemed that they would not recover. As a result, most of the cephalopod beaks recovered from the gizzard stomach compartment were in an advanced state of digestion. Due to the compromised condition of the samples and the inherent small size of the birds' juvenile-sized beaks, stomach content examination and identification of individual prey remains were conducted under 16× magnification in both the 1993–94 and 2001–09 samples. Estimates of fish numbers were derived from dividing total otoliths by two; counts for squid were based on the number of lower beaks. Condition allowing, measurements of lower beak rostral length (cephalopods) and otolith length (fishes) were made to the nearest 0.1 mm using an optical micrometer. Sample size allowing, squid dorsal mantle length (DML) and fish standard length (SL) estimates were made using regression equations presented in Spear *et al.* (2007).

The diet was dominated by ommastrephid and, to a much lesser extent, cranchiid squid (Table 1). Ommastrephids, also known as flying squid, contributed 57% and 37% of the squid, with frequency of occurrence 100% and 97% (1993–94, 2001–09, respectively). The only ommastrephid species identified in the samples was the Purpleback Flying Squid *Sthenoteuthis oualaniensis*. Poor condition precluded positive species identification of most of the ommastrephid beaks. However, most of the damaged beaks were from similar-sized individuals, and we suspect that most, if not all, of these beaks were from *S. oualaniensis*. Assuming that 54 measurable beaks and 15 direct measurements of near intact squid (mainly from the regurgitations) were this species, estimated DML frequency distribution reveals that all were small juveniles ranging from 45 mm to 115 mm DML with a mean of 83 mm DML (Fig. 1). With the exception two adult beaks from *Taonius belone*, almost all the cephalopod species in both the 1993–94 and 2001–09 samples were represented by tiny juvenile and post-larval vertically migrating growth stages, which are abundant in the near-surface waters at night (Bower *et al*. 1999, Young 1978). The fish component of the sample was made up primarily of flyingfish *Exocoetus* spp. (Table 1). Only one otolith and one partially intact fish were measurable; both were juveniles ranging from 130 mm to 134 mm SL (Table 2). The fact that more fish were found in the fresher 1993–94 specimens than in the 2001–09 specimens (4.0% versus 0.1% of items) indicates that much information was lost due to digestion, given that squid beaks can

TABLE 1
Analysis of stomach contents of Newell's Shearwaters found dead beneath power lines on Kauai, 1993–94 (n = 19[a]) and 2001–09 (n = 79)

Prey item	1993–94				2001–09			
	No. prey	%	Occurrence n = 19	FoO[b]	No. prey	%	Occurrence n = 79	FoO[b]
Fishes	26	4.0	19	100	6	0.1	4	5.1
Phosichthyidae								
Vinciguerria nimbaria	5	0.8	1	5.3				
Exocoetidae	11	1.7	5	26.3	6	<0.1	2	5.0
Exocoetus sp.	7	1.1	2	10.5	0	-	-	-
Exocoetidae (unidentified)	4	0.6	2	10.5	3	<0.1	2	2.5
Nomeidae								
cf *Cubiceps* sp. (unidentified)	3	0.5	1	5.3				
Gempylidae								
Juvenile (unidentified)	1	0.2	1	5.3				
Tetradontidae								
Lagocephalus sp.	1	0.2	1	5.3				
Fish (unidentified)	5	0.8	4	21.1	3	<0.1	2	2.5
Cephalopods	616	95.8	19	100	6601	99.9	79	100
Pyroteuthidae								
Pterygioteuthis spp	47	7.3	11	57.9	1097	16.6	68	86.1
Onychoteuthidae	5	0.8	5	26.3	30	0.5	21	26.6
Onykia sp.	3	0.5	3	15.8	9	0.1	8	10.1
Onychoteuthis sp.	2	0.3	2	10.5	21	0.3	14	17.7
Ommastrephidae	369	57.4	19	100	2446	37.0	77	97.5
Sthenoteuthis oualaniensis	42	6.5	8	42.1	46	0.7	15	19.0
cf *S. oualaniensis* (unidentified)	69	10.7	11	57.9	207	3.1	48	60.8
Ommastrephidae (unidentified)	258	40.1	16	84.2	2193	33.2	77	97.5
Chiroteuthidae								
Grimalditeuthis bonplandi	1	0.2	1	5.3	4	0.1	3	3.8
Cranchiidae	47	7.3	11	57.9	474	7.2	70	88.6
Megalocranchia fisheri	18	2.8	8	42.1	217	3.3	66	83.5
Taonius belone	0	-	-	-	2	<0.1	2	2.5
Liocranchia sp.	3	0.5	2	10.5	86	1.3	31	39.2
Leachia pacifica	14	2.2	4	21.1	47	0.7	19	24.1
Cranchiidae (unidentified)	12	1.9	3	15.8	122	1.8	38	48.1
Squid (unidentified)	145	22.6	14	73.7	2 500	37.8	74	93.7
Bolitaenidae	2	0.3	1	5.3	50	0.8	29	36.7
cf *Japatella* sp. (unidentified)	1	0.2	1	5.3	31	0.5	20	25.3
Bolitaenidae (unidentified)	1	0.2	1	5.3	19	0.3	10	12.7
Shrimp-like crustaceans	2	0.3	1	5.3	7	0.1	3	3.8
Total no. prey	643				6 609			

[a] The 1993-94 samples include two regurgitations of birds at nesting burrows.
[b] FoO = frequency of occurrence.

remain intact for several days (parts identifiable even after weeks) but most otoliths are completely digested within a day, and larger ones remain intact only slightly longer (Spear *et al.* 2007).

