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BREEDING BIOLOGY OF THE BLUE-GRAY NODDY

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The Blue-gray Noddy (*Procelsterna cerulea*) is widely distributed throughout the central and south Pacific (Murphy 1936, King 1967, 1973). Edgar et al. (1965) and Soper (1969) reported incidental observations from the Kermadec Islands north of New Zealand. Murphy (1936) described birds collected in Chile. Ashmole and Ashmole (1967) reported on feeding ecology at Christmas Island (Pacific). Comments on the range and probable breeding season for Blue-gray Noddies in Hawaii (*P. c. saxatilis*) are reported by Richardson (1957) and Clapp et al. (1977). Most Blue-gray Noddies that breed in Hawaii occur on Necker and Nihoa Islands, which have estimated peak populations of about 2000–3000 each (Clapp and Kridler 1977, Clapp et al. 1977); fewer than 12 pairs breed on La Perouse Pinnacle, French Frigate Shoals (Amerson 1971), and Gardner Pinnacles (Clapp 1972). Caum (1936) implied that this species also breeds on Kaula Island when he reported "a small colony living in the steep cliffs at the North Horn" in mid-August 1932, but recent visitors have found none.

We report observations on the breeding biology of Blue-gray Noddies on Nihoa Island during winter 1980–1981. We compare our data with previous reports and with observations from the South Pacific during the 1960's by the Pacific Island Biological Survey Program of the Smithsonian Institution and during the 1970's by Clapp.

STUDY AREA AND METHODS

Nihoa Island (23°06'N, 161°58'W), about 400 km northwest of Honolulu and 63 ha in extent, is the largest remnant volcanic cone in the Northwestern Hawaiian Islands. It has perpendicular cliffs rising to 275 m on the north and west sides. The southern cliffs are smaller and consist of rock faces exposed by erosion. Weathering has exposed small cavities in which Blue-gray Noddies nest. Weather at Nihoa is characterized by low pressure cyclonic storms throughout winter, and only rarely are the offshore waters calm enough to permit landing.

Rauzon studied the breeding biology of this species on Nihoa from 31 January to 22 February 1981. Four study areas among the southern lava cliffs provided 56 nest sites. Initial enumeration with spray paint and study of nest sites began on 3 February. Site monitoring each 6–9 days thereafter yielded 3 sets of observations. Rauzon weighed eggs with a 100-g Pesola spring scale and measured them to the nearest .1 mm with a Vernier caliper. Clapp in the central Pacific measured with a dial caliper.

We used morphometric characteristics to categorize chicks into 6 developmental stages that roughly correspond to weekly growth. These stages are: *Stage 1*—Chick covered with light gray down; weighs less than 10 g; egg tooth present. *Stage 2*—Chick still downy, weighing from 11 to usually less than 25 g; egg tooth may or may not be present. *Stage 3*—Remiges and rectrices begin to appear; egg tooth gone. *Stage 4*—Feathers erupt from pin feathers; pin feathers present on contour tracts. *Stage 5*—Remiges and rectrices well-developed and contour feathers begin to erupt; weight similar to adults. *Stage 6*—Body completely feathered with traces of down on head and back; young is adult size but has not attained adult weight.

We determined growth rates by measuring changes in body weight and changes in the lengths of culmen, tarsi, and wings using standard techniques (Palmer 1962, Pettingill 1970). We took a "long" measure of the tarsus from the articulation of the phalanges to that of the tibiotarsus (Fig. 1) because this is a more repeatable measurement for small, active chicks than the standard tarsal measurement.

We analyzed growth rate data following procedures developed by Ricklefs and White (1975) and Ricklefs and White-Schuler (1978) for constructing growth curves for individual birds of various but unknown ages. These techniques are particularly suitable because Blue-gray Noddies on Nihoa hatch over a protracted period and all stages of chick development are present. We plotted these data to obtain an estimate of daily growth that can be used to estimate ages of chicks with unknown hatching dates.

We collected 15 regurgitations from juvenile and adult birds. Samples were analyzed using standard techniques (Harrison et al. 1983).

