THE STATUS OF SEABIRD RESEARCH IN THE NORTHWESTERN HAWAIIAN ISLANDS

Craig S. Harrison and Thomas S. Hida

U.S. Fish and Wildlife Service, P.O. Box 50167, Honolulu, Hawaii 96850; Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, P.O. Box 3830, Honolulu, Hawaii 96812

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 hypooleuca), 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 plummeted 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 Pelecaniformes, within the first few meters. Ashmole and Ashmole (1967) contend that large predatory fish, especially scup-birds, 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 inability 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 noddis 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 noddis (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
(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

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**TABLE 2. TOTAL FOOD SAMPLES COLLECTED JANUARY THROUGH NOVEMBER 1979**
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 Pelecaniformes (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

![Diagram of diet composition](image)

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

\[ \text{IRI} = F(N+V) \]

where

- \( \text{IRI} \) = 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 hatchet-fish (Sternopychidae) 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.
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*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 NWRI 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 necessarily 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 noddy 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 NWRI 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 NWRI seabird populations using techniques similar to Wiens and Scott (1976).
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
data are needed for Ommastrephidae, Exocoetidae, Mullidae, Synodontidae, and Decapterus sp.

ACKNOWLEDGMENTS

Richard Shomura, Southwest Fisheries Center Honolulu Laboratory, made this work possible in innumerable ways. Mike Seki provided invaluable assistance in the laboratory. Richard Young consented to help identify the squid, a most difficult group. It is a pleasure to thank these people.

REFERENCES


AN INVESTIGATION INTO UNUSUAL MORTALITY IN THE HAWAIIAN MONK SEAL, MONACHUS SCHAUINSLANDI

William G. Gilmartin, Robert L. DeLong, Alvin W. Smith, Lynn A. Griner, and Murray D. Dailey

Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, P.O. Box 3830, Honolulu, Hawaii 96812; National Marine Mammal Laboratory, National Marine Fisheries Service, NOAA, Seattle, Washington 98115; Naval Ocean Systems Center, San Diego, California 92152; Zoological Society of San Diego, San Diego, California 92112; Southern California Ocean Studies Consortium, Long Beach, California 90801

ABSTRACT

Increased mortality was reported in the endangered Hawaiian monk seal population at Laysan Island in the spring of 1978. An investigation of the possible causes of the mortality included sampling of healthy, sick, and dead individuals. Analyses comprised gross and microscopic pathology, hematology, serum chemistry, virology, bacteriology, parasitology, and toxicology. Gastric ulceration in varying degrees due to nematodes was a consistent finding. Evidence of calicivirus (VESV and SMSV) and Salmonella was found in the population. Two of 18 seals tested had elevated total white blood cell counts. A few individuals differed significantly from mean serum chemistry values but no trend was apparent. Liver tissues of two seals tested for ciguatoxin and maito-toxin were positive.

Monachus schauinslandi mortality clinical pathology ciguatera

INTRODUCTION

The Hawaiian monk seal, Monachus schauinslandi, is an endangered species which breeds only in the Northwestern Hawaiian Islands from
Necker Island west to Kure Atoll. Recent censuses indicate the total population has decreased by about 50% since 1958 (Johnson et al., in preparation).

In the spring of 1978, high mortality was observed in monk seals at Laysan Island (B.W. Johnson and P.A. Johnson, Aquatic Mammals Behavioral Research Company, Honolulu, Hawaii 96822, personal communication, 1978). Disease signs apparent in the monk seals were consistent. Animals come ashore emaciated or began to noticeably lose weight as they lay on the beach. The seals abandoned normal hauling out behavior—failing to move into the vegetation behind the beach crest at night. Within 2 to 3 weeks of beginning the weight loss, the animals became completely debilitated and then died in the splash zone or at the high tide line (B.W. Johnson and P.A. Johnson, personal communication, 1978).

This report discusses data collected on specimens taken from 19 dead and 18 live monk seals during April and May 1978 as part of an investigation into the reported mortality.

MATERIALS AND METHODS

Between 4 May and 13 May 1978 we collected specimens and data from a total of 24 Hawaiian monk seals at two locations in the Northwestern Hawaiian Islands to determine if there was any apparent disease process in the seals which might cause the mortality. Ten live yearlings or juvenile seals (MS-01-78 to MS-10-78) and one adult (MS-11-78) were sampled at Laysan Island. In addition, we received tissue sets in formalin1 from 13 monk seals (collected by Brian W. and Patricia A. Johnson on Laysan Island, 1 March to 1 May 1978) which died at Laysan Island prior to our arrival. Samples were to be collected from a large number of sick as well as apparently healthy animals; however, a storm just prior to our arrival cleared the beaches at Laysan Island of most of the very sick animals with the disease signs mentioned earlier. Seal MS-11-78 was very emaciated and weak and died while being restrained for collection of the samples. At French Frigate Shoals six dead seals were found, only one of which was fresh enough to be necropsied, even through it had been dead at least a day and the tissues were badly autolysed. The other five were too decomposed to yield any information relative to cause of death.

The live animals were physically restrained and blood was collected from the intra-vertebral extradural vein. Packed red cell volumes and white blood cell counts were determined in the field. Serum and plasma for the other clinical blood tests and serological studies were frozen for later analysis. Clinical chemistry tests were performed using standard laboratory procedures (Bio-Science Laboratory, Van Nuys, California). Serum samples from all animals were tested for agglutinating

1Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.
antibodies to *Leptospira* antigen pools nos. 1, 2, and 3. They were also tested for serum neutralizing (SN) antibodies to 19 calicivirus types (vesicular exanthema of swine virus types A49, C52, D53, F54, G55, I55, J55, K55, San Miguel sea lion virus types 1, 2, 4, 5, and marine calicivirus isolates designated 427, 274, fluke, V86, 804T, and 913T) using previously described microtiter techniques (Monta and Bryon, 1974; Smith et al., 1976).

*Leptospira* isolation attempts were made on samples of liver, kidney, and cerebrospinal fluid taken from MS-11-78. The procedure has been previously described (Smith et al., 1974a; Smith et al., 1974b).

