THE STATUS OF SEABIRD RESEARCH IN THE NORTHWESTERN HAWAIIAN ISLANDS

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ABSTRACT

The five-year objectives of the U.S. Fish and Wildlife Service (FWS) are to enumerate Northwestern Hawaiian Islands seabird populations, inventory food utilized, locate major feeding areas, and determine consumptive rates. To date, preliminary assessment of populations has begun and a comprehensive food habits study is nearing completion. The 3,000 food samples from 18 seabird species analyzed thus far indicate that most birds feed opportunistically on shoaling fish and squid. The fish families Exocoetidae, Mullidae, Carangidae, Synodontidae, Dussumieriidae, Coryphaenidae, Molidae, and Holocentridae and the squid family Ommastrephidae appear to be especially important. Prey length data indicate that most terns and shearwaters feed on prey species in the 2 to 8 cm range and that boobies feed in the 10 to 20 cm range. An encouraging feasibility study using radiotracking with the brown noddy on Oahu resulted in a technique to locate feeding areas. Future objectives include completion of food studies and refinements of population estimation techniques. Information gaps still include location of feeding areas and knowledge of consumptive rates of seabirds. We need a better understanding of life histories, age structure, and annual production of important prey items including Ommastrephidae, Exocoetidae, Mullidae, and Synodontidae.

Northwestern Hawaiian Islands
seabirds
feeding ecology

INTRODUCTION

Seabirds are a relatively poorly studied group of birds. They can be characterized as being relatively long-lived, displaying deferred maturity, reproducing slowly, and possessing salt excretion glands which enable them to drink salt water (Bourne, 1963; Lack, 1967). Most species spend most of their lives at sea, but the fact that they must return to land to breed emphasizes the fact that they are terrestrial expatriates. Hutchinson (1950) contends that seabirds perform an important function for reef communities by concentrating nutrients in a localized area.

Large portions of the worldwide breeding range of the black-footed albatross (Diomedea nigripes), Laysan albatross (D. immutabilis), Bonin petrel (Pterodroma hypoleuca), Christmas shearwater (Puffinus nativitatus), sooty storm-petrel (Oceanodroma tristrami), blue-gray noddy (Procelsterna cerulea), and gray-backed tern (Sterna lunata) are within the Northwestern Hawaiian Islands (NWHI). Additionally 11 breeding species occur in the archipelago with total numbers of seabirds being estimated at 10 million birds. Seabird populations have plummetted when fisheries directly competed with birds for the same prey species in Peru (Idyll, 1973), South Africa and Southwest Africa (Crawford and Shelton, 1978), and possibly California (Ainley and Lewis, 1974). Recent fishery-seabird models indicate that birds may be unable to produce young if forage fish fall to 70% of virgin levels (MacCall, 1980). Tropical seabirds generally feed at the surface, or in the case of some birds of the order Pelicaniformes, within the first few meters. Ashmole and Ashmole (1967) contend that large predatory fish, especially scombrids, are important because they drive prey to the surface and make them available to the birds.

The internationally recognized importance of the NWHI seabird resource and the potential for adverse impacts from improperly managed fisheries in other parts of the world prompted the U.S. Fish and Wildlife Service to agree to enumerate NWHI seabird populations, inventory food utilized, locate major feeding areas, and determine consumptive rates. Crawford and Shelton (1978) point out, "The interrelationships of pelagic fishery and seabird populations signify the overriding importance of sound fishery management for other ecosystem components."

METHODS

The remoteness of the Nihoa to Kure study area has made access a major problem. Cruises on the R/V Townsend Cromwell, military air command flights to Midway, U.S. Coast Guard flights to Kure, and recent FWS involvement on Tern Island have provided sporadic opportunities to study the marine bird resources. In addition, field camps on Laysan Island from March to August in 1979 and 1980 have provided an opportunity to intensively follow reproductive biology, collect monthly food samples, and make detailed population estimates.