RESULTS AND DISCUSSION

Breeding season on Nihoa.—Observations from sporadic visits to Nihoa during 1980–1981 are helpful in determining the breeding season. Clapp found no evidence of nesting on 5 November 1980. On 3 February 1981, 34 (61%) of the nests contained eggs and 22 (39%) contained chicks spanning all growth stages. We estimate that 14 of the chicks were 2–5 weeks old and none was capable of independent flight. No nest contained more than a single egg or chick. A. L. Newman (pers. comm.) found no dependent young in mid-May 1981. The incubation period of the somewhat larger White Tern (*Gygis alba*) and Black Noddy (*Anous tenuirostris*) are 36 days (Dorward 1963) and 35 days (Ashmole 1962), respectively. If, as seems likely, the incubation period of Blue-gray Noddies is of similar duration, the onset of laying at Nihoa commenced in early December and ended no later than mid-March.

Clapp et al. (1977) stated that the Blue-gray Noddy on Nihoa "breeds throughout the year, but the majority of the birds apparently breed during the spring and summer." Fisher (1906) collected 2 eggs "very much incubated" on Nihoa on 1 June 1902. Eggs and/or dependent young have been reported on a number of other visits from June–August (Clapp et al. 1977). Harrison visited Nihoa 5–6 August 1978, and he and Rauzon visited there 23 May 1979, but found no active nests or dependent young on either visit.

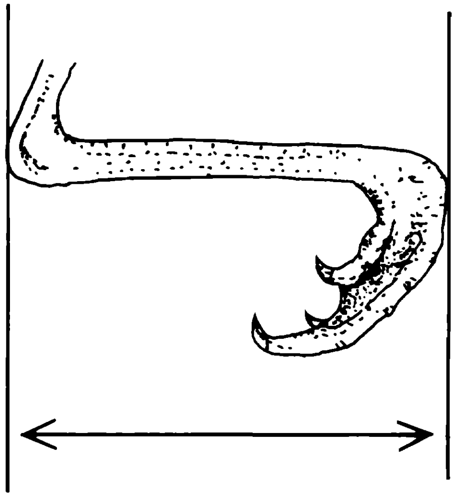

FIGURE 1. "Long" measurement of the tarsus, measuring distance from the articulation of the phalanges to that of the tibio-tarsus.

Weights of adults collected in summer (Table 1) were significantly less than those collected in winter ($P < .001$, ANOVA). The difference suggests that more food may be available for Blue-gray Noddies in winter and may partially explain the timing of the breeding season on Nihoa.

Breeding seasons elsewhere.—Data on breeding of Blue-gray Noddies elsewhere in the Northwestern Hawaiian Islands are scant. Our own observations and those compiled by Clapp and Kridler (1977) suggest that the breeding season on Necker Island, near Nihoa, is similar to Nihoa.

The breeding season near the equator in the central Pacific is reasonably consistent from area to area, but apparently varies among colonies in duration and peak. Schreiber and Ashmole (1970) indicated that the breeding season on Christmas Island (1°52'N, 157°20'W) was usually May–December with a peak August–November. Rauzon found nests on Christmas Island with eggs in late July 1982. At their principal colonies in the central Pacific, McKean (3°36'S, 174°08'W) and Phoenix (3°43'S, 170°43'W) islands, Blue-gray Noddies apparently breed during all months (Table 2). We suggest that McKean and Phoenix populations usually have a breeding peak June–August with much reduced breeding December–April. The span of breeding appears to be similar, but perhaps more protracted than that on Christmas Island, but the peak is somewhat earlier.

In the Kermadec Islands, southwestern Pacific, Soper (1969) found breeding "well-advanced . . . all stages were present from eggs to flying young" during mid-November.

TABLE 1. Comparison of weights of adult Blue-gray Noddies from Nihoa with those from other areas in the Pacific.

Island	n	Time of year	x̄ (g)	SD	Range
Nihoa	30	February	57.9	5.3	51.0–69.0
Nihoa	52	Summer	53.1	3.6	46.5–65.0
Phoenix	10	Late January	52.3	3.5	45.3–58.0
Tutuila[a]	5	Late February	49.8	4.8	45.0–57.0
Fanning	4	Mid-March	45.8	4.4	41.0–51.4
McKean	10	Late April	51.6	3.4	47.0–57.0
McKean	16	Late October	46.0	3.0	41.0–51.0
Christmas	5	Late November	51.2	4.4	45.5–55.6

[a] American Samoa.

