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RESEARCH PROGRAM

TECHNICAL REPORT EL-89-10

SPECIES PROFILES: LIFE HISTORIES AND
ENVIRONMENTAL REQUIREMENTS OF COASTAL
VERTEBRATES AND INVERTEBRATES
PACIFIC OCEAN REGION

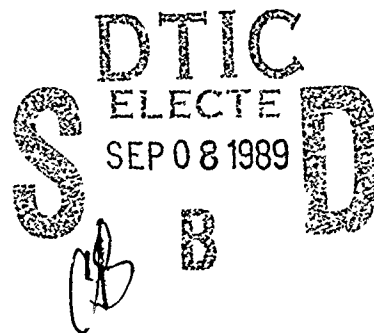
Report 1

GREEN TURTLE, *Chelonia mydas*

by

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National Marine Fisheries Service
National Oceanic and Atmospheric Administration
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19 ABSTRACT (Continue on reverse if necessary and identify by block number) Species profiles are literature summaries of the taxonomy, morphology, distribution, life history, and environmental requirements of aquatic species. They are designed to assist in environmental impact assessments. The green turtle, <u>Chelonia mydas</u> , is found throughout the Pacific Ocean region. Its status is listed as endangered by the International Union for Conservation of Nature and Natural Resources and as threatened in the U.S. Endangered Species Act and is included in Appendix 1 of the Convention on International Trade in Endangered Species of Wild Fauna and Flora. Females nest on a 2-, 3-, or ≥4-year cycle, laying one to six clutches per season and averaging between 100 and 110 eggs per clutch. Nesting normally takes place in the summer months. Hatching mortality from predation in the marine environment is thought to be high. After an initial ≥3-year carnivorous pelagic stage, green turtles become primarily herbivores, residing in (Continued)					
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— shallow coastal areas where they feed on sea grass and/or algae. Growth rates appear to vary with diet and are generally slow. Turtles average 25 years to reach sexual maturity in Hawaii. Adult green turtles are long-lived and have few predators other than man. The use of modern equipment in hunting turtles and the disregard of local conservation laws have placed many turtle populations in jeopardy. Other problems affecting the future of green turtle populations include alteration of nesting beaches and foraging habitats, the growing incidence of fibropapillomas, the ingestion of plastics or other marine debris, and entanglement with marine debris. ~~cc: /~~

PREFACE

This report was published as part of the Environmental Impact Research Program (EIRP), sponsored by Headquarters, US Army Corps of Engineers (HQUSACE). Technical Monitors were Dr. John Bushman, Mr. David P. Buelow, and Mr. Dave Mathis of HQUSACE. Dr. Roger T. Saucier, Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES), was EIRP Program Manager.

This report is designed to provide coastal managers, engineers, and biologists with a brief comprehensive sketch of the biological characteristics and environmental requirements of the green turtle, Chelonia mydas, and to describe how populations of the species in the Hawaiian waters may be expected to react to environmental changes caused by coastal development. The report has sections on taxonomy, life history, ecological role, environmental requirements, growth, exploitation, and management. The report was prepared by Robert G. Forsyth and George H. Balazs of the Southwest Fisheries Center, Honolulu Laboratory, National Marine Fisheries Service, under the support agreement WESCW88-188.

The authors gratefully acknowledge reviews by Messrs. Michael T. Lee, US Army Engineer District, Honolulu; Earl E. Possardt, US Fish and Wildlife Service; Richard E. Brock, University of Hawaii; and Ms. Karen Bjorndal, University of Florida.

Mr. Edward J. Pullen, Coastal Ecology Group, served as contract monitor for this study under the general supervision of Dr. C. J. Kirby, Chief, Environmental Resources Division, EL, WES, and Dr. John Harrison, Chief, EL, WES.

During the preparation of this profile, COL Dwayne G. Lee, EN, was the Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

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CONVERSION TABLE

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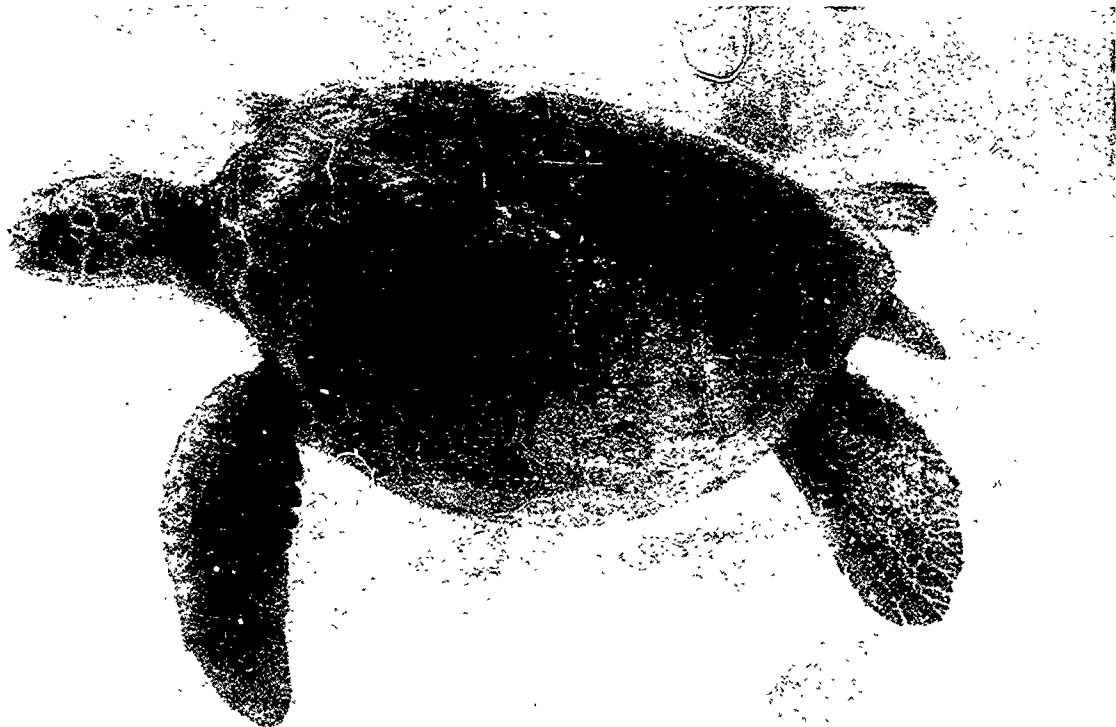
<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
meters (m)	0.5468	fathoms
kilometers (km)	0.6214	statute miles
kilometers (km)	0.5396	nautical miles
square meters (m ²)	10.76	square feet
square kilometers (km ²)	0.3861	square miles
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m ³)	35.31	cubic feet
cubic meters (m ³)	0.0008110	acre-feet
milligrams (mg)	0.0003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	2205.0	pounds
metric tons (t)	1.102	short tons
kilocalories (kcal)	3.968	British thermal units
Celsius degrees (°C)	1.8(°C) + 32	Fahrenheit degrees