Given their association with tuna schools, and the similarity in the cephalopod portion of the diet, we can expect the Newell's Shearwater diet to be similar to that of Christmas *P. nativitatus* and Wedge-tailed *P. pacificus* shearwaters, which also take flying squid and fish, especially flyingfish (Spear *et al.* 2007). Fish in the diet of Wedge-tailed Shearwaters contributes 41% by number (twice the mass of squid), with frequency of occurrence being 56%; for Christmas Shearwaters the figures are 51% (and twice the mass squid) and 100%. The presence of the Oceanic Lightfish *Vinciguerria nimbaria* in Newell Shearwater's diet indicates that this seabird may specialize in feeding over yellowfin tuna *Thunnus albacares*, similar to Wedge-tailed and Christmas shearwaters, and as also confirmed from at-sea sightings (Spear *et al.* 2007). Both flying squid and flyingfish are important in the diet of yellowfin tuna, as sampled by Grubbs *et al.* (2002) around fish-aggregating devices positioned a short distance south and west of the Hawaiian Islands.

While opportunistic scavenging and direct predation through individual surface-picking would not be major feeding modes of Newell's Shearwater, they apparently do not pass up the opportunity to pick at dead floating squid or engage in direct predation of living small juvenile squid that are normal inhabitants of surface waters, given the size of some of their prey. This is also found with the Wedge-tailed Shearwater (Spear *et al.* 2007). Evidence for scavenging is supported by the presence of adult beaks from *Taonius belone*, an exclusively mesopelagic species that does not undergo vertical migration and is not normally found above 400 m (Young 1978). In addition, the estimated mantle length of two of these squid was almost as long as a Newell's Shearwater (Table 2). Direct predation on individual juvenile squid is supported by the presence of small numbers of an additional nine species of cephalopods, the post-larval stage and juveniles of which are commonly found dispersed at the surface. In general, the squid and fish taken were much less than 12 cm in length (Fig. 1). Any prey above 10 cm would likely require more handling time, exposing the Newell's Shearwaters to piracy from other seabirds. Indeed, prey acquisition among participants in flocks feeding over tuna and other predatory fish is highly structured by prey size as it relates to bill size and handling time (Spear *et al.* 2007).

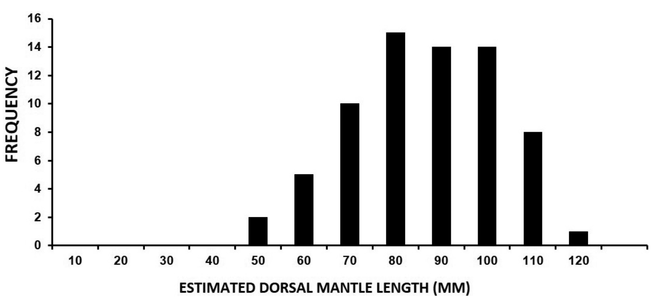

Fig. 1. Frequency distribution of Purpleback Flying Squid *Sthenoteuthis oualaniensis* in the diet of Newell's Shearwaters, with dorsal mantle length estimated by regression from 54 lower beak rostral lengths and dorsal mantle length of 15 intact squid (n = 69).

TABLE 2
Estimated lengths of several species of prey taken by Newell's Shearwaters

Prey	mm	
	Lower beak rostral length or otolith largest diameter	**Dorsal mantle length or total length**
Pterygioteuthis sp.	1.2–1.8 (n = 9)	46–66
Onychoteuthis sp.	0.9–1.4 (n = 3)	83–113
Taonius belone	4.2–4.3	216–220
Megalocranchia fisheri	2.9	128
Exocoetus sp.	5.9	134[a]

[a] A whole specimen recovered was 130 mm in length.

Newell's Shearwaters provisioning chicks return with food irregularly every one to three nights (Ainley *et al.* 1997; B. Zaun, Kilauea National Wildlife Refuge, pers. comm.). Since the chicks sampled were being fed by parents, the diet described here was obtained within a few hundred kilometers of Kaua'i, an area subject to intensive commercial fishing for tuna and other predatory fish species. Much remains to be learned about the at-sea ecology of the Newell's Shearwater and how it is affected by fishing, a task made increasingly difficult owing to the continued steep decline in this species' population on Kaua'i and elsewhere in Hawai'i (Ainley *et al.* 1997, 2000).

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