The nest.—Blue-gray Noddies in Hawaii apparently nest only in cliffs and rocky outcrops. Cliff faces in the lee of northwestern cyclonic storms and northeastern trade winds are preferred. Blue-gray Noddies form loose nesting aggregations dictated in part by the proximity of cavities within lava flows; isolated cavities are not selected. Rudimentary nests of twigs and bird bones are constructed on the floors of the nest site. Accumulations of guano suggest that sites are repeatedly occupied for roosting or nesting.

Nests on Christmas Island occur on coral rubble (Schreiber and Ashmole 1970) and those in the Kermadec Islands beneath tussock grass (Soper 1969). Nests in the Phoenix Islands are in small cavities in rock walls, on the ground under slabs of coral, or under vegetation. Of 20 nests found during a survey of Phoenix Island, 10 were beneath clumps of *Lepturus repens*, 3 under *Portulaca lutea*, and 4 under clumps of dried *Boerhavia repens*. Eggs are usually placed less than .3 m from access to the sky, but 1 egg on Phoenix was concealed at least 1 m back under a coral slab.

Eggs.—Thirty-five eggs were measured for length, width, and weight. One of these was a runt as defined by Koenig (1980) and was excluded from the sample. Egg volumes were derived from these means using the expression $V = K (LB^2)$ as derived for seabirds by Stonehouse (1963), where $K = .512$, L = maximum length, and B = breadth or maximum diameter. Eggs from Nihoa are significantly larger in length, breadth, and weight compared with those from Christmas, McKean, and Phoenix islands (ANOVA, $P < .001$ for each test; Table 3). Eggs from the Kermadec Islands are also larger than those from the central Pacific, but without the original data we cannot determine whether the difference is statistically significant. The average weight of 51 eggs from all stages of development on Nihoa was 14.4 g (SD = 1.2, range 12.0–17.0). Eggs lost .5–2.0 g during 12.5 days ($n = 14$, $\bar{x} = .75$, SD = .64).

Reproductive success.—Six of the initial 35 eggs failed to hatch during the study period and 4 chicks died of unknown causes during early stages

TABLE 2. Nesting phenology of Blue-gray Noddies on McKean and Phoenix islands.

	1963		1964		1965			
	Oct	Feb	Jul	Oct	Feb	May	Jul	Oct
Phoenix	E&C +++		E&C +++	E&C +++		E&C +++		E&C +++
McKean	E&C +++		E +++	C +++	E +		E +++	E&C ++
	1966				1967		1968	1973
	Apr	Jul	Oct	Dec	Jan	Jul	Oct	Jun
Phoenix	E +		E&C +++	E&C ++	E&C ++			E&C +++
McKean		E +++				E +++	C +	

E = eggs + = few
C = chicks ++ = common
+++ = numerous

of development. Two eggs cracked in the nest cavity and 4 were abandoned. One abandoned egg showed evidence of predation by Nihoa Finches (*Telespyza ultima*), but no predation of incubated eggs occurred. Laysan Finches (*T. cantans*) cause considerable egg loss to nesting terns on Laysan Island (Ely and Clapp 1973).

Because we could not follow all marked nests through fledging, we cannot precisely estimate reproductive success. Fifteen of the initial 35 eggs hatched, 6 were lost, and 13 were still being incubated at the conclusion of our study. Dorward (1963) reported 34% and 46% of the White Tern eggs laid on Ascension Island hatched in 2 consecutive years. Of the initial 22 chicks when our study began, 8 were newly hatched and 14 were 2–4 weeks old. Of the 15 additional chicks that hatched, 3 died of unknown causes in early stages of development. Only 1 older chick in the initial group perished. The mortality rate of all chicks was 10.8%. At the end of the study, 14 chicks were in the first 3 stages of growth and 18 were in the latter 3 stages. Two were older than 6 weeks, fully feathered with smaller than adult mean wing lengths.