Salmonella incidence in the seals was tested by collection of rectal swabs from all animals and placing them into transport medium in the field. These cultures were tested by one of the authors (Gilmartin) for salmonellae by beginning enrichment and isolation procedures previously described (Gilmartin et al., 1979) within 24 hours of collection of the sample but were also maintained in the holding medium for over 2 weeks, when another attempt was made at isolation of salmonellae (N.A. Vedros, Naval Biosciences Laboratory, Oakland, California 94625, personal communication, 1978).

Swabbings were taken from the nose, throat, and rectum of each animal for virus isolation. These and small slips of lung, liver, kidney, and tonsil from animal no. 11 were placed in ampules of phosphate-buffered glycerine, pH 7.2, and immediately frozen to -55°C. Tissues were thawed and ground up, then they and the swab samples were clarified by centrifugation at 3,000 rpm. Supernatant fluids were placed in a Vero monkey, *Cercopithecus aethiops*, kidney cells and porcine kidney cells (PK-15), incubated at 37° and 30°C, and passaged at least four times as previously described (Smith et al., 1974b).

Stool specimens were collected, as available, from the seals and frozen for later flotation and examination for ova.

Rectal temperatures were determined using an electronic thermistor with a flexible probe inserted at least 30 cm through the rectum.

Tissues for microscopic histopathologic studies were preserved in formalin and examined after hematoxylin and eosin staining.

One canine tooth was extracted from each of the dead seals for aging using a new technique developed for small cetaceans (Pierce and Kajimura, 1978).

Liver specimens from two seals (MS-11-78 and MS-12-78) were assayed for dioxan (2, 3, 7, 8 - tetrachlorodibenzo-p-dioxan) using gas chromatography and high resolution mass spectrometer techniques (M. Gross, University of Nebraska, Lincoln, Nebraska 68588, personal communication, 1978.)

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2Difco Laboratories, Detroit, Michigan. These pools contain *Leptospira ballum*, *L. canicola*, *L. icterohemorrhagiae*, *L. bataviae*, *L. grippotyphosa*, *L. pyogenes*, *L. autumnalis*, *L. pomona*, and *L. wolffii*. 

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Tests for tissue residues of ciguatoxin by radioimmunoassay procedures (Hokama et al., 1977) and ciguatoxin and maiktotoxin by bioassay techniques were performed.\textsuperscript{3}

Statistical analyses were performed on the clinical chemistry, hematology, and temperature data to test for individuals with values different than the mean. All the live seals sampled with one exception were young (yearlings to juveniles); therefore the adult (MS-11-78) was excluded from these statistical tests and the mean and standard deviation of the data from these animals were taken as a close approximation to parametric values since normals for the population were not known. The farthest-outlying variates within a given sample (i.e., sodium) were then tested to see if they statistically belonged within that sample using a one-tailed t-test of one variate against the assumed population mean (Sokal and Rohlf, 1969). Also, because of the great distance between the islands (approximately 320 nm), the data for the young monk seals from Laysan Island (MS-01-78 through MS-10-78) were tested with a two-tailed Wilcoxon two-sample test (Sokal and Rohlf, 1969) against those from French Frigate Shoals (MS-13-78 through MS-19-78) for all categories to determine if there were differences between the island populations.

RESULTS AND DISCUSSION

Animals from two age groupings, the young and very old, were represented in the dead animals which were recovered by the Johnsons and the authors. Ten of 14 seals which died and were recovered at Laysan Island were between 1 and 5 years of age; the others were between 18 and 30 years. The net loss in monk seals at Laysan Island during the period from March to July 1978 is estimated to be at least 50 animals (Johnson and Johnson, 1980).

Of the 13 seals which had died prior to our arrival at Laysan Island and from which we received tissue sets, there were seven males and six females. Four of the six dead seals at French Frigate Shoals were females and sex could not be determined for the other two.

Twelve of the live young monk seals sampled were females, five were males and the single adult at Laysan Island (MS-11-78) was a male. Four of the seals sampled at Laysan Island (MS-01, MS-04, MS-07, and MS-10) became emaciated and disappeared by mid-June 1978. The seals sampled at French Frigate Shoals were not similarly monitored.

Statistical tests were performed on the clinical data to identify animals with test results significantly different (P < 0.05) from the mean of all monk seals sampled. The tests were done to aid in recognizing ill animals in a species for which these clinical parameters had not been determined.

\textsuperscript{3}Radioimmunoassay for ciguatoxin and bioassay for ciguatoxin and maiktotoxin were performed by Dr. Y. Hokama and Dr. J. Miyahara, respectively, at the University of Hawaii, John A. Burns School of Medicine, Pathology Department, Honolulu, Hawaii 96822.
When each individual seal's hematology and clinical chemistry test results were compared to the mean of the group, many had at least one test value different from the mean (Table 1). There were only three cases where two animals differed from the mean (P ≤ 0.05) in the same direction on the same test: MS-05 and MS-07, elevated total white cell count; MS-06 and MS-18, high cholesterol; and MS-08 and MS-15, high alpha-1 globulin.

Monk seals MS-05 and MS-07, with the high white cell counts, are noteworthy because MS-07 is one of four animals which disappeared and presumably died later in the season. MS-07 had the highest white cell count (18,700) of all seals tested and was one of three young seals sampled which appeared underweight and lethargic. Neither of these two with the elevated total white cell counts had any other outstanding clinical data values. Of the other two monk seals which appeared underweight at sampling, one (MS-06) had only a significantly elevated cholesterol and glucose level, which may indicate a fasting animal, and the other (MS-01) had no clinical blood tests different from the mean of the group.

The three other animals which disappeared in an emaciated condition during the summer, MS-01, MS-04, and MS-10, did not exhibit any remarkable findings except for a high lactic dehydrogenase (LDH) in MS-10.

The only other animals with any noteworthy abnormal clinical pathology were MS-09 with a high total protein and beta globulin and MS-16 with a very low packed red cell volume and a high serum glutamic pyruvic transaminase (SGPT). *Salmonella sieburgi* was isolated from a rectal swab taken from MS-09 and it is the only case from which salmonellae were recovered (N.A. Vedros, personal communication, 1978). Although *Salmonella* are common isolates in some pinnipeds (Gilmartin et al., 1979), the high beta globulin and total protein in this animal are probably not related to a chronic infectious bout with this organism as no serum antibody could be detected (N.A. Vedros, personal communication, 1978).