The variety of studies carried out to date precludes a detailed description of techniques and methods. Population assessments have been made with several techniques including direct counts and stratified random sampling. All food samples have been collected on the islands by utilizing generally non-lethal techniques. Approximately 100 Bonin petrels and Bulwer's petrels (Bulweria bulwerii) had to be sacrificed due to inabilities to induce regurgitation. In the laboratory, standard analytical techniques including sorting, identification, counting, volumizing, and measuring standard lengths were carried out (Ashmole and Ashmole, 1967). A telemetry project utilizing a 5.4 g transmitter package is described in detail in a forthcoming publication (Harrison and Stoneburner, in preparation). Reproductive biology, phenology, incubation shifts, and chick feeding intervals on Laysan Island were carried out with standard observation techniques, details of which will appear in forthcoming publications.

RESULTS AND DISCUSSION

It cannot be overemphasized that all statements and conclusions are tentative in this continuing study. Population estimates will be refined. Subtleties of feeding habits, including a somewhat different assessment of critical prey items, may well turn up when geographic and seasonal considerations are explored and the entire data base is accessible with automatic data processing techniques.

Populations

Seabird populations, like any real population of wild animals, are dynamic over time. This volatility is confounded by the fact that estimation techniques for some species are inherently imprecise. For example, cliff nesting blue-gray noddies and white terns (*Gygis alba*) on Nihoa and Necker are extremely difficult to census without low level aerial photographic capabilities. Sooty terns (*Sterna fuscata*) can be censused effectively only when incubating eggs. Adults scatter when an investigator enters a colony and once eggs hatch, chicks form crèches and density estimates become very imprecise. Given the propensity of this species to lay in sub-colonies over a 6 to 8-week period, an accurate census is only possible on a particular island by placing investigators at that location for at least a month during spring. Counts of roosting red-footed boobies (*Sula sula*) and black noddies (*Anous tenuirostris*) peak at approximately 0400 and censuses at other times of the day underestimate, often grossly, the true numbers of birds in a colony. On sandy atolls, nests or immobile young, e.g., albatross, are generally the easiest birds to census. This technique ignores large numbers of non-breeding birds which roost at a colony and forage in the vicinity. The attachment of pre-breeders and failed breeders to a colony is insufficiently understood for any species, but is necessary to determine true colony size and concomitant requirements for nearby marine food resources. Burrow nesting birds such as Bonin petrels and wedge-tailed shearwaters (*Puffinus pacificus*) also present special problems. Burrows can be easy to census if not crushed in the process, but may extend far underground and must be excavated in order to determine occupancy. It is a goal for the second half of this study to develop repeatable census methodologies for each species and habitat.

Table 1 presents our best present estimates of NWHI seabird populations and, additionally, mean adult weights for each species. Most bird weights are from Laysan Island and represent a sample size of approximately 50 adult weights per species. NWHI birds are generally heavier than birds from Christmas Island (Pacific Ocean) as reported by Ashmole and Ashmole