U.S. Customary to Metric

inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
statute miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft ²)	0.0929	square meters
square miles (mi ²)	2.590	square kilometers
acres	0.4047	hectares
gallons (gal)	3.785	liters
cubic feet (ft ³)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28350.0	milligrams
ounces (oz)	28.35	grams
pounds (lb)	0.4536	kilograms
pounds (lb)	0.00045	metric tons
short tons (ton)	0.9072	metric tons
British thermal units (Btu)	0.2520	kilocalories
Fahrenheit degrees (°F)	0.5556 (°F - 32)	Celsius degrees

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GREEN TURTLE, Chelonia mydas

NOMENCLATURE/TAXONOMY

Scientific name . . . Chelonia mydas
 (Linnaeus) 1758
 Preferred common name Green
 turtle
 Other common names . . . Hawaii--Honu;
 Tonga--Fonu, Fonu Tu'a'uli, Fonu
 Tu'akula, Fonu Tu'apolata, Tuai
 Fonu; Society Islands--French:
 Tortue, Tahitian: Honu; Guam--hagan,
 kame; Western Samoa--laumei;
 Tokelau--fonu; Fiji--vonu damu, vonu
 loa, mako loa, ika damu
 Class Reptilia
 Order Testudinata
 Family Cheloniidae

GEOGRAPHIC RANGE

Chelonia mydas can be found in
 all tropical and temperate seas
 between lat. 35°N and 35°S and in
 waters remaining above 20°C in the
 coldest month of the year (King 1982).
 Although the green turtle is a circum-
 global species, it should not be
 regarded as a single interbreeding
 assemblage, but as discrete popula-
 tions genetically isolated from each
 other (Groombridge 1982).

Major worldwide nesting sites for green turtles include beaches on the Pacific and Caribbean coasts of Mexico; the Galápagos Islands off Ecuador; the Caribbean coast of Costa Rica; the South American coasts of Surinam, Guyana, and French Guiana; Ascension Island and the Cape Verde Islands in the mid-Atlantic; in the Indian Ocean on the coast of South Yemen; and the east coast of Saudi Arabia as well as several islands in the Persian Gulf. Europa Island in the Mozambique Channel is an important nesting colony, and in Africa, there is nesting in Somalia, Tanzania, and Mozambique. Both coasts of Thailand and Malaysia, especially the offshore islands, still have large numbers of nestings (Pritchard 1979).

Green turtles nest and reside throughout the vast Pacific Ocean region (Figure 1). Most nestings today are on small uninhabited islands or remote beaches which are not readily accessible and have not been over-exploited by man (Figure 2). Some of the more important nesting areas are Raine Island, Pandora Cay, and the Capricorn Bunker Group, Australia (Limpus and Fleay 1983); the Manus District of Papua New Guinea (Spring 1982a); d'Entrecasteaux Reef in New Caledonia (Pritchard 1982); Scilly Island in the Society Islands; Rose Atoll in American Samoa (Hirth 1971); Canton Island in the Phoenix Group (Balazs 1975); and French Frigate Shoals (Figure 3) in the Northwestern Hawaiian Islands (NWHI) (Balazs 1982c).

REASON FOR INCLUSION IN SERIES

Green turtles and their eggs are an important food source for many coastal and island villagers throughout the Pacific Ocean region. They



Figure 1. Nesting green turtle. Painted number is for short-term resighting during the nesting season. East Island, FFS, NWHI.

also play an important part in religious and ceremonial practices in some cultures, although far more so in former times (Johannes 1986). Until recently, the green turtle was important commercially; historically, it played a major role in the European exploration and settlement of the Western Hemisphere and parts of Asia by supplying large amounts of protein that could be easily stored (alive) on ships (Pritchard 1979).

Except for stable populations in Australia, the green turtle populations in the Pacific are currently in jeopardy. They are listed as endangered by the International Union for Conservation of Nature and Natural Resources (IUCN). They also are listed in the U.S. Endangered Species Act and in Appendix 1 of the Convention on International Trade in Endangered Species of Wild Fauna and Flora. (France, Italy, Japan, and Surinam have entered reservations for the Appendix 1 listing (Groombridge 1982),