The high SGPT of MS-16 would indicate some liver pathology. The low hematocrit may be due to hemorrhage associated with severe gastric ulceration due to nematode infestation which will be discussed below. Despite the frequency and apparent severity of these parasitic ulcerations observed in dead animals, MS-16 was the only living seal tested which had a low packed cell volume.

The rectal temperature statistics in Table 1 show that all animals tested were within a range of 1.5°C. All of these animals were asleep and dry when initially approached so there had probably been little or no physical activity prior to our restraining them. Thus, these temperatures (with a mean of 36.3°C) reflect resting status, and are very close to that previously reported for young Hawaiian monk seals. Several monk seals were monitored throughout the restraint period, and no change in the temperature reading was noted. Temperatures taken by various means in some other phocids are reported between 36.0°C and 37.0°C.
<table>
<thead>
<tr>
<th>Test</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Range</th>
<th>Animals Significantly Different at ( P \leq 0.05 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium (meq/liter)</td>
<td>152.7</td>
<td>8.1</td>
<td>134-167</td>
<td>MS-08 (134)</td>
</tr>
<tr>
<td>Potassium (meq/liter)</td>
<td>5.84</td>
<td>0.63</td>
<td>4.6-7.0</td>
<td>MS-03 (7.0)</td>
</tr>
<tr>
<td>Chloride (meq/liter)</td>
<td>108.7</td>
<td>4.8</td>
<td>96-119</td>
<td>MS-08 (96)</td>
</tr>
<tr>
<td>Calcium, total (meq/liter)</td>
<td>5.54</td>
<td>0.37</td>
<td>5.0-6.1</td>
<td>MS-13 (119)</td>
</tr>
<tr>
<td>Inorganic phosphorus (mg/100 ml)</td>
<td>7.49</td>
<td>1.49</td>
<td>5.3-9.6</td>
<td></td>
</tr>
<tr>
<td>Cholesterol (mg/100 ml)</td>
<td>206.7</td>
<td>54.5</td>
<td>121-314</td>
<td>MS-06 (314)</td>
</tr>
<tr>
<td>Urea nitrogen (mg/100 ml)</td>
<td>37.1</td>
<td>12.3</td>
<td>21-63</td>
<td>MS-17 (63)</td>
</tr>
<tr>
<td>Uric acid (mg/100 ml)</td>
<td>2.74</td>
<td>0.51</td>
<td>1.7-3.4</td>
<td>MS-02 (1.7)</td>
</tr>
<tr>
<td>Bilirubin, total (mg/100 ml)</td>
<td>0.38</td>
<td>0.28</td>
<td>0.2-1.2</td>
<td></td>
</tr>
<tr>
<td>Alkaline phosphatase (units)</td>
<td>222.0</td>
<td>131.2</td>
<td>74-580</td>
<td></td>
</tr>
<tr>
<td>LDH (units)</td>
<td>758.9</td>
<td>454.7</td>
<td>62-1,640</td>
<td></td>
</tr>
<tr>
<td>SGPT (units)</td>
<td>137.8</td>
<td>57.6</td>
<td>76-290</td>
<td>MS-16 (290)</td>
</tr>
<tr>
<td>SGOT (units)</td>
<td>146.9</td>
<td>45.7</td>
<td>72-220</td>
<td></td>
</tr>
<tr>
<td>Glucose (mg/100 ml)</td>
<td>91.1</td>
<td>24.6</td>
<td>49-141</td>
<td>MS-06 (141)</td>
</tr>
<tr>
<td>Total protein (g/100 ml)</td>
<td>7.32</td>
<td>1.01</td>
<td>4.9-9.5</td>
<td>MS-09 (9.5)</td>
</tr>
<tr>
<td>Albumin (g/100 ml)</td>
<td>2.82</td>
<td>0.36</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td>Alpha-1 globulin (g/100 ml)</td>
<td>0.32</td>
<td>0.33</td>
<td>0.08-1.2</td>
<td>MS-08 (1.2)</td>
</tr>
<tr>
<td>Alpha-2 globulin (g/100 ml)</td>
<td>1.09</td>
<td>0.53</td>
<td>0.4-1.96</td>
<td></td>
</tr>
<tr>
<td>Beta globulin (g/100 ml)</td>
<td>0.80</td>
<td>0.25</td>
<td>0.4-1.3</td>
<td>MS-09 (1.3)</td>
</tr>
<tr>
<td>Gamma globulin (g/100 ml)</td>
<td>2.30</td>
<td>0.57</td>
<td>1.3-3.4</td>
<td>MS-06 (3.4)</td>
</tr>
<tr>
<td>Albumin/globulin ratio</td>
<td>0.64</td>
<td>0.09</td>
<td>0.5-0.8</td>
<td></td>
</tr>
<tr>
<td>Packed red cell volume (5)</td>
<td>57.1</td>
<td>4.0</td>
<td>46.0-62.5</td>
<td>MS-16 (46.0)</td>
</tr>
<tr>
<td>White cell count, total (cells/mm³)</td>
<td>9,745</td>
<td>3,178</td>
<td>5,170-18,700</td>
<td>MS-05 (15,400)</td>
</tr>
<tr>
<td>Rectal temperature (°C)</td>
<td>36.3</td>
<td>0.54</td>
<td>35.5-37.0</td>
<td></td>
</tr>
</tbody>
</table>
Rectal swab cultures from more than half of the animals yielded *Edwardsiella tarda* which is of dubious significance as an intestinal tract pathogen.

Neither viruses nor leptospires were isolated from any sample; however, animal MS-05 did carry SN antibodies against VESV I55 at the 1:40 dilution and animals MS-13 and MS-19 carried SN titers of 1:10 against SMSV-I. All other tests for virus and *Leptospira* antibodies were negative; however, the finding of calcivirus antibodies (VESV and SMSV) in 3 of 18 animals certainly suggests occasional contact with these agents and may be some indication that virus reservoirs exist along the northwestern Hawaiian Islands chain. Alternatively, northern elephant seals, *Mirounga augustirostris*, have been reported as far west as Midway Islands (M.J. Rauzon, National Fish and Wildlife Laboratory, Anchorage, Alaska 99503, personal communication, 1978), the western limit of the monk seal range, and calcivirus have been isolated repeatedly from nursing and weaned elephant seals along the southern California coast (A.W. Smith, Naval Biosciences Laboratory, Oakland, California 94625, personal communication, 1978, 1979). Although there is no evidence to suggest that the recent die-off was in any way related to the presence of calcivirus, it should be remembered that these agents have been associated with a vesicular disease and reproductive failure in California sea lions, *Zalophus californianus*, northern fur seals, *Callorhinus ursinus*, and domestic swine and cats.