TABLE 1. POPULATION ESTIMATES AND ADULT WEIGHTS, NORTHWESTERN HAWAIIAN ISLANDS

	Nihoa	Necker	FFS	Gardner P.	Laysan	Lisianski	P & H	Midway	Kure	Mean weight (kg)
Black-footed Albatross	100	350	4,700	0	67,000	3,500	14,000	30,000	600	2.6
Laysan Albatross	tr	1,800	1,600	tr	550,000	8,000	45,000	500,000	2,400	2.4
Bonin Petrel	0	0	750	0	40,000	1,000,000	1,000	10,000	2,500	0.178
Bulwer's Petrel	250,000	200	500	tr	20,000	tr	tr	0	0	0.101
Wedge-tailed Shearwater	25,000	4,500	13,000	tr	1,000,000	500,000	26,500	20,000	1,500	0.390
Christmas Shearwater	800	0	tr	0	10,000	2,000	tr	100	tr	0.362
Sooty Storm-Petrel	tr	0	tr	0	2,500	0	7,500	0	0	0.084
Red-tailed Tropicbird	500	200	450	100	4,000	4,500	200	3,000	2,000	0.630
Masked Booby	350	500	1,200	800	2,000	1,200	600	20	100	2.2
Red-footed Booby	3,500	1,400	750	tr	2,500	3,000	200	1,000	600	1.1
Brown Booby	225	50	135	20	250	200	200	tr	100	1.3
Great Frigatebird	10,000	2,000	1,400	250	8,000	2,500	900	200	500	1.4
Sooty Tern	100,000	50,000	250,000	750	2,000,000	1,700,000	80,000	50,000	12,000	0.209
Gray-backed Tern	10,000	7,500	1,750	4,000	40,000	15,000	1,900	50	100	0.147
Blue-gray Noddy	2,500	2,500	tr	tr	tr	0	0	0	0	0.045
Brown Noddy	20,000	50,000	10,000	5,000	30,000	15,000	8,400	3,000	1,200	0.208
Black Noddy	2,000	1,000	11,000	400	5,000	5,000	4,300	5,000	2,000	0.107
White Tern	3,000	600	3,700	400	1,500	500	tr	6,000	tr	0.112

Note: tr = trace

(1967). Most population data are taken from the Atoll Research Bulletin series (Amerson, 1971; Amerson et al., 1974; Clapp, 1972; Clapp and Kridler, 1977; Clapp et al., 1977; Clapp and Wirtz, 1975; Ely and Clapp, 1973; Woodward, 1972). Our data have generally corroborated these estimates, but some changes will undoubtedly be forthcoming at the conclusion of this study. Revisions will reflect both genuine population changes and improved census technology. Estimates for Midway are our own. The largest concentrations of total birds and avian biomass occur on Laysan, Lisianski, and Midway. Midway's populations have been reduced by large scale habitat destruction and the introduction of *Rattus rattus*.

Food habits

Published accounts of feeding habits of tropical Pacific seabirds are limited. Ashmole and Ashmole (1967) provided data for 8 Christmas Island species (N = 800) and Schreiber and Hensley (1976) added 3 additional species for the same study area (N = 175). Table 2 lists samples collected by species and month through November 1979. This study is the most comprehensive tropical seabird work yet attempted. We expect to have

TABLE 2. TOTAL FOOD SAMPLES COLLECTED JANUARY THROUGH NOVEMBER 1979

SPECIES	MONTH												TOTAL
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Black-footed Albatross		41	12	28	42	3							126
Laysan Albatross	1	15	20	30	50	4	1						121
Bonin Petrel			5	36	51								92
Bulwer's Petrel					20	13	10	27					70
Wedge-tailed Shearwater					20	19	13	19	11	7	24		113
Christmas Shearwater			4	3	22	11	28	39	7				114
Sooty Storm-Petrel				7	1								8
Red-tailed Tropicbird		4			31	25	63	51	22	18			214
Masked Booby			11	16	42	10	12	33	2	3	15		144
Red-footed Booby	13	25	15	10	55	11	18	41	14	15	22		239
Brown Booby			4	10	25	8	20	27			21		115
Great Frigatebird		5	5	15	50	11	14	19	7	12	6		144
Sooty Tern			7	21	99	27	28	79	9				270
Gray-backed Tern			7	23	88	10	5	33					166
Blue-gray Noddy					42			1					43
Brown Noddy			14	14	69	4	70	61	3	9	1		245
Black Noddy	17	8	8	31	95	13	79	45	15	37			348
White Tern	4	6	2	4	34	23	18	61	28	11	5		196
TOTAL	35	104	114	248	836	192	379	536	118	112	94	0	2768

adequate sample sizes for all breeding NWHI species except for the sooty storm petrel, but the extremely digested sample condition makes it difficult to provide as much information as we had hoped for the Bulwer's petrel and the Bonin petrel. Data presented here are generally based on sample sizes of 30 to 50 per species and ignore potentially important differences in year, season, and location. We suspect seasonal changes may be very important. Continuing collections are designed to fill information gaps in geography and season.

