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EXCERPT OF KAHULUI BAY MAUI STUDY COMPONENTS

PRELIMINARY ASSESSMENT OF HABITAT UTILIZATION BY HAWAIIAN GREEN TURTLES IN THEIR RESIDENT FORAGING PASTURES

George H. Balazs, Robert G. Forsyth, and Alan K. H. Kam
Southwest Fisheries Center Honolulu Laboratory
National Marine Fisheries Service, NOAA
Honolulu, Hawaii 96822-2396

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U.S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary
National Oceanic and Atmospheric Administration
Anthony J. Callo, Administrator
National Marine Fisheries Service
William E. Evans, Assistant Administrator for Fisheries

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BACKGROUND

The herbivorous Hawaiian green sea turtle, Chelonia mydas, is a long-range migrant breeder that spends most of its life foraging and resting in nearshore benthic habitat. Adult females undertake reproductive migrations at intervals of 2 or more years, while the adult males often migrate to breed on an annual basis. The colonial breeding site for the Hawaiian green turtle is French Frigate Shoals, a cluster of sand islets in the Northwestern Hawaiian Islands situated at lat. 23°45'N, long. 166°10'W, the approximate midpoint of the 2,450 km linear Hawaiian Archipelago. French Frigate Shoals, along with several other sites in the Northwestern Hawaiian Islands, are part of the National Wildlife Refuge System administered by the U.S. Fish and Wildlife Service. Tagging studies have shown that turtles nesting at French Frigate Shoals come from numerous resident foraging areas throughout the Hawaiian Archipelago (Fig. 1).

At least 90% of all reproduction by green turtles in the Hawaiian Islands occurs at French Frigate Shoals. The breeding season at this remote site lasts for about 4 months (May-August) although many turtles, especially males, depart for their resident pastures after only a month or two. Copulation, which precedes nesting, occurs in shallow protected waters close to the islet where the female comes ashore to deposit her eggs. The females lay from one to six egg clutches (mean 1.8) at 11- to 18-day intervals within each season. During the internesting intervals, they actively avoid further mating attempts by males, but remain in shallow water near their nesting beach or, along with males, haul out to rest on the shoreline. Terrestrial basking of this nature is rare among sea turtles, being limited to a few populations of green turtles found exclusively in the Pacific. In Hawaii this behavior is restricted almost entirely to the Northwestern Hawaiian Islands. It is believed to be carried out for thermoregulation, and also possibly for protection from the tiger shark, Galeocerdo cuvieri, an important predator of the green turtle.

Hatchling Hawaiian green turtles measuring 5 cm in carapace length emerge from nests and enter the sea at French Frigate Shoals between July and October. The hatchlings swim immediately away from shore into pelagic habitat where they reside for at least 2 years. During this oceanic phase they are almost never seen, and therefore are not accessible for ecological investigation. Residency is thought to take place at or near the ocean surface, most likely along driftlines or areas where currents converge. Available food sources concentrated in these areas consist of various macroplankton. A combination of ocean currents and a strong swimming ability is believed to account for the turtles' eventual dispersal into nearshore benthic habitat. Turtles <35 cm are virtually never found in coastal waters of the Hawaiian Islands. The 35 cm size class is therefore assumed to be the minimum at which recruitment occurs to nearshore habitat from the pelagic environment. A generalized life history and habitat model for the Hawaiian green turtle is shown in Figure 2.

The eight main and inhabited islands consisting of Hawaii, Maui, Kahoolawe, Lanai, Molokai, Oahu, Kauai, and Niihau in the southeastern segment of the archipelago (Fig. 1) account for 96% (1,165 km) of the

1,210 km coastline found in Hawaii. Most Hawaiian green turtles from 35 cm juveniles to mature adults >82 cm reside in the nearshore habitat of these eight islands. Factors responsible for this distribution include the greater amount of available habitat, an abundance of certain marine vegetation preferred for food, and oceanic currents that appear favorable in transporting young turtles to the main islands for recruitment into coastal habitat. The benthic habitat surrounding the main islands is, however, limited in scope since great depths generally occur just a few kilometers from shore.