Our incomplete data probably estimate nesting success that is too high. We applied Mayfield's (1975) technique to estimate nest-day success. Although Mayfield treated incubation and nestling periods separately, we pooled these. From 10 losses during 638 nest-days of observations, we estimate the mortality to be .016% per nest-day. The survival rate of any nest was $1 - .016 = .984\%$ per nest-day. Multiplying this estimate by the number of nest-days yields an overall survival rate of 90%. This estimate excludes losses early in egg laying or incubation.

TABLE 3. Comparison of lengths, breadths, and calculated egg volumes for populations[a] of Blue-gray Noddies.

Island	n	Length			Breadth			Volume		
		$\bar{x}$ (mm)	SD	Range	$\bar{x}$ (mm)	SD	Range	$\bar{x}$ (cc)	SD	Range
Nihoa	34	40.2	1.49	37.7–44.9	27.7	0.59	26.9–29.0	15.8	0.85	14.4–17.4
Christmas	43	37.8	1.34	35.1–40.1	26.4	0.71	24.3–28.4	13.7	1.00	11.0–16.3
Phoenix	9	38.1	1.56	36.0–40.6	26.1	0.55	25.2–27.1	13.3	0.88	12.2–14.6
McKean	20	38.1	1.42	36.2–41.0	26.1	0.62	25.1–14.8	13.3	0.95	11.8–14.8
Kermadec[b]	21	42.9	1.10	40.9–45.7	28.9	0.60	27.1–30.2	—	—	—

[a] The Blue-gray Noddies on Christmas Island belong to the nominate race, those from the Phoenix Islands to *P. c. nebouxi*, and those from the Kermadecs to *P. c. albivitta* (Peters 1934).

[b] Soper (1969).

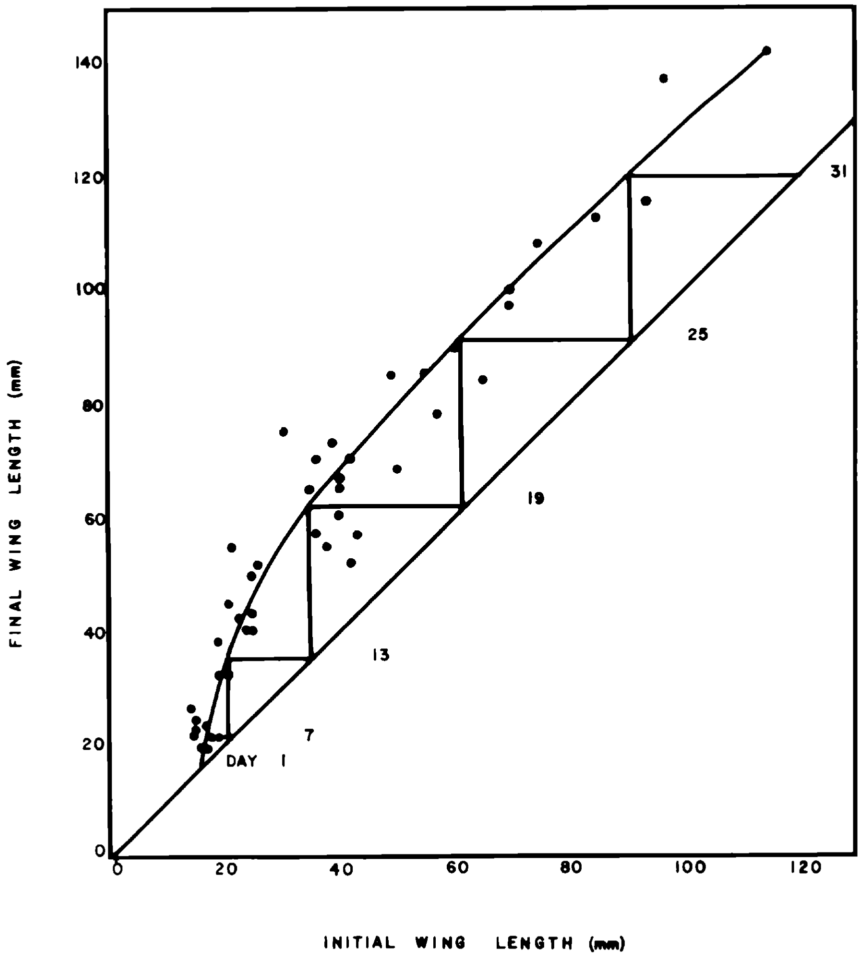

FIGURE 2. Relationship of wing lengths in Blue-gray Noddies measured each 6 days on Nihoa. Vertical and horizontal lines are used to derive age-growth relationship. Curve fitted by eye. See text.