NWHI seabirds feed on fish, squid, and arthropods. By volume, the blue-gray noddy feeds on the highest percentage of arthropods (25%), especially the insect Halobates sp. Remaining species feed on no more than 8% of this phylum. Procellariiformes (albatross, shearwaters, and petrels) feed on slightly more fish than squid by volume, except for the Laysan albatross (70% squid) and the Bonin petrel (86% fish). The Pelicaniformes (boobies, tropicbirds, and frigatebird) feed almost exclusively on fish (>93% by volume) except for the red-footed booby (Sula sula) (Figure 1). Terns feed predominantly on fish with the

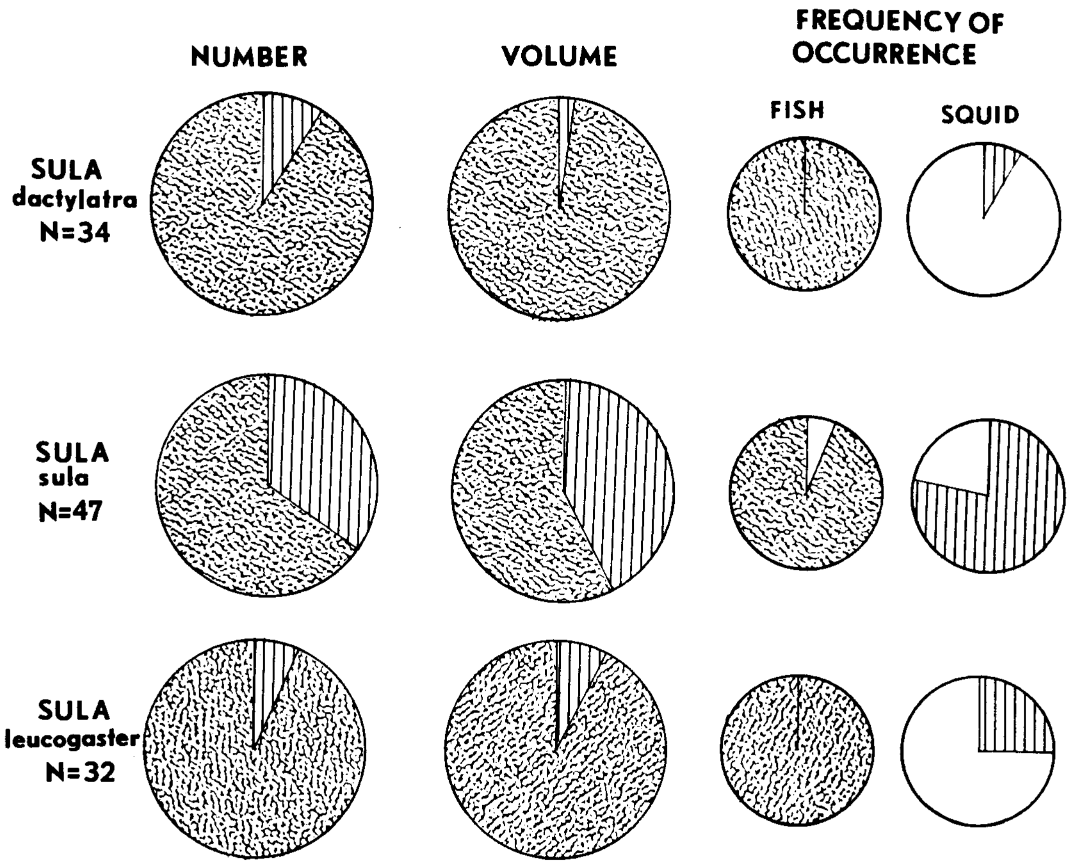


Figure 1. Relative importance of fish (stippled) and squid (lined) in diets of 3 boobies

exception of the sooty tern which feeds on 38% fish and 62% squid. Generally, NWHI seabirds eat a greater percentage of fish than species on Christmas Island.