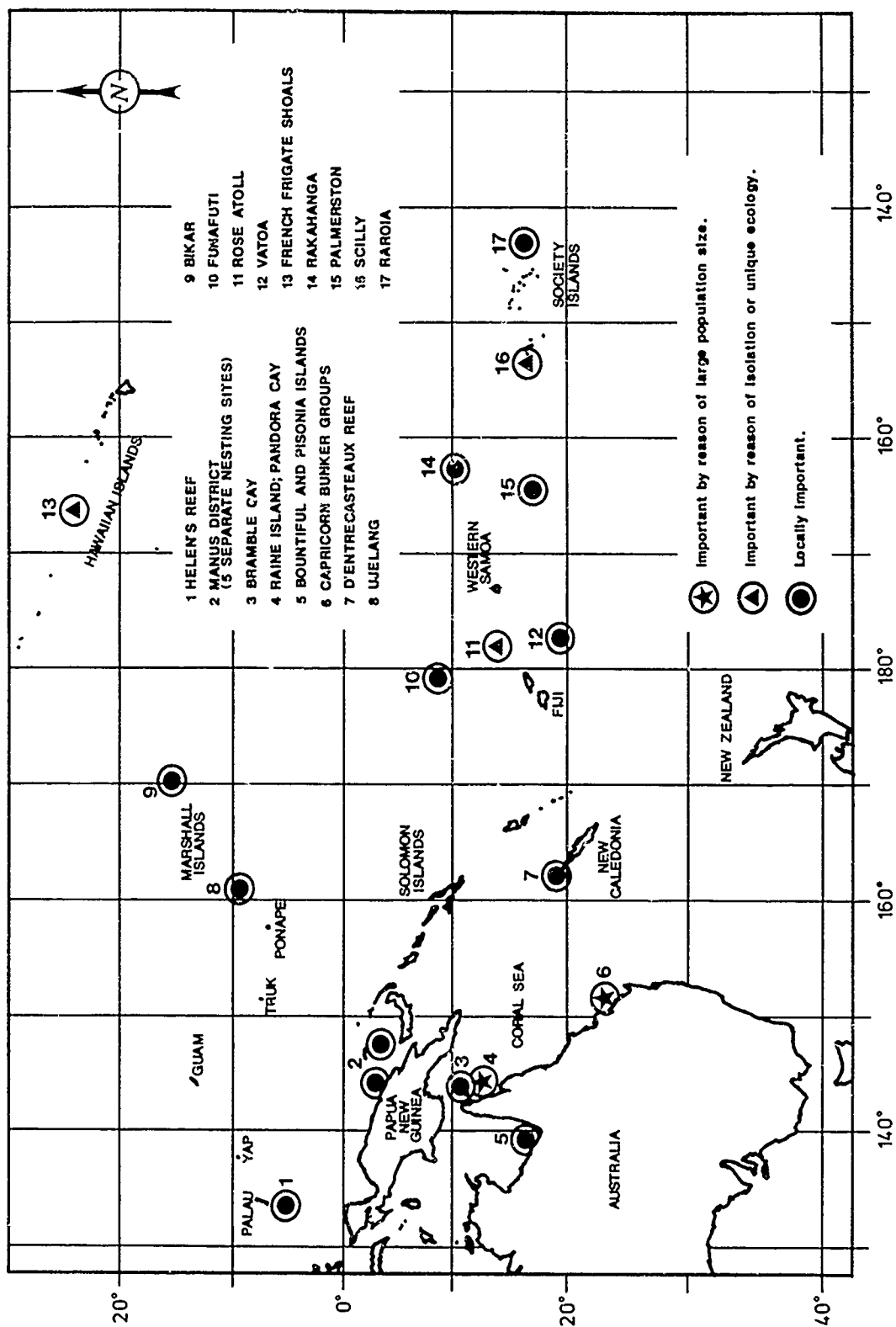


Figure 2. Distribution of notable nesting sites of green turtles in the Pacific Ocean region.



Figure 3. Aerial view of East Island at FFS in the NWHI. Largest green turtle nesting colony in the Hawaiian Islands.

but Japan recently withdrew this option.)

MORPHOLOGY AND IDENTIFICATION AIDS

The green turtle is the largest of the hard-shelled marine turtles, measuring up to 125 cm in carapace length and 230 kg. Its carapace is heart shaped and smooth; its body is very streamlined for efficient movement through the water. The head is relatively small and anteriorly rounded. The front flippers are long, and the normal mode of progression both in the water and on land involves simultaneous sweeps of the forelimbs.

The normal carapace scute pattern for the green turtle includes an anterior nuchal (precentral) scute, 5 median vertebral (central) scutes, with 4 pairs of costal (lateral) scutes, 11 pairs of marginal scutes, and 1 pair of supracaudal (postcentral) scutes (see front cover photo).

It is not uncommon to have variations in scute numbers.

Coloration of the carapace is a dark blue black as a hatchling, changing to a pattern of radiating streaks of buff, gold, brown, and black in juveniles. This pattern is variable even for turtles of the same size and population. As an adult, coloration shows somewhat less variability with background colors of green, olive, brown, buff, or black.

The plastral scutes of the green turtle from front to rear consist of a single intergular followed by the paired gular, humeral, pectoral, abdominal, femoral, and anal, ending with a single postanal. The plastron is connected to the carapace by four pairs of inframarginal scutes. The coloration is white in hatchlings, turning to a pale yellow or orange as the turtles mature. Hawaiian green turtle hatchlings go through a radical color change in the plastron pigmentation that has not been reported in other populations. At 5.8-cm carapace length (2 weeks old), the plastron becomes diffused with black and gray pigment. This intensifies until hatchlings reach 7 to 8 cm in carapace length (4 weeks old) (Figure 4). Thereafter, it fades away, usually disappearing completely by 13 cm or less (20 weeks old). Free-ranging turtles presumably undergo these same changes; however, because posthatchlings have not been observed during their pelagic stage, this has not been verified (Balazs 1986b).

The head scalation typically includes a large frontoparietal scale on the crown, preceded by a smaller frontal and a single pair of elongate prefrontals. On each side of the frontal is a supraocular, followed by four postocular scales. Behind the

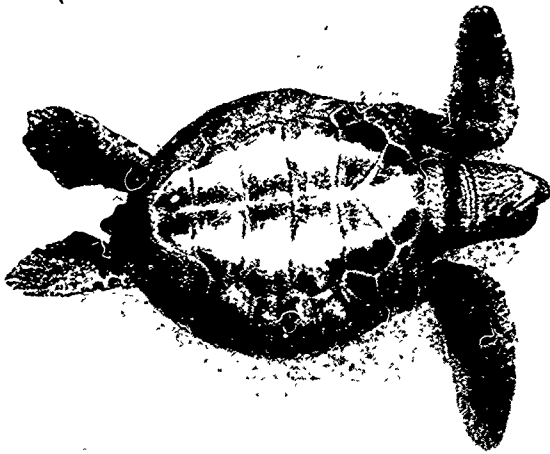


Figure 4. Four-week-old Hawaiian green turtle showing dark pigmentation phase of plastron.

supraocular is a temporal, and situated behind the frontoparietal is a pair of parietals with an additional temporal on the outer margins of each parietal.