Parasite ova found in the stool of the 10 young live seals at Laysan Island are described in Table 2. The following flatworm ova were recovered from the gastrointestinal tract of the adult (MS-11-78) which died at Laysan Island: *Corynosoma rauschi*, *Contracaecum turgidum*, *Diphyllolothrium cameroni*, *D. elegans*, and *D. hians*. *Contracaecum turgidum*, *Corynosoma rauschi* and *D. hians* were found in the stomach and intestines of MS-12-78 at French Frigate Shoals. These same parasite species were represented in many of the 13 animals which died at Laysan Island between 1 March and 1 May 1978.

All of the animals from which the tissue sets were collected, including the two examined by the authors, were cachectic and severely emaciated. Common findings in these 15 animals included: heart, lack of adipose tissue on the epicardium surface; liver, centrallobular congestion, with foci of centrallobular necrosis; lungs, congestion and alveolar hemorrhage in about half of the seals; spleen and lymph nodes, little or no evidence of lymphopoietic activity; testes, no evidence of spermatogenesis in males estimated to be subadult to adult; and, gastrointestinal tract, numerous foci of ulceration (many were actively hemorrhaging) with nematodes embedded deep into the stomach wall in all animals and many had additional intestinal lesions from cestodes, similarly embedded in the mucosa.

It is important to note that in December 1978, two additional monk seals were found dead at Laysan Island (B.W. Johnson and P.A. Johnson, personal communication, 1978) in an emaciated condition resembling that seen in April and May; however, these seals, on examination, had very light gastric nematode infestations and only minor ulceration at the phylorus.
TABLE 2. PARASITE OVA IN STOOL OF YOUNG LAYSAN MONK SEALS, 1978

<table>
<thead>
<tr>
<th>Monk Seal</th>
<th>Cestode Ova*</th>
<th>Capillorid Type Ova*</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS-01</td>
<td>M</td>
<td>--</td>
</tr>
<tr>
<td>MS-02</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>MS-03</td>
<td>H</td>
<td>--</td>
</tr>
<tr>
<td>MS-04</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td>MS-05</td>
<td>N.D.</td>
<td>N.D.</td>
</tr>
<tr>
<td>MS-06</td>
<td>N.D.</td>
<td>N.D.</td>
</tr>
<tr>
<td>MS-07</td>
<td>N.D.</td>
<td>N.D.</td>
</tr>
<tr>
<td>MS-08</td>
<td>H</td>
<td>--</td>
</tr>
<tr>
<td>MS-09</td>
<td>H</td>
<td>--</td>
</tr>
<tr>
<td>MS-10</td>
<td>H</td>
<td>--</td>
</tr>
</tbody>
</table>

*Number of ova in 400 power microscope field: L (light) = <25, M (moderate) = 25 to 75, H (heavy) = >75, N.D. = not determined

The extensive pathology caused by parasites, even though common to all of the monk seals which were necropsied during the period of high mortality in the spring, may be the result of seasonal fluctuations in gastric nematode parasite load and not, necessarily, a major factor in the spring 1978 mortality. Gastric nematode infestations, many with associated ulcerations, are relatively common in pinnipeds and since gastrointestinal tracts of only emaciated animals were examined, it is not possible to know the associated parasite pathology in the "normal" population. Table 2, however, indicates many of the apparently normal seals were carrying heavy cestode loads.

No dioxan was detected in the liver samples tested. Ciguatoxin and maitotoxin bioassay analyses of liver tissues from the adult which died at Laysan Island (MS-11-78) and the juvenile at French Frigate Shoals (MS-12-78) were positive. Estimated levels were 30 to 50 times that found in the liver of a control monk seal which had been maintained in captivity for 15 years. Radioimmunoassay for ciguatoxin in the same tissues revealed the liver of MS-11-78 to be about 25% above the control liver, while MS-12-78 was 9% below the control. Subsequent studies, the results of which will be published elsewhere, have shown that eels (known to be a part of the monk seal diet), collected near the islands on which the monk seals haul out, can debilitate and kill northern elephant seals after consumption of as little as 1.7% of the animal's body weight (DeLong and Gilmartin, in preparation).

The parasite associated pathology and the presence of ciguatoxin in the animals were the major findings which might account for this die-off of monk seals. Lack of any pathology in any organ systems (other than gastrointestinal) may discount any infectious disease processes of viral or bacterial origin.
Further study is needed to assess the impact of heavy gastrointestinal parasitism on pinnipeds relative to their general health and ability to feed and otherwise function normally. The signs displayed by the dying monk seals observed at Laysan Island are not inconsistent with what might be expected if the parasites were responsible, but they also could have been caused by the ciguatera syndrome. Ciguatera, which will kill a phocid seal, is known to be present in tropical reef environments and is present in the island chain in at least one of the monk seals' food fish. Continued disease monitoring of the seal population and experimental work in parasitology and ciguatera toxicology will be necessary to resolve the impact of these on the Hawaiian monk seal.

REFERENCES


A REVIEW OF BASIC BIOLOGICAL DATA ON THE GREEN TURTLE IN THE NORTHWESTERN HAWAIIAN ISLANDS

George H. Balazs

Hawaii Institute of Marine Biology, P.O. Box 1346, Kaneohe, Hawaii 96744

ABSTRACT

This paper presents an overview of results obtained from a research program of the green turtle (Chelonia mydas) in the Northwestern Hawaiian Islands. Information is provided on reproductive ecology, migratory patterns, predation, food sources, growth rates, and terrestrial basking. Priority research needs include continued monitoring and tagging with Inconel tags at the breeding colony of French Frigate Shoals, radio tracking to determine marine habitat usage, and expansion of tagging efforts in resident foraging pastures throughout the Hawaiian Archipelago.