Development of nestlings.—At hatching, chicks are covered with light gray down similar in color to adult plumage. Parents continually brood chicks until the down begins to be replaced by pin feathers during the third week, when wings and tail feathers erupt from their sheaths. Scapulars erupt during the fourth week, and by the sixth week only traces of down remain on the head and neck.

Wing growth.—Because visits to Hawaiian colonies of Blue-gray Noddies are brief and opportunistic, we used a method developed by Ricklefs and White (1975) and Ricklefs and White-Schuler (1978) to determine

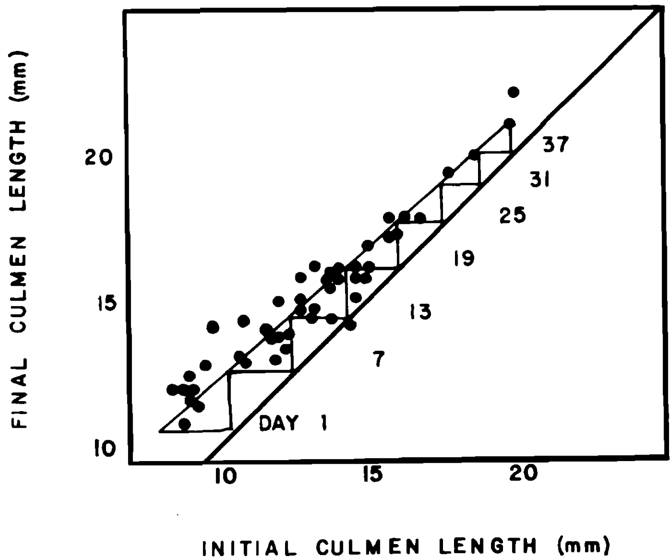

FIGURE 3. Relationship of culmen lengths in Blue-gray Noddies measured each 6 days on Nihoa. See Fig. 2 and text.

the age of chicks for future visits. We plotted 45 wing lengths measured at the first encounter as a function of wing length 6 days later (Fig. 2). To determine the rate of growth, a smoothed curve was drawn by eye through the plotted points. We drew alternating vertical and horizontal lines beginning at the smallest recorded hatching measurements and progressing up between the curve and the diagonal which represents zero growth. The age of a chick can be estimated by locating its wing length on the curve and referring to the corresponding point on the diagonal marked in weekly growth increments.

Wing growth of Blue-gray Noddies is initially slow but accelerates as the primaries develop. Because wings do not grow at a constant rate, this technique provides only a rough estimate of age (LeCroy and LeCroy 1974).

Culmen growth.—The culmen grew steadily and continuously after hatching, with growth slowly decreasing as adult wing length was reached (Fig. 3). In contrast, the culmen of Black Noddies continues to grow after the wings have matured (Ashmole 1962). Figure 4 may be used to estimate age of chicks in the method described above for wings. Culmen lengths, when used in conjunction with wing lengths, provide a more reliable estimate of age (Ricklefs and White 1975). Initial culmen growth compensates for the lag in wing development, while the later feather growth compensates for the lag in culmen development.

Tarsal growth.—The rate of tarsal growth roughly parallels the rate of culmen growth, yet the scatter of points prevents age comparisons.