Table 3 presents a ranking of important fish families in NWHI seabird diets. The rankings are obtained by use of the formula developed by Pinkas et al. (1971) in which

$$IRI = F(N+V)$$

where

IRI = Index of Relative Importance
F = Frequency of Occurrence
N = Numerical Percentage
V = Volumetric Percentage

We agree with their contention that while this equation may not be the last word in assessment of importance of prey items, it is superior to the exclusive use of any one of the commonly calculated statistics which comprise it. Rankings may change with time of year and locality, but at present we recognize the flying fish (Family Exocoetidae, especially *Exocoetus volitans* and *Cypselurus* spp.), the jacks (Family Carangidae, almost entirely *Decapterus* spp.), and the goatfish (Family Mullidae) to be of outstanding importance. Inshore feeding birds are marked with an asterisk in Table 3. Additional important forage families for this group are Dussumieriidae (*Spratelloides delicatulus*), Synodontidae (lizardfish), and Coryphaenidae (both species of mahimahi).

Squid are almost entirely of the family Ommastrephidae, and include the genera *Ommastrephes*, *Symplectoteuthis*, and *Hyaloteuthis*.

Figures 1, 2, and 3 portray feeding comparisons of three congeneric boobies, the masked booby (*Sula dactylatra*), the red-footed booby (*Sula sula*), and the brown booby (*Sula leucogaster*). These figures portray percentages of the major prey groups (number, volume, frequency of occurrence), comparative use of fish families, and comparative lengths of fish consumed. An upcoming monograph will display data for all species and compare localities and seasons where appropriate.

Seabird diets are complex and not easy to generalize in the NWHI. They feed opportunistically on surface shoaling fish and squid and occasionally supplement this diet with crustaceans and insects. They have evolved to utilize an assemblage of prey species, which may help to moderate the vicissitudes of the sub-tropical marine environment. The presence of mid-water fish such as lanternfish (Myctophidae) and hatchetfish (Sternoptychidae) suggest that some species feed nocturnally or crepuscularly, but direct observations are lacking except for sooty terns and wedge-tailed shearwaters (Gould, 1967). Many NWHI populations have apparently evolved breeding chronologies to take advantage of seasonally abundant fish larvae and juveniles of Mullidae, Synodontidae, and Holocentridae.

TABLE 3. RANKED IMPORTANCE OF FISH FAMILIES IN NWHI SEABIRD DIETS

Seabird	Carangidae	Coryphaenidae	Dussumieriidae	Engraulidae	Exocoetidae	Gempylidae	Holocentridae	Molidae	Monacanthidae	Mullidae	Myctophidae	Nomeidae	Ostraciontidae	Scombridae	Synodontidae
Black-footed Albatross					1										
Laysan Albatross					1			2							
Bonin Petrel										1	2				
Wedge-tailed Shearwater	3								2	1					
Christmas Shearwater	2				1					3					
Red-tailed Tropicbird	2	4			3			1							
Masked Booby	2				1									3	
Red-footed Booby	3			2	1										
Brown Booby *	2				1					3					
Great Frigatebird	2				1										
Sooty Tern	5				2	4	3			1					
Gray-backed Tern *	4		1		3					6		2	5		
Blue-gray Noddy *					3					1					2
Brown Noddy	3		6		7	5	4			1					2
Black Noddy *			4		2					1					3
White Tern *		3			2					1					