Hawaiian green turtle
Chelonia mydas
reproductive ecology
migrations
predation
food sources
growth rates
basking

INTRODUCTION

Systematic investigations of the life history and ecology of the green turtle (Chelonia mydas) in the Hawaiian Archipelago were initiated by the author in 1973 with financial assistance from the New York Zoological Society, the U.S. Fish and Wildlife Service, and the Hawaii Institute of Marine Biology. This research has continued to the present time under grants awarded by the State of Hawaii, Office of the Marine Affairs Coordinator (1976-80) and the University of Hawaii Sea Grant College Program (1977-80). In collaboration with Dr. G. Causey Whittow of the University of Hawaii, support has also been obtained from the National Geographic Society to study the unique land basking behavior of Hawaiian Chelonia. Prior to 1973, studies of Hawaiian green turtles were limited to intermittent tagging during visits to the Northwestern Hawaiian Islands by personnel of the Hawaii Division of Fish and Game, the U.S. Fish

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and Wildlife Service, and the Pacific Ocean Biological Survey Program. In addition, starting in 1967, members of the Koral Kings Diving Club periodically captured and tagged immature green turtles at Midway during the course of recreational diving.

While the author's research program encompasses aggregations of Chelonia occurring throughout the entire 2,450 km length of the Hawaiian Archipelago, greater emphasis has thus far been placed on the northwestern segment of the chain. The rationale for this action is based on the fact that (1) breeding presently only takes place in the Northwestern Hawaiian Islands, (2) landbasking, which only occurs in the Northwestern Hawaiian Islands, provides relatively easy access to both males and females, and (3) most of the islands in the northwestern segment of the chain are units of the Hawaiian Islands National Wildlife Refuge designated as Research Natural Areas. Consequently, at least in recent years, green turtles resident to these areas have not been subjected to human exploitation. The major objectives of the author's work have been (1) to identify areas presently used for breeding, basking, feeding and resting purposes, (2) to assess the size, productivity and ecological characteristics of breeding colonies and monitor annual fluctuations, (3) to determine migratory patterns, (4) to identify food sources, (5) to ascertain natural growth rates and ages at sexual maturity, and (6) to determine factors that limit the population.

The green turtle constitutes most of the sea turtles in the Hawaiian Archipelago and is the only species that lives and breeds in the Northwestern Hawaiian Islands. Under provisions of the U.S. Endangered Species Act, the Hawaiian Chelonia population is presently listed as Threatened. Two other species of sea turtles that occur in Hawaiian waters are the hawksbill (Eretmochelys imbricata) and the leatherback (Dermochelys coriacea), both of which are designated as Endangered.

The present paper provides an overview of significant findings thus far derived from the author's research program. An abbreviated list of publications resulting from this work is provided in the "References" section. A more comprehensive treatment of the subject, including a complete bibliography of Hawaiian sea turtles, is presented in Balazs (1979c).

RESEARCH METHODS

The basic methodology used in this program involves the individual identification of turtles with numbered metal tags applied to the trailing edges of the front flippers. Until September of 1976, all tags placed on Hawaiian Chelonia were made of Monel 400, an alloy comprised of copper and nickel. Since 1976, tags specially manufactured from Inconel 625, an alloy of nickel and cadmium, have been used as the primary means of individual recognition. The change to Inconel was made following the author's determination that considerable corrosion had occurred in many of the Monel tags used on Hawaiian Chelonia. No signs of deterioration have thus far been found in Inconel tags.

Tags are applied to unrestrained turtles during the latter phase of the nesting process and, as circumstances permit, during the course of
basking behavior. Taggings are also carried out on turtles captured in the water while they are foraging, resting, and in transit. Such captures are accomplished using a long-handled scoop net or by grasping the animals while diving. Since 1973, 1,127 green turtles have been tagged throughout the Hawaiian Archipelago, with 889 of these occurring in the Northwestern Hawaiian Islands. Of this latter total, 301 were adult females, 135 were adult males, and 253 were immature individuals (<81 cm straight carapace length) in which sex could not be distinguished.

Research methods associated with tagging include the recording of body measurements and the noninjurious sampling of food items from the mouth and stomach. Other methods involve nondisturbing and systematic observations of reproduction, basking and foraging, as well as the analysis of turtle remains salvaged from predators and other causes of mortality.

RESULTS

Reproduction

In excess of 90% of all breeding by Hawaiian Chelonia has been found to occur at French Frigate Shoals, a 35-km long crescent-shaped atoll situated in the middle of the archipelago at 23°45'N, 166°10'W (Figure 1). Small groups of turtles and separately nesting individuals using Laysan, Lisianski, and Pearl and Hermes Reef account for the remaining reproductive effort. Only a few nestings have even been recorded at Kure and Midway.

Figure 1. French Frigate Shoals
Courtship and copulation take place in the shallow waters of French Frigate Shoals during the early portion of the breeding season, usually between mid-April and early June. Nesting commences during the middle of May, reaches its peak during late June, and declines to a low level by early August. Some sporadic nesting may occur until mid-September. Nesting takes place over the entire land area of the islets of East, Whale-Skate, Trig, Gin and Little Gin, and along the south shore of Tern. Of the females present for each breeding season, approximately 55% nest on East (4.0 ha) and 35% nest on Whale-Skate (6.8 ha). East Island has therefore been the principal site of research during each breeding season since 1973.

Green turtles nesting at French Frigate Shoals have a mean carapace length of 92 cm with a range of 81 to 106 cm (N = 379). Up to six egg clutches may be laid by each female within a season, however the mean is only 1.8 (N = 208). Approximately 40% of the turtles lay only once in a season, while 10% make nesting attempts on several consecutive nights but do not lay eggs and often are not seen again. Fewer than 5% of the turtles have been recorded changing islands within a season once nesting has started. The length of time between oviposition in turtles that lay more than once in a season ranges from 11 to 18 days with a mean of 13 days (N = 89). During this internesting interval, many of the turtles identified by temporary numbers painted on the carapace are regularly seen basking on the same island where nesting takes place and swimming in the adjacent waters. A maximum diving depth of 12.8 m was recorded with depth gauges attached to two females during internesting intervals in June of 1979.

Usually less than half of the turtles that emerge for nesting on any one night successfully lay eggs. The remaining turtles continue to emerge on subsequent nights until oviposition is achieved or the turtle is no longer present. Many of these nesting attempts involve the nearly complete excavation of an egg chamber before abandonment takes place and another site is selected. In other cases, only rudimentary body pits are dug before a site is abandoned. Four factors contributing to the incomplete excavation of a nest include injuries or amputations of a turtle's hind flippers, insufficient moisture in the substrate, contact with large chunks of coral, and contact with abandoned antenna wire and other debris present on East and Tern.