Immature Hawaiian green turtles living in the wild have been found to grow at a slow rate. From 10 to 60 years may be needed to reach sexual maturity (Balazs 1982; Zug and Balazs 1985). Based on 10 years of tagging data, the total number of adult females nesting at French Frigate Shoals has been estimated at approximately 750 (Wetherall 1983). Other major aspects of existing knowledge on the Hawaiian green turtle population have been presented in Balazs (1976, 1978, 1980b, 1983), Dizon and Balazs (1982), and Whittow and Balazs (1982). Along with other sea turtles under United States jurisdiction, the Hawaiian green turtle is listed and protected (since 1978) under provisions of the U.S. Endangered Species Act.

Although green turtles only spend a small portion of their lives on land, most research worldwide has been focused at these sites. This is due to the critical importance of the breeding colony to the overall survival of each population, and also the easy access afforded to relatively large numbers of nesting females, eggs, and hatchlings in the terrestrial environment. Green turtles, like many other highly mobile marine animals, are difficult to study in their underwater habitat. Nevertheless, a knowledge of the habitat requirements for nearshore foraging, resting, and other developmental needs is essential for the conservation and management of the species. The necessity of undertaking habitat-related research in resident foraging pastures has been emphasized repeatedly during recent years (Carr et al. 1978; Carr 1980; Bjorndal 1982; Carr et al. 1982; Shabica 1982; Coston-Clements and Hoss 1983; Hopkins and Richardson 1984).

Studies previously initiated in the main Hawaiian Islands on green turtles in their nearshore habitat have established a foundation for doing more extensive work at this location. Recent studies conducted elsewhere on various aspects of green turtles in their resident foraging pastures include those of Ireland (1979); Bjorndal (1980, 1982, 1985); Mendonca and Ehrhart (1982); Ehrhart (1983); Ogden et al. (1983); Limpus et al. (1984); Frazer and Ehrhart (1985); Limpus and Reed (1985); and Ross (1985). In addition, a comprehensive assessment of green turtle foraging habitat has been accomplished at Johnston Atoll, 830 km to the southwest of the Hawaiian Islands (Balazs 1985b). Along with earlier foraging pasture studies by Hirth and Carr (1970) and Hirth et al. (1973), and the works cited above, the results of the present study will serve as a model for comparative research and should have broad application to a number of geographically separate green turtle populations.

The aim of the study reported herein was to identify and assess, through a series of field surveys, a select number of resident foraging habitats situated along the coastlines of four (Oahu, Molokai, Maui, and Lanai) of the main Hawaiian Islands. The study sites were chosen because of their interesting or representative ecology, the presence of substantial numbers of turtles, and/or the historical prominence of the site as it relates to green turtles.

ASSESSMENT METHODS

Field studies totaling 74 days were conducted between February and November 1985 to accomplish the assessment (Table 1). The three principal study sites focused upon were Kawela Bay on Oahu, Palaau on Molokai, and Kahului Bay on Maui. Selection of these locations resulted from previous exploratory surveys, as well as information obtained from interviews with fishermen and other local residents indicating high concentrations of turtles. The presence of turtles in prominent numbers was used as an indicator that the habitat fulfilled the animals foraging and resting requirements. An additional nine other sites, listed in Table 1, were chosen for less intense appraisal. All 12 of these areas were deemed to be of special interest or potential importance to the overall population of the Hawaiian green turtle. Other sites of significance are known to exist in the main Hawaiian Islands, notably the Na Pali Coast of Kauai, and Punaluu, Kaalualu, and Kiholo on the Island of Hawaii. However, except for the studies previously mentioned (Balazs 1976, 1980b, 1982), more comprehensive investigations must await the availability of sufficient resources.

Underwater Surveys

Underwater surveys with scuba and by skin diving were made to examine key foraging and resting places and to gather relevant ecological data. A 4.5 m Zodiac with an outboard motor was used in this work as needed. The Zodiac that was available for work on Maui and at Keomuku, Lanai was equipped with an electronic depth finder.

Two or three divers working within visual range of one another systematically covered as much underwater habitat as possible within the allotted time. With the exception of Kahului Bay where brief skin diving occurred at night, all diving surveys took place during the daytime. The use of scuba to search for turtles at night in resting habitat would undoubtedly have resulted in greater numbers being located at certain sites. Turtles are less apt to flee from an approaching diver at night. In addition, the use of underwater dive lights can temporarily blind or disorient turtles making them easier to capture. Nevertheless, the nighttime use of scuba was not considered feasible or safe for most of the study sites examined.