Sex is externally indeterminate before the onset of maturity. Females are a minimum of 80-cm straight-line carapace length at maturity; males are slightly smaller. At or just before maturity, the tail of the male elongates and thickens at the base. The tail of the male reaches a short distance beyond its hind flippers, whereas the female's tail barely extends beyond the posterior end of the carapace.

LIFE HISTORY

Mating

Courtship and copulation take place in shallow water in the general vicinity of the nesting beaches. Most copulations occur early in the mating

season, and females do not copulate after laying their first clutch of eggs (Balazs 1980b). There is some uncertainty as to when fertilization actually takes place. Some researchers believe that fertilization is delayed until the following nesting season. This hypothesis raises the question of when the eggs of virgin females are fertilized, as well as the process by which spermatozoa would be stored for 2, 3, or at least 4 years between nestings. Most authorities now believe that fertilization is of the current season's eggs. This would still require the short-term storage of spermatozoa because most green turtles lay multiple clutches of eggs (Ehrhart 1982).

Reproductive Cycle

Adult females that remigrate to nesting beaches tend to do so on 2-, 3-, or 4-year cycles or longer. However, low recovery rates of remigrating females suggest that many females may nest only once in their lifetime. A 21-year study involving 12,000 tagged females at Tortuguero showed only a 16.4% remigration rate (Hughes 1982). High tag loss may account for this low number, but high mortality from fishing pressure and other impacts is certainly a possibility.

Nesting

Nesting normally takes place throughout the summer months (seasons reverse for the Southern and Northern Hemispheres) in the Pacific islands, with strong seasonal peaks that vary with location. Nesting occurs at night on sandy beaches above the high watermark. Once the female locates a suitable area to deposit her eggs, she digs a body pit by using her fore-

flippers in a strong sweeping motion and throwing the sand behind her. This process lowers the whole turtle 9 to 18 in. Once this is completed, she digs out the flask-shaped egg cavity by using her hind flippers in alternating actions. Once the cavity is finished, oviposition commences (Pritchard 1979). The number of eggs deposited can vary widely, but the average is between 100 and 110. Oviposition normally takes 20 to 30 min (Balazs 1980b). On completion, the egg chamber is filled in with the hind flippers. Then with the foreflippers, the turtle fills in the body pit, leaving a pit in front of the actual nest.

Most females nest more than once a season. At East Island in the NWHI, as many as six egg clutches from a single female have been recorded. The mean, however, is 1.8 clutches. Time between nestings at East Island ranges from 11 to 18 days, with a mean of 13 days (Balazs 1980b). These numbers are generally consistent with data collected at other Pacific islands.

Research shows that green turtles have strong site fixity in nesting. Remigrating females return to the same nesting beach time after time. The possibility exists that hatchlings are somehow imprinted so that they return to the same beach once they reach maturity (Hirth 1971). Owens et al. (1982) have described an alternate explanation, termed "social facilitation model." In this hypothesis, first-time nesters encounter and follow experienced adults to the nesting beach, which they "learn" by olfactory and other navigation systems.

Eggs

Green turtle eggs are spherical and white. Most eggs are covered with

mucous when they leave the cloaca (Hirth 1971). Average diameter and weight for eggs at East Island (NWHI) are 44 mm and 50 g, respectively. Incubation ranges from 54 to 88 days, with a mean of 64.5 days (Balazs 1980b). Egg size varies slightly from one population to another.

The excavation of 40 nests after emergence at East Island (NWHI) showed that 88.5% of the eggs were fertilized and that fertility of eggs tended to decrease slightly in later clutches (Balazs 1980b).

Sea turtle eggs do not hatch when incubated outside the temperature range of 24° to 34°C. Also, the higher the temperature, the shorter the incubation period is (Limpus et al. 1983). Incubation temperatures also have been shown to affect sexual differentiation. Even a change of 1° or 2°C can affect the sex ratio; lower temperatures result in a higher percentage of males, whereas higher temperatures yield more females (Mrosovsky and Yntema 1982).

Hatchlings

It usually takes 3 to 7 days for Chelonia hatchlings to break free from their eggs and dig to the surface. Movement to the surface is a joint effort bringing the hatchlings up as one or two groups. If high (greater than 33°C) sand temperatures are encountered near the surface, they cease activity and wait for nightfall and lower sand temperatures. The hatchlings emerge at night, usually a few hours after sunset, and, once oriented, move quickly toward the beach. Emerging at night eliminates exposure to hot sand surfaces that could be lethal or inhibiting and also eliminates exposure to diurnal terrestrial and marine predators (Hirth

1971). Once hatchlings enter the water, they swim vigorously out to sea. At this time, all contact is lost with the hatchlings until they reappear as juveniles in coastal feeding grounds.

Longevity

Little is known about the natural lifespan of *C. mydas*. Two captive Hawaiian green turtles, sent to Canada in 1956 as juveniles and later returned to Sea Life Park on Oahu, are still alive after 32 years (Balazs 1983a). Tag recoveries of 12 turtles (4 females and 8 males) originally tagged as adults in Hawaii exceed 9 years, and at Tortuguero in Costa Rica, 1 tagged nesting female has been resighted over a 19-year period (Balazs 1980b). This information suggests that green turtles are relatively long-lived.

Work has been initiated by Zug and Balazs (1985) in using a skeleto-chronological technique in aging green turtles. Estimates of age are being made through observations of the cyclic marks of skeletal growth in humeri of *Chelonia*. Early results suggest slow growth and late maturity for turtles in Hawaii. The two oldest turtles aged in this work were estimated to be 135 and 81 years old. This technique was used by Zug et al. (1986), with apparent success in aging loggerhead turtles, *Caretta caretta*.

Basking

In a few remote areas of the Pacific, green turtles have the habit of coming ashore to bask (Figure 5). The only areas where this behavior has been well documented are the Gulf of Carpentaria and North West Cape in Australia, the Galápagos Islands, and the NWHI. In Australia, only females



Figure 5. Basking green turtles at East Island, FFS, NWHI.

bask and then only during the breeding season, possibly to escape overzealous males. Basking in the Galápagos Islands has not been observed now for several years and may no longer be a behavioral characteristic of the population. Basking is still common for *Chelonia* in the NWHI and has been documented on all island groups in the chain (Balazs 1980b; Kam 1986) (Figure 6).