A sample of 50 egg clutches counted during oviposition showed a mean of 104 eggs per clutch (range 38 to 145). Multiple regression analysis of these data was conducted to determine if significant relationships exist between the number of eggs in a clutch (y) and the independent variables of time of oviposition within the season (x₁), ratio of the curved and straight carapace widths of the female (x₂), and straight carapace length of the female (x₃). Larger females were found to lay significantly more (p < .05) eggs per clutch. Although there was a tendency for fewer eggs per clutch to be laid as the season progresses, this was not significant (p = .10). The relationship between the curved-straight width ratio (an index of body thickness) and number of eggs per clutch was also not significant (p = .30). The resulting formula for predicting the number of eggs in a clutch is

\[ y = -268.704 + (-0.271)x_1 + 93.768x_2 + 2.819x_3 \]
The mean incubation period, or length of time to hatchling emergence, has been found to be 64.5 days (range 54 to 88 days, N = 38). Multiple regression analysis of these data showed no significant relationships between incubation period and time of oviposition within the season, coarseness of the nest substrate, or depth of the egg chamber. The mean egg chamber depth was 60 cm (range 48 to 74 cm). A significant relationship (p < .05) was found between depth of the egg chamber and coarseness of substrate, with shallower chambers being excavated in coarser substrate. No significant relationship was found between egg chamber depth and size of the nesting female.

Table 1 presents the results of 40 precounted egg clutches that were excavated and examined following the natural emergence of hatchlings. Multiple regression analyses of these data were conducted to determine if significant relationships exist among (1) % eggs hatched, (2) % hatchling emergence, (3) % dead hatchlings, (4) % partially developed but dead embryos, and (5) % eggs with no apparent development; and the independent variables of (1) time of oviposition within the season, (2) coarseness of the nest substrate, (3) depth of nest, and (4) straight carapace length of the female. The only significant relationship (p < .05) found was that the percentage of hatchlings emerging at the surface decreases in egg clutches that are laid as the season progresses.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Eggs Hatched</td>
<td>76.7</td>
<td>24.2</td>
<td>0-100</td>
</tr>
<tr>
<td>% Hatchlings Emerging at the Surface</td>
<td>70.8</td>
<td>24.0</td>
<td>0-97.6</td>
</tr>
<tr>
<td>% Dead Hatchlings in the Nest</td>
<td>5.9</td>
<td>9.4</td>
<td>0-52.1</td>
</tr>
<tr>
<td>% Eggs Partially Developed but Dead Embryos</td>
<td>10.8</td>
<td>9.9</td>
<td>0-50.0</td>
</tr>
<tr>
<td>% Eggs without Development</td>
<td>12.5</td>
<td>22.4</td>
<td>0-100</td>
</tr>
</tbody>
</table>

Reproductive cycles, as measured by remigration intervals, have been documented in 21 nesting females. Fourteen of these turtles (66.7%) displayed a two-year cycle and six (28.6%) a three-year cycle. One turtle (4.7%) was not seen again until six years after being tagged. Thus far, no nesting turtles have been recovered at French Frigate Shoals after only a one-year absence. The present predominance in recordings of two-year nesting cycles is due to the significant increase in tag recoveries made during the 1979 breeding season of turtles tagged two years earlier in the 1977 season. Because 1977 was the first season in which the more durable Inconel tags were used at French Frigate Shoals, continued monitoring and tagging will be necessary to accurately determine the most common nesting cycle. The reproductive cycles of adult males have been documented in 16 cases. Nine (56.2%) of these represented a one-year cycle, five (31.3%) a two-year cycle, and two (12.5%) a three-year cycle. The modulation of
reproductive cycles has thus far been recorded in two turtles. This involved a phase change from a three-year to a two-year cycle in a female, and a change from a two-year to a one-year cycle in a male.

The approximate number of females nesting annually at French Frigate Shoals since 1973 has ranged from 94 in 1976 to 248 in 1978 (Figure 2). The mean annual number for this seven-year period is 180. An estimated total of not more than 20 females nest annually at Laysan, Lisianski, and Pearl and Hermes Reef. Earlier estimates of the size of the annual breeding colony at French Frigate Shoals made by Hendrickson (1969) and later quoted by Amerson (1971) ranged from 2,600 to 5,200 turtles. These data have now been shown to be invalid.

![Figure 2. Number of green turtles nesting annually at French Frigate Shoals.](image)

Using the basic reproductive data that have been presented (i.e., 104 eggs per clutch, 1.8 clutches per female, 70.8% emergence of hatchlings per clutch, 180 females per season), an estimated mean annual production at French Frigate Shoals would be 23,857 hatchlings. If the same parameters are assumed for the 20 females nesting at other areas, then 2,651 additional hatchlings would result. The mean annual production of hatchlings for the Hawaiian Archipelago would therefore be 26,508.

**Migrations**

The breeding assemblage at French Frigate Shoals consists of turtles that periodically migrate from widely separated resident feeding areas throughout the Hawaiian Archipelago. These migrations have been documented for both males and females through 52 long-distance tag recoveries, 31 of which involved French Frigate Shoals and the main Hawaiian Islands, and 21
that involved French Frigate Shoals and the northwestern locations of Laysan, Lisianski, and Pearl and Hermes Reef (Figure 3). The longest voyages thus far recorded are from French Frigate Shoals to Hilo Bay (Hawaii), and from the Ka'u District (Hawaii) to French Frigate Shoals, both of which represent one-way minimum ocean distances of 1,100 km. Fourteen recoveries (4 males, 10 females) have been made between Pearl and Hermes Reef and French Frigate Shoals, a distance of 1,050 km. Mating is therefore taking place between some males and females that live in areas separated by as many as 2,150 km.

Figure 3. Migrations of adult green turtles in the Hawaiian Archipelago documented by tag recoveries. The actual routes traveled are unknown.

Records of migrations in the Hawaiian Archipelago are unique among sea turtle populations due to the two-way tagging opportunities afforded by the basking behavior, and by the research emphasis placed on turtles in their resident feeding areas. These factors have made it possible to document movements from the feeding areas back to the breeding grounds, a missing segment in all one-way tagging programs where it is only feasible to tag nesting turtles. The ability to record long-distance migrations of males is also a rare research occurrence.