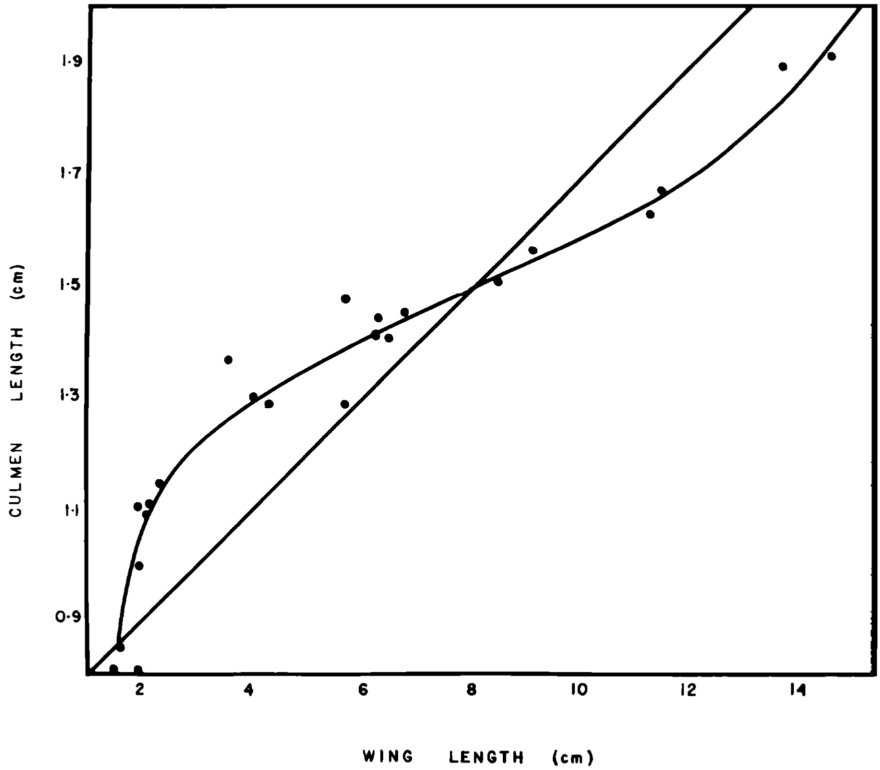

FIGURE 4. Relationship between wing and culmen lengths in Blue-gray Noddies on Nihoa. Curve fitted by eye.

Weight change.—Variation in the size of newly-hatched chicks and their meal sizes may lead to considerable differences in weights of chicks of the same age (LeCroy and LeCroy 1974, Ricklefs and White 1975). We present weights of different stages of development (Table 4). The greatest increase in mean weight occurred during stage 5 when chicks became slightly heavier than adults. Five stage 6 chicks lost an average 4.1 g. The difference in weight between stages 5 and 6 is significant ($P < .001$, ANOVA).

FOOD HABITS AND FEEDING BEHAVIOR

Breeding Blue-gray Noddies ate many larval lizard fishes (Synodontidae), flounders (Bothidae), and goatfishes (Mullidae) (Table 5). Shrimps and small squids were also important components of the diet. During May and June, Blue-gray Noddies consume large numbers of sea-striders (*Halobates sericeus*), (Cheng and Harrison 1983); we found some in the February samples. Flyingfishes (Exocoetidae), copepods, and goatfishes are much more important during spring and summer months (Harrison et al. 1983) than they are during February.

TABLE 4. Weights (g) and measurements (cm) of Blue-gray Noddy growth stages.[a]

		Weight		Culmen		Tarsus (long)		Wing	
Stage	n	x̄	SD	x̄	SD	x̄	SD	x̄	SD
Newly hatched	1	5.0	—	0.9	—	1.7	—	1.5	—
1	11	9.9	3.8	1.0	0.06	1.7	0.15	1.6	0.25
2	19	23.2	4.5	1.2	0.07	2.1	0.14	2.1	0.32
3	17	37.6	6.1	1.4	0.09	2.5	0.15	4.1	1.08
4	14	49.3	4.6	1.5	0.11	2.6	0.10	6.4	1.65
5	11	57.4	7.6	1.7	0.14	2.7	0.16	9.1	1.70
6	5	53.3	6.2	2.0	0.10	2.7	0.05	14.6	0.71
Adult	30	57.9	5.3	2.6	0.10	2.7	0.11	17.6	0.60

[a] See text for description of growth stages.

Blue-gray Noddies elsewhere also eat minute prey, but species differ with location. On Christmas Island, they eat larval fishes, copepods, and sea-striders (Ashmole and Ashmole 1967). Small crustaceans have been reported as principal prey items on Lord Howe Island (Oliver 1930), the Kermadecs (Soper 1969), and Chile (Murphy 1936). Our data from McKean and Phoenix islands indicate a diet of small fishes and sea-striders there.