Terrestrial Surveys

Terrestrial surveys were conducted along coastlines to observe foraging turtles and characteristics of the nearshore and intertidal habitat. Observations were often carried out during morning twilight, a known active feeding period for the Hawaiian green turtle. At Kahului Bay, turtles attracted for thermoregulation to the warmwater discharge from a power plant were censused from shore as they periodically surfaced to breathe.

Capture Efforts

Turtles were sampled alive and unharmed by means of (1) large-mesh tangle nets, (2) a bullpen net, and (3) scuba and skin diving to facilitate capture by hand. All three of these methods have been successfully employed to study and tag green turtles in coastal waters of the Hawaiian Islands.

Large-mesh tangle nets were used to catch turtles at Kawela Bay and Kahului Bay. These nets were constructed of 2-mm diameter nylon twine with a stretched diagonal mesh of 46 cm (23 cm^2 mesh) and depths ranging from 1.5 to 3.5 m. The length of the nets ranged from 20 to 60 m. The nets were set at the surface extending vertically through the water column. They were deployed close to shore (<100 m) using a large inner tube with a plywood bottom. The nets were checked from land with binoculars and a spotlight (at night) every 20-30 min to see if turtles had been caught. Entangled turtles were removed from the net as soon as possible and brought to shore in the inner tube.

A large bullpen net owned by a commercial fisherman was used to sample turtles at Palaau. This method of fishing was introduced to Molokai several decades ago from the Philippines where it is called "baklad." At present only two bullpens are known to be in use in the Hawaiian Islands. Both are on Molokai where the wide shallow reef flat along the southern shore makes their use feasible.

The bullpen consisted of four pieces of net set from a specially designed 6.5 m boat. The pieces were deployed in a manner to block off and divert turtles (and fish) swimming along the reef flat into an enclosure where they were unable to escape. One section of net 250 m long served as a guide, set perpendicular to shore, that prevented the turtles from moving parallel to the shoreline. When this barrier was encountered, the turtles turned seaward and followed the guide into another section of net 200 m long set in a circle. Two other 100 m pieces of net were each positioned at 45° angles to the guide at the point where it fed into the circular enclosure. These wing nets created a funneling effect to help lead the turtles into the enclosure and prevent escape once inside. The nylon webbing used in the four pieces of net had a stretched mesh of 5-7 cm. The depth of each net was 4 m, but they were set in water ranging from only 0.5 to 3 m deep. Once captured, turtles were removed from the enclosure by grabbing them as they hit the net trying to escape, and by seining the enclosure during the course of landing the commercially sought fish.

The tagging of turtles caught incidentally during bullpen netting on Molokai is an ongoing activity in cooperation with commercial fisherman Edward Medeiros and State of Hawaii Aquatic Biologist William Puleloa.

Tagging and Biometrics

Turtles were tagged for long-term identification with numbered and addressed Inconel[1] alloy tags, size 681, custom made by the National Band and Tag Company of Newport, Kentucky. Balazs (1980b, 1982, 1983) described the history of these tags used in Hawaii and their superior corrosion resistance in contrast to ones made of Monel alloy. The tags measure 25 x 9 x 8 mm, weigh 3.5 g, and are self-piercing and self-locking. The manufacturer's applicator was modified slightly to lessen damage to tissue around the tagging site (Balazs and Gilmartin 1985). Depending on the turtle's size, from one to three tags were applied to offset tag loss. Tagging sites were the trailing edges of the front flippers and, when appropriate, along the inside trailing edge of a hind flipper well under the carapace.

Biometrics recorded on each turtle consisted of: straight-line and curved carapace length from the center of the precentral scute to the posterior tip of a postcentral scute; straight-line carapace length from the center of the precentral to the notch between the postcentrals; straight-line and curved carapace width at the widest point (the sixth marginal scute); straight-line plastron length along the midline; straight-line head width at the widest point; tail length from the posterior rigid edge of the plastron to the tip of the tail; and straight-line flipper width from the claw scale to the sixth scale on the trailing edge. Body weight was also recorded on a small number of turtles.

The straight-line carapace length taken to the posterior tip of a postcentral scute is the standard measurement used throughout this report, unless otherwise stated.