Basking normally takes place during the day, but it is not uncommon for turtles to also haul out in the late evening and "bask" into the night (Balazs 1980b; Forsyth et al. 1988). Observations of basking green turtles at French Frigate Shoals (NWHI) revealed that relatively cool beaches are selected for basking, major time is not invested in basking behavior, and an increase in body temperature from solar radiation appears to limit the time they stay ashore (Whittow and Balazs 1982).

The current hypotheses for basking behavior include thermoregulation,



Figure 6. Basking green turtle with Hawaiian monk seal. East Island, FFS, NWHI.

aiding ecdysis, freeing the turtle of ectoparasites or eliminating epizootic algae, aiding in the synthesis of vitamin D, facilitating social behavior, and avoiding predators (Hirth 1971; Balazs 1980b). Garnett et al. (1985) believe that energy conservation may be the principal purpose for basking behavior in Australia.

Migration and Navigation

Green turtles periodically migrate between foraging and nesting beaches. Low recovery rates of tagged turtles have made it difficult to establish migratory routes, and modes of navigation are still unknown (Hirth 1971). Tag recoveries have shown that turtles will migrate from foraging areas to nesting beaches even when "suitable" nesting sites are available locally (Meylan 1982b).

Figure 7 shows documented migrations of green turtles in the Pacific (Balazs 1982b). Relatively few turtles

have been tagged in the Pacific Basin; nevertheless, some of the longest recoveries recorded are from this area. The recovery in New Caledonia of green turtles tagged at Scilly Island in the Society Islands indicated that turtles migrate in excess of 4,000 km (Meylan 1982b).

Migratory speeds calculated from tag return data show most turtles can travel 20 to 40 km a day, even when going against the prevailing currents. These calculations are from turtles traveling long distances and are minimum averages made with the assumption that turtles are captured immediately after arrival at the capture site (Meylan 1982b).

The current hypotheses of turtle navigation include bicoordinate celestial navigation, light-compass sense, olfactory cues, perception of Coriolis force, magnetic sense, inertial guidance, sonar sense, subtle oceanographic cues such as currents and wave patterns, and perhaps a composite of several of these factors (Hirth 1971).

GROWTH CHARACTERISTICS

When the hatchling emerges from the nest, it weighs approximately 30 g and has a straight-line carapace length just over 5 cm. At this time, the turtle "disappears" and does not "reappear" until it reaches a size of 35 cm or more. Generally referred to as "lost years," this is a time when the turtle is living in a pelagic environment. Since there have been no observations of turtles during this period, their diet is unknown but assumed to be small invertebrates and fish eggs. Hawaiian *Chelonia* raised in captivity from hatchlings required at least 19 months to reach a straight-line carapace length of 35 cm. These

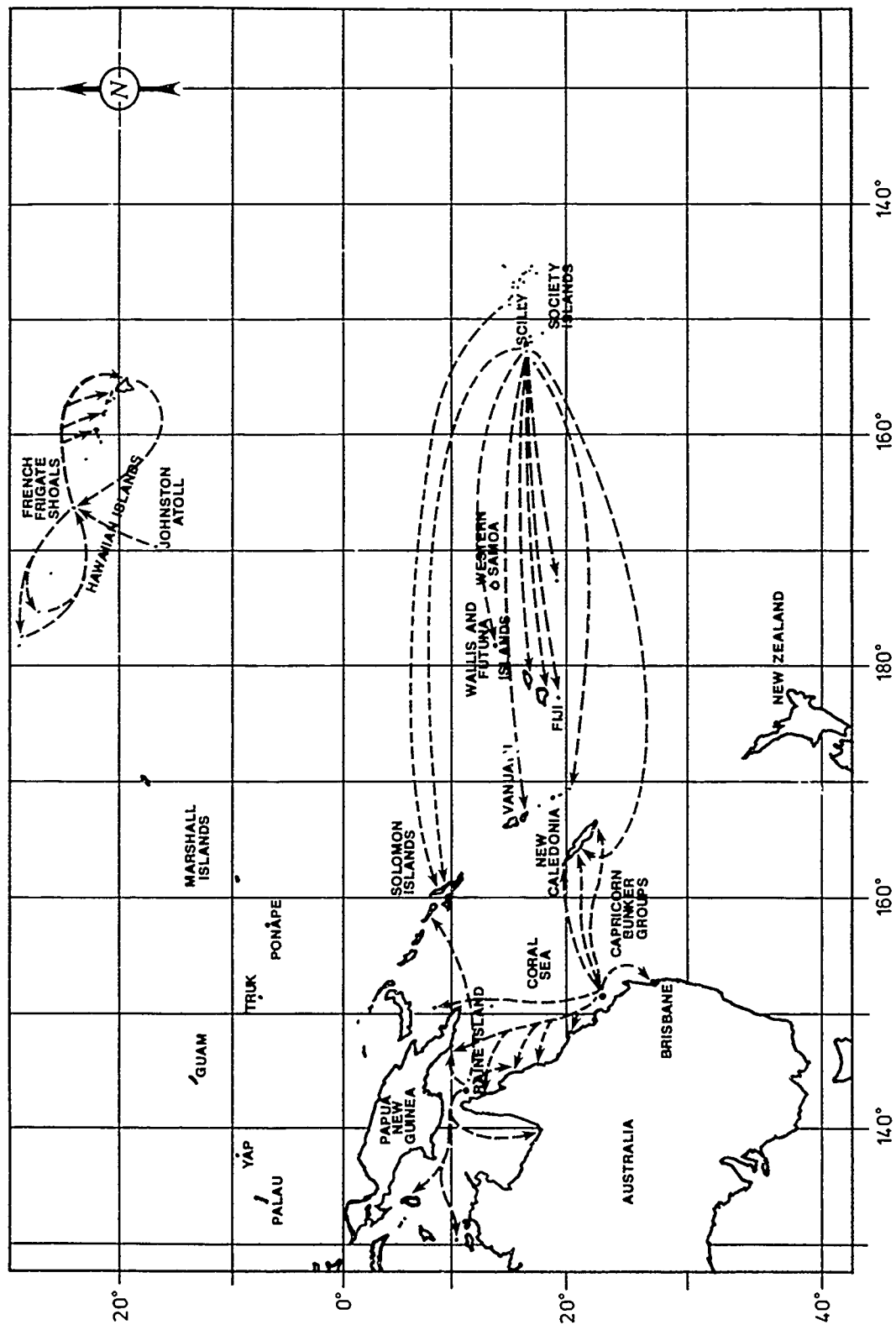


Figure 7. Migrations of green turtles in the Pacific Ocean region, as shown by recaptures of tagged individuals. Arrows do not necessarily show routes of travel.