*Inshore feeding birds

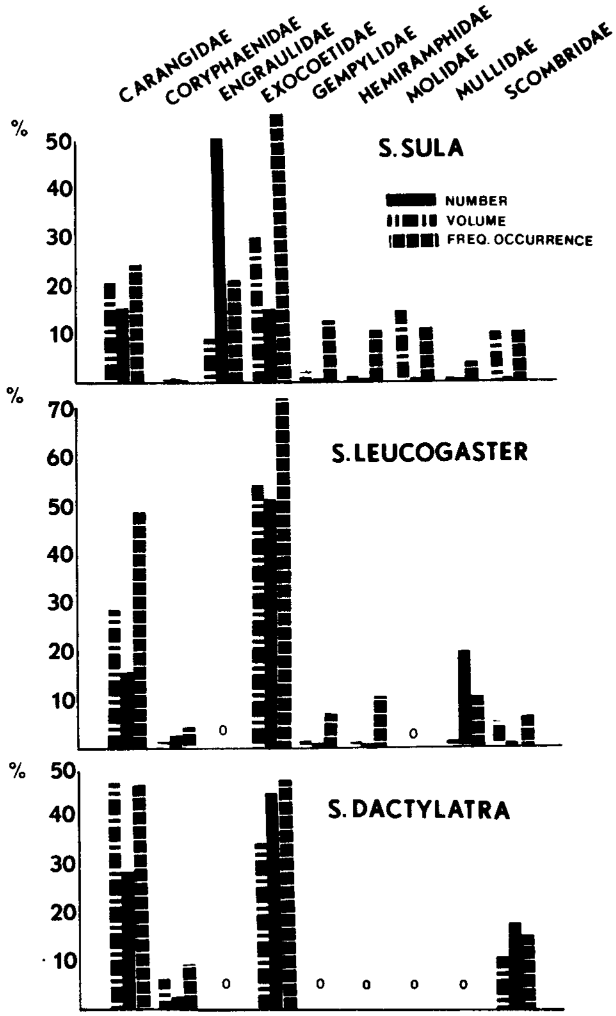


Figure 2. Comparison of fish families preyed on by three booby species

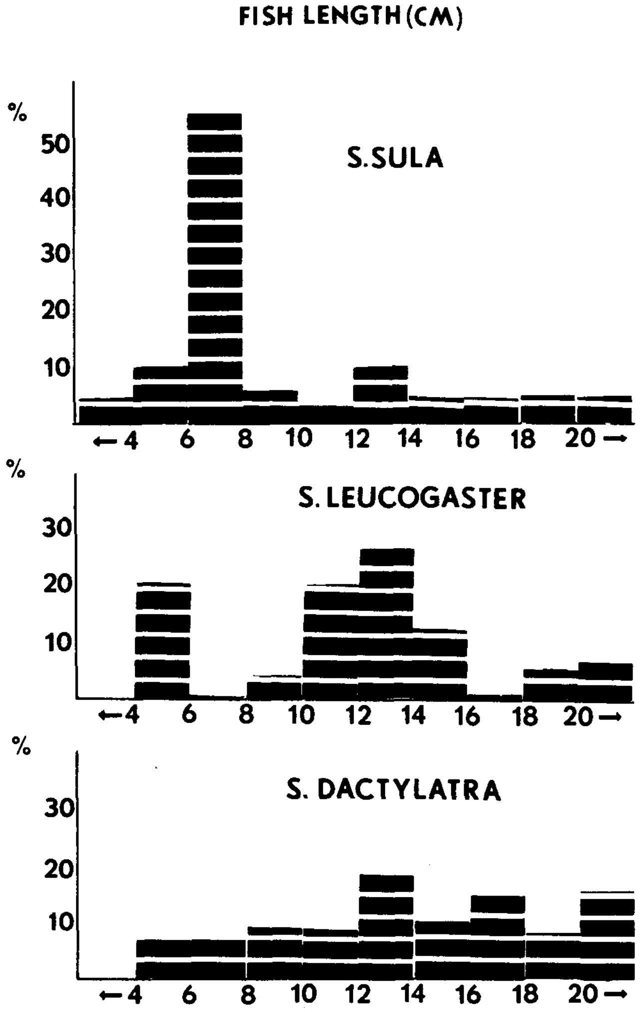


Figure 3. Comparison of fish lengths preyed on by three booby species

Feeding rates

We have no direct information concerning feeding rates. Table 1 lists the first published values for weights of NWHI seabirds. Our Laysan Island studies on growth rates of young, fledging times, and reproductive chronology could be used to determine consumptive rates and the amount of food necessary to raise young if some basic physiological data concerning energy metabolism were available.