With the exception of two cases, the 146 recaptures of immature turtles (35 to 81 cm) tagged in the Hawaiian Archipelago have all been made in the same resident area where initial tagging occurred. Of the two long-distance recoveries, one involved a 38-cm turtle tagged at Midway and recaptured at Wake Island, 1,900 km to the southwest. However, the weak and apparently pathological condition of this turtle indicates that it may have passively drifted there with prevailing winds and currents. The other long-distance recovery involved a 40-cm turtle tagged at Midway and subsequently reported as having been captured and released alive in Hilo Bay, a
distance of 2,300 km. Although two Monel tags were originally placed on this turtle, only one tag was found at the time of recovery. The possibility therefore exists that the tag number was misread due to corrosion or other causes, and that this turtle was not the one tagged at Midway.

Post-hatchling turtles less than 35 cm are rarely found at the inshore feeding areas of the archipelago inhabited by larger turtles. The whereabouts of these smaller turtles is presently unknown, however it is assumed that their developmental habitat is located somewhere in the pelagic environment.

Natural predation

Predation on eggs is not known to occur at French Frigate Shoals. Although two species of ghost crabs (Ocypode ceratophthalmus and Ocypode laevis) are present in relatively small numbers, neither of these crustaceans have been found burrowing into nests.

Predation on hatchlings takes place by both species of ghost crabs, but *O. ceratophthalmus* is consistently more successful due to its larger size. This predation only occurs in or immediately above the narrow intertidal zone where both crabs periodically dig burrows. The number of hatchlings eliminated by ghost crabs probably does not exceed 5%, or an estimated annual average of 1,200 individuals. Although frigatebirds (*Fregata minor*) are among the seabirds present at French Frigate Shoals, they are not known to prey on hatchlings on land or in the inshore waters, such as reported in some sea turtle populations (Hirth, 1971). Predation on hatchlings by carnivorous fishes also does not appear to be significant. Numerous ulua (*Caranx ignobilis*, *Caranx melampygus*), wrasses (*Thalassoma purpureum*, *Bodianus bilunulatus*) and small sharks (*Carcharhinus amblyrhynchos*) have been captured by the author near East Island during the months when hatchlings enter the water, however no evidence of predation has thus far been found.

Tiger sharks (*Galeocerdo cuvier*) are virtually the only known natural predators of Hawaiian *Chelonia* larger than 35 cm. Shark research and control programs periodically conducted around the main Hawaiian Islands found that 18% (Ikehara, 1961), 10.8% (Fujimoto and Sakuda, 1972), and 12.7% (Tester, 1969) of the tiger sharks examined with food in their stomachs had been feeding on turtles. At French Frigate Shoals and Pearl and Hermes Reef, turtle parts were recorded in 31% and 36%, respectively, of the tiger sharks captured that contained food (Taylor and Naftel, 1978). A single shark at Pearl and Hermes Reef accounted for five turtles ranging from 53 to 64 cm. Four of the turtles identified from tiger sharks at French Frigate Shoals were adults ranging from 81 to 94 cm. The digestion rates of turtle parts by tiger sharks are unknown, therefore it is not possible to determine how long this material may have been retained in each stomach.

The only other known natural predator of green turtles in the Hawaiian Archipelago is the large grouper, *Epinephelus tauvina*. Only a single case of such predation has been recorded in the main islands, and no reports currently exist for the Northwestern Hawaiian Islands.
Food sources

Green turtles in the Hawaiian Archipelago have been documented feeding on 56 species of benthic algae, one marine angiosperm, and nine types of invertebrates. However, the major food sources utilized consist of only nine species of algae (Table 2).

<table>
<thead>
<tr>
<th>Location</th>
<th>Benthic Algae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northwestern Hawaiian Islands</td>
<td>Caulerpa racemosa</td>
</tr>
<tr>
<td>(N = 56)</td>
<td>Spyridia filamentosa</td>
</tr>
<tr>
<td></td>
<td>Turbinaria ornata</td>
</tr>
<tr>
<td></td>
<td>Codium edule</td>
</tr>
<tr>
<td></td>
<td>Codium arabicum</td>
</tr>
<tr>
<td></td>
<td>Codium phasmaticum</td>
</tr>
<tr>
<td></td>
<td>Ulva fasciata</td>
</tr>
<tr>
<td>Main Islands</td>
<td>Pterocladia capillacea</td>
</tr>
<tr>
<td>(N = 85)</td>
<td>Amanstia glomerata</td>
</tr>
<tr>
<td></td>
<td>Codium edule</td>
</tr>
<tr>
<td></td>
<td>Codium arabicum</td>
</tr>
<tr>
<td></td>
<td>Codium phasmaticum</td>
</tr>
<tr>
<td></td>
<td>Ulva fasciata</td>
</tr>
</tbody>
</table>

The distribution and abundance of benthic algae in the Hawaiian Archipelago are not well known, however standing crop densities of the species preferred by green turtles appear to be far greater in the main islands. For example, certain resident feeding areas around Hawaii, Maui, Oahu, and Kauai have dense growths of the red alga, Pterocladia capillacea, whereas in the Northwestern Hawaiian Islands this is a rare species which is only known to occur in small quantities near Lisianski. Concomitantly, Amanstia glomerata is abundant at many main island foraging areas, but scarce in the northwestern segment of the archipelago. Three other algal species, Caulerpa racemosa, Turbinaria ornata, and Spyridia filamentosa, identified as principal food sources in the Northwestern Hawaiian Islands, have never been found as dietary components in the main islands, even though they occur at a number of locations. This would suggest that turtles in the Northwestern Hawaiian Islands feed on these three species out of necessity due to an absence or limited supply of other algae considered more desirable.