turtles were fed a diet of pelleted dry food, fresh frozen squid, and fish (Balazs 1980b). Once the juveniles reach a size of 35 to 40 cm, they begin to appear in coastal areas and start a herbivorous existence.

Growth information is obtained by tagging and recapturing turtles in their natural environment. In a study of growth rates of immature green turtles undertaken by Balazs (1982a) in the Hawaiian Archipelago, growth rates varied from area to area, but within one area, growth rates were consistent even though turtle sizes varied. The most rapid rates of growth were recorded for turtles foraging extensively on Pterocladia capillacea. This study included seven study sites ranging from the Kau District on the Island of Hawaii (lat. 19°08'N, long. 155°30'W) to Kure Atoll (lat. 28°25'N, long. 178°10'W) at the opposite end of the archipelago. Extrapolating from rates in this study, it would take a 35-cm turtle in the Kau District 8.7 years to reach sexual maturity (81 cm is the minimum size at which nesting takes place in Hawaii) and 47.9 years for a 35-cm turtle at Kure Atoll (the slowest growth rate in the archipelago). These estimates assume that long-range migrations to other foraging areas are not made. All 69 turtles recaptured in this study were found in the same area where they were originally tagged. The recapture intervals ranged from 2 to 37 months. This shows a tendency towards long-term residency, backed by the fact that generally a full size range of turtles can be found at these foraging sites (Balazs 1982a).

Independent studies in Australia (Limpus 1979; Limpus and Walter 1980) and Great Inagua, Bahamas (Bjorndal and Bolten 1988), also showed much slower growth rates than previously

estimated for this species. Bjorndal and Bolten (1988) concluded that green turtle growth is dependent on the quality of the diet and that these data will allow the use of growth rates in different areas to assess the quality of the habitat.

Once green turtles reach maturity, growth rates decline (Carr and Carr 1970). Most growth data on adults are gathered at nesting beaches when females come ashore to deposit their eggs. The size range of nesting females in Hawaii is 80.8 to 106.2 cm straight-line carapace length, with a mean of 92 cm (Balazs 1980b). This wide range, coupled with slow growth rates after reaching maturity, leads some researchers to believe that turtles are maturing at different sizes.

FISHERY

The importance of green turtles as a fishery varies throughout the Pacific. In Hawaii and other areas under U.S. jurisdiction in the Pacific, green turtles are listed as threatened under the Endangered Species Act and cannot be legally taken. In Australia, turtles can be taken by indigenous people and then only for subsistence (Limpus and Fleay 1983). In most other areas in the Pacific, turtles can still be legally harvested with some restrictions.

Traditional methods of capturing turtles include netting with large-diameter mesh net, harpooning with either a fixed or detachable spear tip, by hand, and the taking of nesting females (Spring 1982b; Johannes 1986). Today, Pacific islanders use high-speed boats with outboard engines to hunt green turtles. They have easy access to areas that before could be

reached only with difficulty and then only at certain times of the year. They use scuba gear and spear guns to take turtles. In Palau, they attach polypropylene rope to the butt of the spear gun. The other end of the rope is attached to a combination float and fish-stringer. When a large turtle is shot, they release the spear gun, wait for the prey to tire, then retrieve it once the float resurfaces. This practice also occurs in Yap (Johannes 1986).

Most turtles today are caught by the inhabitants of coral atolls and coastal villages, some still depending on the turtle for subsistence. Even so, concern does exist for the future of the turtle in the Pacific. Older villagers are beginning to notice a decline in the number of turtles. The emergence of a "money economy" and gradual breakdown of traditional taboos coupled with the advantages of modern equipment are impacting the turtle (McCoy 1982; Spring 1982b). There is no way to really tell how many turtles are being caught and to what degree the population may be threatened by overhunting.

Chelonia eggs are also collected by the local inhabitants of the islands and coastal areas of the Pacific. Nesting beaches in many areas have been designated as "off limits" because of the dwindling number of nesting turtles and eggs. In Australia, eggs are collected by the indigenous people, but compared with exploitation of turtles, egg collection appears to have little impact on wild populations (Kowarsky 1982). In Tokelau on the islands of Fakaofo and Nukunonu, whenever a clutch of eggs is found, it is dug up, whereas Atafu has a ban on the taking of eggs, except for a few that are allowed to be removed from each nest (Balazs 1983b).

In Palau, laws regarding the harvesting of turtles and their eggs are respected by only a few fishermen (Johannes 1986).

In 1979, the South Pacific Commission and the National Marine Fisheries Service (Southwest Fisheries Center Honolulu Laboratory) jointly held a workshop in Noumea, New Caledonia, to address the problems facing marine turtles in the tropical Pacific islands. Turtle experts from the United States, Australia, and the Pacific islands gathered to discuss and make recommendations that would help secure turtle populations of the region for island people. These recommendations included providing increased protection to sea turtles and their preferred habitats (South Pacific Commission 1980).

ECOLOGICAL ROLE

Food

Green turtles are primarily herbivores but will eat animal matter opportunistically (Table 1). They will eat jellyfish when these are abundant (Limpus 1978) and, on a few occasions, have been reported to eat fish eggs (Fritts 1981). Captive turtles are normally fed a diet of fish and/or squid. Information on food sources is obtained by (1) direct feeding observations, (2) analysis of stomach contents of dead turtles, (3) recovery of incompletely digested food in fecal pellets, and (4) sampling of stomach contents of live turtles by using a flexible plastic tube (Balazs 1980a).