Feeding areas

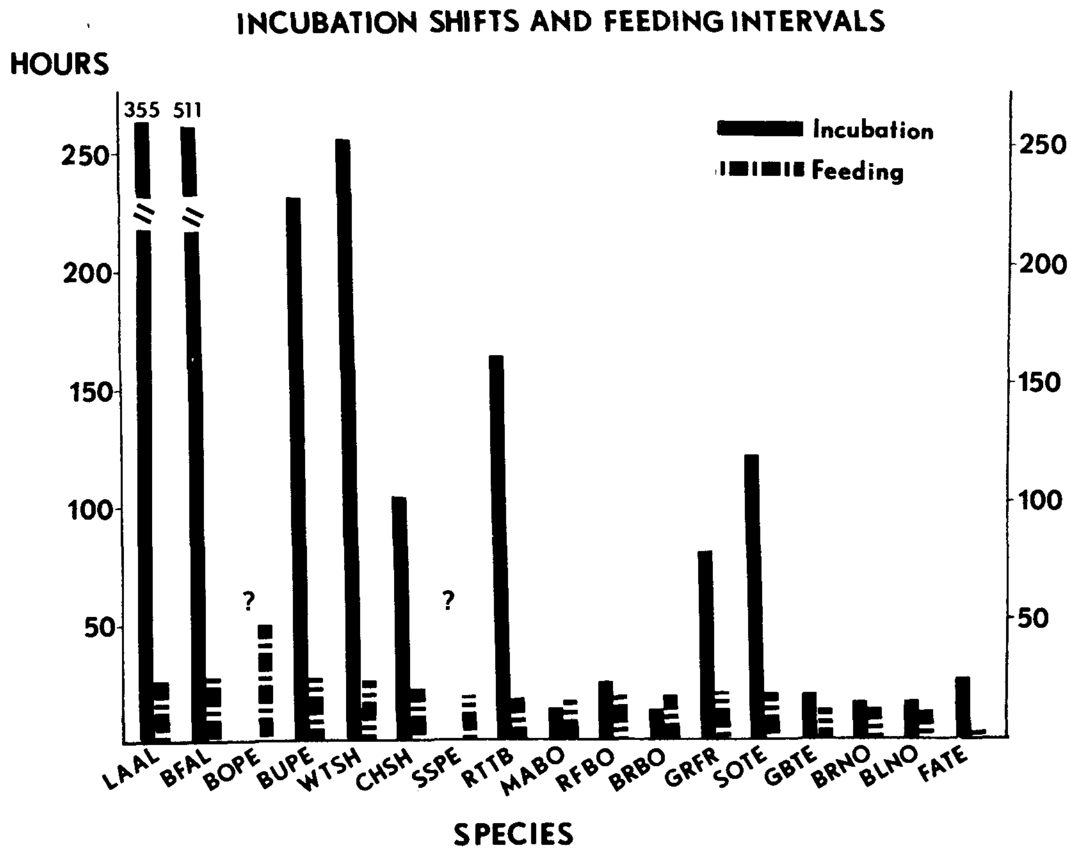
Bourne (1963) stated, "There is clearly a need for more direct observations of where and how birds feed at sea." This situation has not changed in almost two decades. Figure 4 depicts an indirect measure of feeding areas by portraying the lengths of time incubating adults are away at sea during one shift and length of time between feedings for growing chicks. If these times are a true reflection of feeding areas, a sharp contraction of feeding range occurs when the egg hatches. However, we do not necessaily accept the unproven hypothesis that there is a strong correlation between feeding distance and length of time an adult spends away from the colony. For example, two species with vastly different incubation intervals could be feeding in precisely the same area, but one may take longer to locate and obtain its prey.

A feasibility study of radiotracking the brown noddy (*Anous stolidus*) took place on Oahu in September 1979. Although the birds flew beyond our 16-km detection range and consequently we did not learn the precise feeding areas, two important points can be made from Figure 5. The first is that birds of this species do not seek out food in random direction. There is clearly a southerly departing azimuth. The second is that, contrary to views occasionally expressed in the literature, this species does not depart against the prevailing northeast tradewinds and return with them with full stomachs. The fact that Manana Island brown noddies return against the wind indicates southern feeding grounds may be superior to northeastern areas during summer. Aerial location capability in this study would probably have pinpointed feeding areas.