The food sources of Hawaiian Chelonia less than 35 cm that are believed to be living in the pelagic environment are completely unknown due to the absence of data. It is, however, reasonable to assume that during this period the turtles are carnivores feeding on invertebrates that occur at or near the surface. In waters surrounding the archipelago, this could include Physalia, Velella, Janthina, the megalops stage of some portunid crabs, and immature individuals of certain oceanic squids that come to the surface at night in large numbers.
Growth rates

Thirty-one immature turtles have been recaptured in which growth could be detected after intervals ranging from 2 to 37 months. Three of these turtles were recaptured on two occasions, thereby providing a total of 34 growth measurements. Thirty-four other immature turtles that were recaptured after intervals of 2 to 20 months showed no measurable growth. This included 1 turtle at Necker, 24 at French Frigate Shoals, 3 at Lisianski, and 6 at Midway. All of these animals were vigorous and appeared to be in good health. The mean rates of growth found at the five study areas in the Northwestern Hawaiian Islands ranged from .07 to .14 cm per month in carapace length (Table 3). If these rates remain constant until maturity, as available data suggest, then turtles measuring 35 cm that are new recruits would require from 27.4 years (at Necker) to 54.8 years (at Kure) to reach 81 cm, the minimum size at which nesting takes place in the population. From 33.9 to 67.9 years would be needed to grow from 35 to 92 cm, the mean size of nesting Hawaiian Chelonia. Table 3 presents similar projections for 35-cm turtles that establish residency at the other foraging areas investigated in the Northwestern Hawaiian Islands.

<table>
<thead>
<tr>
<th>Location, Number Tagged, and Size Range</th>
<th>Growth Rate (cm per month)</th>
<th>Interval in Months</th>
<th>Years to Maturity (35 to 81 cm)</th>
<th>Years to Maturity (35 to 92 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Necker, N = 7, 39.4-48.3 cm</td>
<td>.14 - .13</td>
<td>20</td>
<td>27.4 - 33.9</td>
<td>3.8 - 33.9</td>
</tr>
<tr>
<td>French Frigate Shoals, N = 130, 36.4-67.9 cm</td>
<td>.08 - .13</td>
<td>3-36</td>
<td>47.9 - 59.4</td>
<td>29.5-191.7</td>
</tr>
<tr>
<td>Lisianski, N = 23, 35.9-53.3 cm</td>
<td>.13 - .13</td>
<td>2</td>
<td>29.5 - 36.5</td>
<td>29.5 - 36.5</td>
</tr>
<tr>
<td>Midway, N = 252, 36.5-59.4 cm</td>
<td>.09 - .11</td>
<td>8</td>
<td>42.6 - 52.8</td>
<td>10.3-127.8</td>
</tr>
<tr>
<td>Kure, N = 25, 29.5-61.6 cm</td>
<td>.07 - .10</td>
<td>3</td>
<td>54.8 - 67.9</td>
<td>31.9-95.8</td>
</tr>
</tbody>
</table>

Relatively faster growth rates have been recorded at foraging areas in the main Hawaiian Islands. Along the Ka‘u District, a mean of .44 cm per month has resulted from four recaptures after intervals of 7 to 17 months. In Waimanalo Bay off Oahu, three recaptures showed a mean growth rate of .22 cm per month after intervals of 7 to 22 months. The differences in growth rates found between foraging areas throughout the archipelago are thought to be a function of the sources and abundance of food, rather than seawater temperature. The exceptionally slow growth rates found in the Northwestern Hawaiian Islands undoubtedly have far reaching implications with respect to mortality rates of immature turtles and recruitment to the breeding colony.
Feeding and basking aggregations

Hawaiian Chelonia spend most of their lives residing at inshore areas where they alternate between active foraging and quiescence. In the Northwestern Hawaiian Islands, resident aggregations are known to occur at Necker, French Frigate Shoals, Lisianski, Pearl and Hermes Reef, Midway, Kure, and to a lesser extent at Laysan, Nihoa, and Gardner Pinnacles. Although a few random sightings have been made, it is unknown if turtles reside at, or in some way utilize, the shallow banks with no emergent land located in the northwestern segment of the archipelago.

Basking takes place on calcareous sand beaches at French Frigate Shoals, Laysan, Lisianski, Pearl and Hermes Reef, and Kure. At Laysan and Lisianski, turtles also emerge on calcareous beachrock slabs. At Nihoa, turtles have been recorded basking at the base of the island's northwest cliff. At Necker, basking regularly occurs on a sloping rock ledge and occasionally at a shoreline area comprised of waterworn boulders. Except for La Perouse Pinnacle, basking takes place on all of the islands at French Frigate Shoals, as well as on several unnamed seasonally occurring sandbars. The northern shore of Trig and the eastern shore of Whale-Skate are the most heavily utilized during all months of the year by the resident aggregation. At East Island, basking tends to coincide more with the breeding season. The greatest numbers of basking turtles occur throughout French Frigate Shoals during May and June due to the presence of the migratory breeding assemblage. The incidence of basking then declines as the season progresses. Although basking occurs principally between the hours 1000 and 1800, turtles at Necker have also been found to commonly emerge at night. Similar nocturnal behavior has at times been observed at French Frigate Shoals, Laysan, Pearl and Hermes Reef, and Kure.

The surface temperature of the carapace in turtles basking at French Frigate Shoals can reach up to 42°C. The greatest internal body temperature recorded through the cloaca was 31.3°C at a time when the seawater temperature was 26.3°C. Turtles exhibit very little activity while basking except for occasionally flipping sand on their carapace for thermoregulation. They do not, however, seem to orient their position in relation to the sun. One of the advantages to Hawaiian Chelonia obtained from basking is the reduction in exposure to predation by tiger sharks. Emergence to land at night may be especially advantageous in view of the fact that tiger sharks are mainly nocturnal predators. A further advantage to resting on land would be the conservation of energy by not having to periodically swim to the surface for respiration. Respiration patterns while basking have been found to consist of breath-holds averaging 3.6 minutes, followed by a single shallow breath (Whittow and Balazs, 1979, in press--a, in press--b).

FUTURE RESEARCH NEEDS

Research needs of the Hawaiian green turtle population deemed important for the immediate future include the following activities: (1) continued monitoring and tagging with Inconel tags during additional breeding seasons at French Frigate Shoals; (2) expansion of tagging efforts directed at immature turtles in resident foraging areas, particularly around the main Hawaiian Islands; (3) radio tracking of adult females and males at
French Frigate Shoals to identify marine habitat usage during the breeding season; (4) determination of digestion rates of green turtles in tiger sharks; (5) continued investigations of the ecology and thermal physiology of the rare land basking habit; and (6) survey and tagging of turtles in foraging areas at Wake Island and Johnston Atoll to determine if Hawaiian Chelonia utilize these isolated oceanic locations.

ACKNOWLEDGMENTS

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