Behavior in Foraging Pastures

Green turtles approximately 35 cm or more in length spend most of their

Table 1. Some important food sources recorded for green turtles in the Pacific Ocean region.

Locality	Principal food source
Main Hawaiian Islands	<u>Pterocladia capillacea</u> , <u>Amansia glomerata</u> , <u>Acanthophora spicifera</u> , <u>Halophila hawaiiiana</u> , <u>Codium edule</u> , <u>C. arabicum</u> , <u>C. phasmaticum</u> , <u>Ulva fasciata</u> , <u>U. reticulata</u> , <u>Ahnfeltia concinna</u>
Northwestern Hawaiian Islands	<u>Caulerpa racemosa</u> , <u>Codium arabicum</u> , <u>C. phasmaticum</u> , <u>C. edule</u> , <u>Ulva fasciata</u> , <u>Turbinaria ornata</u> , <u>Spyridia filamentosa</u>
Johnston Atoll	<u>Caulerpa racemosa</u> , <u>Bryopsis pennata</u> , <u>Halophila ovalis</u>
Tonga	<u>Halodule ovalis</u> , <u>Halophila</u> sp., <u>Syringodium isoetifolium</u>
Tokelau	<u>Valonia aegagropila</u> , <u>Turbinaria ornata</u>
Fiji	<u>Halodule pinifolia</u> , <u>H. ovalis</u> , <u>Syringodium isoetifolium</u>
Kermadec Islands	<u>Pterocladia capillacea</u>
Tahiti	Algae
Palau	Seagrass
Truk	Seagrass and algae
Torres Strait, Australia	Red and green algae
Papua New Guinea	Seagrass
Southern Great Barrier Reef, Australia	<u>Chlorodesmis</u> sp., <u>Turbinaria</u> sp., <u>Amansia</u> sp., <u>Enteromorpha</u> sp., <u>Polysiphonia</u> sp., <u>Champia</u> sp., <u>Dictyota</u> sp., <u>Zostera</u> sp., <u>Thalasia</u> sp.

lives living in coastal waters where adequate amounts of preferred benthic algae or seagrasses are present. Algae and seagrasses are restricted to shallow depths where sunlight, substrate, and nutrients are conducive to plant growth. Feeding pastures are normally less than 10 m deep and frequently not more than 3 m (Balazs 1980b).

Feeding strategy varies depending on the habitat characteristics. Turtles observed feeding in rough surf usually take only a single rapid breath before returning to the bottom. In more protected areas, turtles have been observed spending as much as 2 min on the surface, taking three to eight deep breaths before diving (Balazs 1980b). Active turtles surface every 30 sec to 15 min.

Green turtles "sleep" in the general vicinity of feeding pastures, often in water between 20 and 50 m deep. Their preferences are coral recesses and undersides of ledges with sandy bottoms that are relatively free of strong currents. Resting turtles with small radio transmitters were found to have bottom times of up to 2.5 h (Balazs 1980b; Balazs et al. 1987).

Predation

Eggs--Nonhuman predation of eggs is minimal at most nesting beaches in the Pacific Ocean region. Small mammals such as mongooses, feral pigs, and feral dogs are the most effective egg predators, easily locating turtle nests probably by using olfactory cues (Stancyk 1982). However, most extant green turtle nesting occurs on remote uninhabited islands, thereby avoiding effective mammal predation.

Hatchlings--Ghost crabs and hermit crabs are the most widespread land predators but probably take no more than 5% of the hatchlings. However, hatchlings at nesting beaches infested with rats, feral cats, and mongooses have very high mortality. Most researchers believe that, once the hatchlings enter the water, predation by small sharks and reef fishes is quite high; however, it is difficult to assess the impact once the hatchlings enter the marine environment. In a survey conducted near East Island (NWHI) during peak hatching months in 1974, 101 ulua, Caranx ignobilis and C. melampygus; 16 wrasses, Thalassoma purpurum and Bodianus bilunulatus; and 13 gray reef sharks, Carcharhinus amblyrhynchos, were captured. Stomach contents were checked for hatchlings, but no evidence of hatchling predation was found (Balazs 1980b).

Juveniles, Subadults, and Adults--The tiger shark, Galeocerdo cuvieri, is the most commonly observed predator of juvenile, subadult, and adult Chelonia (Stancyk 1982). Intensive shark eradication programs in the main Hawaiian Islands show tiger sharks regularly feeding on turtles. A single shark at Pearl and Hermes Reef (NWHI) accounted for five turtles ranging from an estimated 53 to 64 cm in carapace length (Balazs 1980b). Other large species of shark are known to feed on green turtles, and juveniles have been found in the stomachs of large groupers.

Parasites, Symbionts, and Diseases

Known ectoparasites of green turtles include the burrowing barnacle, Stephanolepas muricata; the piscicolid leech, Ozobranchus branchiatus; and

the talitroidean amphipod, Hyachelia tortuagae. Symbionts include the barnacles, Chelonibia testudinata and Platylepas hexastylus; and the remora, Echeneis sp. (Balazs 1980b).

A number of internal parasites, especially Spirorchidae, have been identified from green turtles in the Pacific. These may well be of significance to the well-being and survival status of the turtle (Glazebrook et al. 1981; Blair 1986, 1987).

Neoplastic growths identified as fibropapillomas (tumors) are being seen on a growing number of green turtles in Hawaii (Balazs 1986a). The cause of these growths is still unknown, but possible causes include immune response to trematode ova, secretion of hirudin by marine leeches, viruses, excessive solar radiation, chemical pollutants that impair the immune system, stress, and a genetic predisposition to neoplasm. These growths range in size from small warts to huge masses 30 cm in diameter and are usually found around the neck, flippers, tail, and eyes. They can result in reduced vision, disorientation, blindness, and physical obstruction to normal swimming and feeding. It is believed that in almost all instances, death ultimately results (Balazs 1986a). An increase in the incidence of fibropapillomas in the Hawaiian population, which has also been seen in Florida green turtles, has prompted members of the Hawaiian Sea Turtle Recovery Team to give high priority to the investigation of incidence, impact, and cause of fibropapillomas (Hawaiian Sea Turtle Recovery Team 1989).