Food Sources and Epizoites

Food sources were determined by sampling the turtles' stomachs with a plastic tube inserted through the esophagus. Water was introduced at low pressure with a garden hose or enema bag to gently flush out food particles. In addition, unswallowed particles of food were removed from the mouth for identification. Field techniques for sampling dietary contents in turtles are discussed in detail in Balazs (1980a) and Legler (1977). Observations made of turtles feeding at specific sites also permitted the direct collection of forage during underwater surveys.

Food items were preserved in dilute Formalin and identified to the lowest taxon possible. Frozen bulk samples collected from foraging habitat in Kahului Bay were biochemically analyzed to determine major nutrients and mineral composition.

Epizoites found on the skin and hard surfaces of turtles were sampled, preserved in dilute Formalin, and identified to the lowest taxon possible.

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[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Deep-Body Temperatures

A telethermometer manufactured by Yellow Springs Instrument Company (Model 46 TUC) equipped with a thermistor probe (No. 401) was used to measure the deep-body temperatures of several turtles at Kawela Bay and Kahului Bay. The probe was inserted through the cloaca until its tip was estimated to lie within the large intestine. This method is identical to the one followed by Whittow and Balazs (1982). Temperatures were recorded immediately after the turtles were captured and brought to shore.

Blood Sampling and Bone Biopsies

Blood sampling followed the methods described by Bently and Dunbar-Cooper (1980) and Owens and Ruiz (1980). A needle and vacuum collection tube were used to draw blood from the paravertebral sinus on either side of the midline of the dorsal neck surface. Serum samples from immature turtles were frozen for future analysis of testosterone levels to determine sex. Whole blood samples were frozen for future analysis of genetic information using specific enzyme stains on isoelectrofocused gels.

Electro-Immobilization

The physical movement of the turtles was effectively controlled on land while collecting data by using a portable electro-immobilizer, Feenix Stockstill Mark I (Feenix International Ltd., Lake Wylie, South Carolina). Electro-leads were clipped to the inguinal region of a hind flipper and to the axial portion of a front flipper on the opposite side. Metal tags applied first at these sites provided ideal contact points to attach the leads. Immobilization and the turtle's recovery of normal movements were immediate when the unit was turned on and off. Immobilization results from minute electrical pulses which affect the nervous system causing skeletal muscles to contract and pain to be blocked out. A similar device called TENS (Transcutaneous Electrical Nerve Stimulation) is used on humans to relieve chronic pain and replace injectable anesthetics. The Feenix Stockstill unit is powered by a 6-V alkaline dry cell battery giving a maximum current of 240 mA at 55 V. A setting of 60-120 mA would usually eliminate all struggling, but still allow normal respiration and movement of the turtle's head and neck. The unit is manufactured for use on large domestic livestock, but was tested successfully by Wood and Wood (1983) as a method of surgical anesthesia for captive green turtles. The present study appears to be the first in which the unit has been routinely used to restrain wild-captured turtles to facilitate data collection and lessen injury to the researcher and the turtle.

channels leading through the surf. It seems likely that resting habitat, especially for larger turtles (>65 cm), may also exist in deeper water on the outer slope beyond the Palaau reef flat.

Directly toward shore from netting site D (Fig. 4) a deep natural trench approximately 300 m long by 75 m wide occurs abruptly in the mud flat in front of the ruins of an ancient fishpond (Pakanaka Pond). Fishermen on Molokai have reported that turtles rest on the bottom at this location. The exact depth is unknown, but may range up to 7 m. An attempt to inspect the bottom with scuba and look for turtles was unsuccessful because of zero visibility in the silt-laden water. Two turtles were seen in this area surfacing momentarily to breathe, but they quickly dove again, probably in response to the presence of the survey boat and personnel.

Kahului Bay, Maui

Physiography

Kahului Bay is located at lat. 20°54'N, long. 156°28'W on Maui's northern windward coast adjacent to the island's major urban centers of Kahului and Wailuku (Fig. 9). Kahului Harbor is situated within this bay and is the only deep-draft harbor on Maui. Protection for vessels is afforded by two breakwaters 2,300 and 2,700 m long, with a 180-m wide entrance channel between them. Breakers occur on both sides of the channel and continue along the coast, especially to the east, for up to 1 km from shore.