FUTURE RESEARCH NEEDS

The feeding study needs to be completed and data exhaustively analyzed using automatic data processing. Population estimation techniques need to be refined and access to the NWHI during critical times of the year for censusing purposes needs to be assured.

Physiological work exploring energy metabolism of wild and captive birds with concomitant bomb calorimetry of important prey items should make it possible to model marine resource utilization and energy flow for NWHI seabird populations using techniques similar to Wiens and Scott (1976).



LAAL - Laysan Albatross
BFAL - Black-footed Albatross
BOPE - Bonin Petrel
BUPE - Bulwer's Petrel
WTSH - Wedge-tailed Shearwater
CHSH - Christmas Shearwater
SSPE - Sooty Storm-Petrel
RTTB - Red-tailed Tropicbird
MABO - Masked Booby
RFBO - Red-footed Booby
BRBO - Brown Booby
GRFR - Great Frigatebird
SOTE - Sooty Tern
GBTE - Grey-backed Tern
BRNO - Brown Noddy
BLNO - Black Noddy
FATE - Fairy Tern

Figure 4. Comparative lengths of incubation shifts and chick feeding intervals for 17 Northwestern Hawaiian Islands seabird species (Knudtson and Naughton, in preparation)

Effort needs to be directed towards the location of feeding areas. The radiotelemetry work needs to be expanded and aerial survey transects need to be flown using standard techniques (Harrison and Hall, 1978; Harrison, in press) to locate feeding areas for important NWHI colonies.

To assess the importance and seasonality of important prey items in seabird diets, basic life histories and estimates of annual production

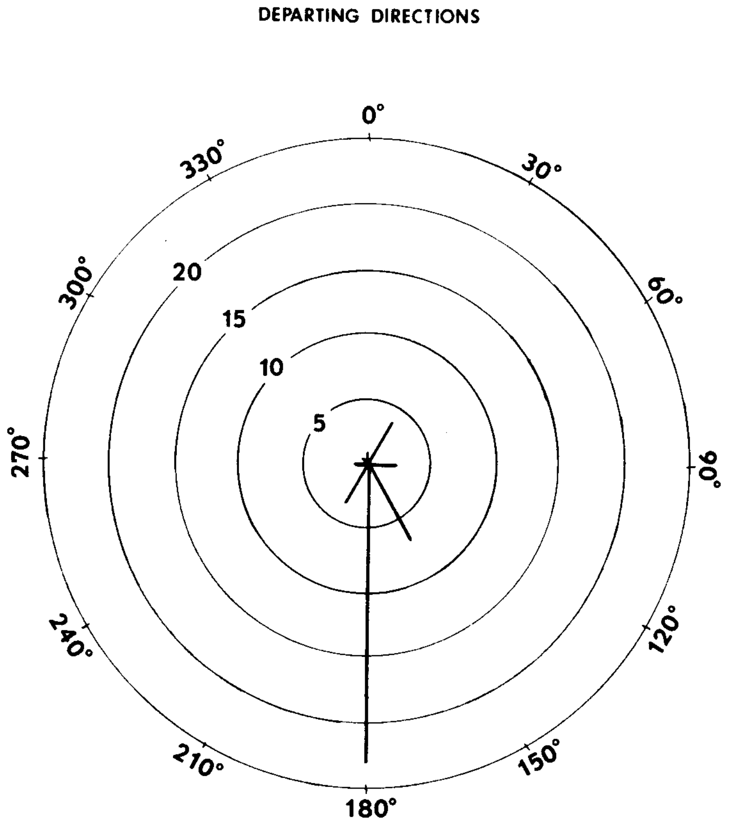


Figure 5. Departing directions of breeding brown noddies from Manana Island. Vector magnitudes signify number of birds detected departing in each 30° sector. (Harrison and Stoneburner, in preparation)

data are needed for Ommastrephidae, Exocoetidae, Mullidae, Synodontidae, and <u>Decapterus</u> sp.

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