ENVIRONMENTAL REQUIREMENTS

Beaches

Green turtles nest on a variety of beach types. Nesting requirements include (1) easy accessibility from the sea, (2) a beach platform high enough that it is not inundated by spring tides or flooded by the water table below, and (3) beach sand that facilitates gas diffusion but is moist enough and fine enough to prevent excessive slippage during construction of the nest (Mortimer 1982).

Human activity and development of beach front property can have a negative impact on turtle nesting beaches. Artificial lighting is the most obvious deterrent. Females are known to shun beaches that have artificial lighting (Mortimer 1982; Coston-Clements and Hoss 1983), and hatchlings are easily disoriented by bright lights which can cause substantial unnatural mortality from crawling hopelessly inland away from the sea. (Limpus and Fleay 1983; Raymond 1984). Physical barriers such as jetties, groins, seawalls, and retaining walls may limit access, excluding turtles from prime nesting habitat. Increased levels of human activity in developed areas appear to discourage females from nesting (Witham 1982).

Internesting Habitat

Study of habitat occupied between nestings within a breeding season has received little attention to date, despite its importance. Large numbers of reproductive turtles may be concentrated in relatively small areas, making them vulnerable to impact by commercial harvesting, incidental catch, or ecological disasters such as oil spills. It is important to define

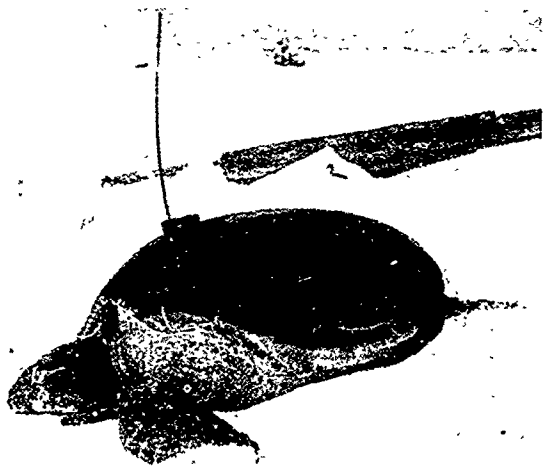


Figure 8. Adult green turtle with radio transmitter attached to carapace (see Dizon and Balazs 1982). Trig Island, FFS, NWHI.

these interesting areas and give them appropriate protection (Meylan 1982a).

Radio tracking of eight green turtles (four males, four females) at French Frigate Shoals (NWHI) during the breeding season showed strong site fixity for males and females alike (Figure 8). All eight turtles stayed in proximity of the nesting islands where transmitters were attached, even though another important nesting island was only 9 km away (Dizon and Balazs 1982).

Foraging Pastures

Green turtles are unique among sea turtles in being primarily herbivores. They are mainly associated with seagrass pastures or areas abundant in desirable marine algae (Hirth 1971). Research in Hawaii on feeding and resting habitats is the most thorough to date in the Pacific islands. Green turtles in Hawaii can be found wherever adequate accessible

food sources and resting habitat are available. The nearshore benthic habitat surrounding the main Hawaiian Islands is limited by dramatic drop-offs usually within a few kilometers of the shore. Algae, the main food source in Hawaii, is found in the nearshore waters where sunlight and proper substrate are conducive to growth. Freshwater seepage stimulates algal growth in many areas, which are often popular feeding spots. Most habitat is hard-bottom surface or coral rubble that is required by their major food sources for proper attachment. One important turtle foraging area, however, on the south coast of Molokai has extensive mud flats where seagrass, *Halophila hawaiiiana*, is present (Balazs et al. 1987).

At Johnston Island, a remote atoll located south of the main Hawaiian islands, green turtles use two feeding areas that exist side by side. On the south shore is a large field of *Caulerpa* that extends 100 m. Slightly seaward, in deeper water, *Bryopsis* is present on the tops of coral heads. Both areas will normally have several foraging turtles that can easily be monitored from a nearby peninsula. Johnston Island is of special ecological interest with regard to environmental contamination because of its use as a storage area for nerve gas, mustard gas, and dioxin. High altitude nuclear testing also took place here in 1958 and 1962 (Balazs 1985b; Balazs and Forsyth 1986).

Resting habitat is found in proximity to foraging areas, usually within 2 km or less. Large turtles prefer small caves or protective outcroppings often associated with submarine cliffs. These usually have fine-grained sand or powdery silt bottoms that the turtles rest on. In Hawaii, these sites are found along an

18- to 27-m drop-off around much of the coastline. Smaller turtles can be found resting closer to shore at the base of coral heads, in crevices, or vertical-walled channels within the reef flat. These areas must protect the turtles from large waves and strong currents (Balazs 1980b).

Pelagic

Posthatchlings are now believed to spend their first years as epipelagic dwellers in borders of currents and eddies. Young turtles swimming seaward eventually encounter convergences that are created by advection and downwelling. These convergences occur more often and last longer than originally thought, making the migrations of young turtles more feasible than originally supposed. The same advection forces that draw in the young turtles also draw in the macroplankton that they feed on. This pelagic stage is longer than originally thought, with current estimates in excess of 3 years (Carr 1987).

Marine debris, which was considered only an aesthetic problem by a 1973 U.S. National Academy of Sciences workshop on ocean pollution, has become a major environmental problem. The dumping of large amounts of plastic into the marine environment has changed the composition and extent of marine debris, affecting marine animals, especially seabirds and turtles (Shomura in press). During the pelagic period, young turtles are being exposed to this ever-increasing amount of debris. The debris is accumulated in the same convergences used by the turtles which are prone to eating plastic scraps and other debris. The number of turtles washing up dead from impaction of the alimentary canal with plastics or from entanglement indicates marine debris may be a major threat to sea turtle survival (Carr 1987). The impact on sea turtles from ingesting or becoming entangled in synthetic marine debris has been extensively documented by Balazs (1985a).



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