Except for two sections of beach, the shoreline inside Kahului Harbor is made up entirely of artificial structures. Wharfs and other facilities, including a large Matson freight terminal, are located on the harbor's east side near the projection of land called Hobron Point. On the west side there is a cement boat ramp. A 40-MW generating station is situated next to the freight terminal outside the harbor boundaries on the seaward side of Hobron Point. In addition to numerous commercial, residential, and agricultural areas surrounding Kahului Harbor, there is also a nearby jet airport, a waterbird refuge (Kanaha Pond), and a sewage plant that disposes of treated effluent by injection into the limestone substratum. Armstrong (1983) and Clark (1980) provide further information on other aspects of Maui's coastal zone in the vicinity of Kahului Bay.

The principal study site for turtles in Kahului Bay was the nearshore waters of Hobron Point in the immediate vicinity of the warmwater outfall of the power plant. The station's cooling water system uses 55 million gallons per day of seawater pumped up from wells 60 m deep. The intake temperature of this water is 23°C, and the outfall temperature is reported to range from 27° to 33°C, depending upon the load (Hawaiian Electric Co. and Bishop Museum 1975). The four steam turbine generating units discharge their cooling water along a 50-m stretch of shoreline just outside the plant. Upon leaving the outfall ports, the heated water cascades a short distance down a boulder embankment and enters the sea with relatively little force. A clear plume of warm water is formed next to the embankment and retained there to some extent by onshore tradewinds. The clear plume contrasts sharply with adjacent water which is very turbid but nevertheless much warmer than farther offshore. The plume is usually about 20 m in diameter and varies in size and shape with wind and tidal conditions.

The power plant was built in 1947 in essentially the same configuration that it exists today. The gathering of a few turtles near the warmwater discharge at night has been known by some plant employees and other local residents for many years. Recently, however, the numbers are believed to have noticeably increased, possibly because fewer are now being killed there since legal protection was granted. Rene Sylva, a former turtle net fisherman first notified research personnel in April 1984 about this aggregation.

A security fence extends around the entire plant, but public access to the discharge area is made possible by a narrow footpath along the top of the 6 m high embankment just outside the fence. A wooden stairway leads down the embankment so that periodic samples of the cooling water can be safely taken by power plant personnel. The stairs and part of the discharge area are illuminated at night by a small floodlight that operates automatically at dusk and dawn. Some background illumination also originates from various security lighting at the power plant and the nearby freight terminal.

A small number of people regularly fish from the embankment at night with rod and reel whenever the onshore winds are not excessive. Other activities carried out here include recreational "turtle watching" during the evening hours, as well as concerted periodic attempts to take turtles, some of which are undoubtedly successful. Several local residents indicated that turtles are sometimes shot here with firearms as a means of capture.

Ecological Aspects of the Turtles Captured

Large-mesh tangle nets used on five nights (7 May and 17-20 June 1985) near the warmwater outfall in Kahului Bay resulted in eight captures (Tables 1 and 21). Overall, 117 m-h of netting effort was expended for each turtle captured. One turtle was caught twice during this time, and two others were captured by hand while skin diving right next to the embankment. A total of nine turtles were therefore examined, measured and tagged at this site (Table 22).

Relatively few turtles were captured in the nets despite the large numbers consistently seen from shore aggregated around the small area of the outfall. The nets were almost certainly being detected and actively avoided by the turtles, even though they were set in turbid shallow water just outside the clear plume formed by the discharge. The turtles were often seen surfacing to breathe alongside the net, thereby giving the impression that they were swimming around, or in some places, possibly under it to reach the warmer water. On several occasions a turtle would become entangled for only a few minutes, during which time there would be bursts of violent splashing before it escaped. When a turtle that was securely caught in the net had to be removed and brought to shore in the inner tube, the subsequent sightings of turtles would decline dramatically for the rest of the night. The departure of most turtles from the area whenever personnel entered the water greatly limited the amount of work that could be accomplished nightly. No turtles were ever seen in the vicinity of the outfall during the daytime, either from shore or during diving surveys, nor were any such reports received during interviews with power plant personnel or other local residents.

The size composition of the nine turtles was: 35-45 cm = 11%; 45-55 cm = 0; 55-65 cm = 0; 65-75 cm = 11%; 75-85 cm = 22%, and >85 cm = 56%. On the basis of tail size (Table 22), it was possible to determine that two of the turtles captured were males (29%) and five others were females (71%). The size classes found at all three principal study sites--Kawela Bay, Palaau and Kahului Bay--are compared in Figure 10.