Ashmole and Ashmole (1967) suggested that Blue-gray Noddies are unique among oceanic seabirds in being significantly insectivorous and in not being dependent upon predatory fishes to drive prey to the surface. Our information suggests that feeding on sea-striders may be somewhat seasonal at Nihoa Island. Cheng and Schulenberger (1980) stated that sea-striders are most abundant in 24–28°C water. Because water temperatures near Nihoa are generally 22.5–25°C during winter (Armstrong 1983), this insect may not be readily available until waters become warmer during spring.

Rauzon observed a flock of 20 Blue-gray Noddies foraging within 2 km of Nihoa, repeatedly dipping into the surface. Clapp observed others feeding in a mixed flock just offshore Fanning Island (Line Islands) and partitioning the air space between themselves and Black Noddies. The Blue-gray Noddies hovered at the water's surface dipping to pick up evidently small items from the water's surface while Black Noddies hovered and dove from heights of 2–3 m to seize food at or just below the surface of the water. Soper (1969) described the feeding behavior in the Kermadec Islands as "hovering and fluttering, repeatedly dipping. They never alighted and apparently never got their feet wet." Young were fed by regurgitation at Nihoa and in the Phoenix Islands; at no time were adults seen carrying food in the bill.

SUMMARY AND CONCLUSIONS

Blue-gray Noddies, the smallest marine terns, are similar in many respects to all tropical terns in Hawaii: single-egg clutches are laid,

TABLE 5. Diet of the Blue-gray Noddy on Nihoa Island during February 1981 (15 samples).

Prey	Number of organisms	Percent of samples in which occurred	Average percent volume
Fishes			
Bothidae			
Bothidae larvae	6	6.7	2.8
Unidentified bothid	12	33.3	6.5
Exocoetidae	1	6.7	0.5
Gempylidae			
Gempylus serpens	2	13.3	1.8
Gobiidae			
Ptereleotris heteropterus	2	13.3	1.1
Unidentified gobiid	1	6.7	0.5
Mullidae	8	20.0	7.7
Nomeidae			
Nomeus gronovii	1	6.7	0.6
Unidentified nomeid	1	6.7	0.2
Ostraciontidae			
Lactoria fornasini	1	6.7	0.5
Scomberesocidae	1	6.7	0.2
Synodontidae			
Trachinocephalus myops	1	6.7	0.1
Unidentified synodontid	60	80.0	22.0
Unidentified fishes	483	46.7	18.0
Mollusca			
Unidentified squid	15	40.0	3.9
Crustacea			
Mysidacea	7	13.3	0.6
Euphausiacea	6	20.0	0.9
Stomatopoda	3	13.3	0.5
Coronida sp.	8	6.7	2.6
Shrimp			
Sergestidae	22	6.7	1.1
Unidentified shrimps	23	60.0	6.0
Crab megalopa	3	13.3	1.4
Insecta			
Halobates sericeus	5	13.3	1.9
Unidentified remains	1	6.7	0.3

growth and development take about 7 weeks, breeding is colonial. Its small size results in eggs that comprise over 27% of adult body weight, compared to 15–20% for most marine terns (Langham 1983). Blue-gray Noddies are widespread in the tropical Pacific, but populations are generally small. This may be the result of its inshore feeding habits and the fact that it is a resident species (Diamond 1978). However, populations in the Hawaiian Archipelago are probably limited by the availability of suitable nest sites in cliffs or rocky outcrops, not food supplies.

Food habits in Hawaii confirm the unique dependence of this species on sea-striders, but consumption may be seasonal. Blue-gray Noddies take the smallest prey of any seabird in Hawaii and may feed on a lower trophic level.

The Hawaiian population is apparently heavier and produces larger eggs than Blue-gray Noddies elsewhere in the Pacific. This conforms with the general proposition that Hawaiian seabirds are larger than those in the central Pacific (Harrison et al. 1983). The Hawaiian population also has a more predictable breeding season than those farther south. This may be due to a greater seasonality of food supply, but the factors that control the timing of breeding are not clear. There does not appear to be any competition for nest sites with other seabirds.

Our information on growth and development will enable future investigators to estimate the ages of chicks during brief visits to Blue-gray Noddy colonies. This will facilitate programs that are designed to monitor the basic health of seabird populations and to detect changes from baseline that may result from human activities or oceanographic conditions.

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