The high proportion of adults present near the outfall was confirmed by estimates of the size of turtles seen surfacing to breathe. It was also verified by skin diving into the plume of clear water and viewing up to 28 turtles (on 2 May 1985) for a short time before they fled. A few turtles in the 45-55 and 55-65 cm size classes, for which no individuals were captured, were in fact seen, but not near the larger turtles. The smallest turtle in the sample (44.8 cm, Table 22) was caught in a net that had been positioned farther seaward from the outfall. Although sufficient data are lacking, there was nevertheless some indication that small turtles <65 cm are restricted to the cooler regions of the discharge. If so, this might be due to territorial behavior by large turtles, or that smaller turtles are less able to tolerate the higher temperatures close to the outfall. This latter possibility would be consistent with thermoregulatory behavior in the Northwestern Hawaiian Islands where turtles <65 cm seldom come ashore to bask. The plume was consistently found to be 30°-31°C at its warmest site during April, May, and June when the field studies were conducted.

The stomach contents sampled from seven of the turtles revealed that four (57%) contained 95% or more Codium edule (Table 23). Another sample consisted of 25% Acanthophora, 25% Amansia, and 50% Laurencia nidifera. Only minute food particles of Pterocladia sp. and Laurencia sp. were in the smallest turtle captured (44.8 cm). An additional 16 other species of benthic algae were identified, but only in trace amounts from the various stomach samples. Two samples also contained a small crab or crab parts which were likely ingested unintentionally along with algae used for food. A nutritional benefit would nevertheless accrue if many of these crustaceans are present on the algae when it is eaten.

The green alga, Chaetomorpha brachygona, was on the carapace of turtles captured near the outfall (Table 9). This genus has not been previously recorded growing on green turtles in Hawaii. In contrast with the other principal study sites, turtles sampled near the outfall had very little or no red algae (Polysiphonia spp.) on their neck and groin. However, the skin barnacle, Platylepas hexastylos, was exceedingly abundant, and some areas of the groin were completely covered. Also, in contrast with the other study sites, turtles examined at the outfall had the burrowing barnacle, Stephanolepas muricata, in moderate numbers (5-10) along the anterior edge of their front flippers. This barnacle is potentially harmful in great numbers because it lives deep in the tissue and derives part of its sustenance from the turtle's blood. It would appear that both Stephanolepas and Platylepas flourish in the warmer water, rather than being adversely affected by it. No dead barnacles were on the turtles to suggest that the higher temperature at the outfall helped to get rid of them. Small schools of the sergeant major, Abudefduf abdominalis, were seen in the clear plume, but there was no indication that they were grazing on the turtles' epizoites.

Five of the nine turtles captured had prominent external injuries or abnormalities (Table 24); three of these had wounds almost certainly caused by a spear or harpoon. Turtles in the warmer part of the discharge are especially vulnerable to attack with a harpoon, since the embankment is directly above them. Another injured turtle that was captured had a blind and atrophied right eye. The cause could not be determined, however, severe eye damage and blindness inflicted by a three-pronged spear have been documented elsewhere in Hawaii. The largest turtle captured, a 96.5 cm adult female (tag No. 8486, Tables 22 and 24), had numerous small fibropapillomas 0.5-3 cm in diameter on the inguinal and axial regions of all four flippers and on both eyes. Nevertheless, it was vigorous when caught in the net and seemed to be in good nutritional condition. On 23 July 1986, 13 months after being tagged, the turtle was reported dead, washed ashore at Nehe Point, 2.2 km to the west of Hobron Point (Fig. 9). The state of decomposition suggested that the turtle had been dead for 5-10 days. The cause of death was not evident, however, some of the tumors are believed to have noticeably increased in size. Two years earlier on 27 July 1984 another large turtle (88 cm) was found dead at Nehe Point. There were tumors on both eyes and the right front flipper was freshly amputated, presumably by a shark. The stomach was filled to capacity with Pterocladia capillacea.

A comparison of the injuries and abnormalities on turtles of different size classes sampled at the three principal study sites is presented in Table 25.

Deep-body temperatures of 28.8° and 27.6°C were recorded in two turtles right after being hand-captured on 18 and 19 June 1985 in the clear plume of the outfall where the temperature was 30°C (Table 13). These turtles may have been in this warmer water for up to 5 h, respectively. The two measurements demonstrate the thermal advantage obtained near the outfall, since the ambient temperature farther from shore was 26.5°C. The benefit would be even greater at other times of the year and during certain weather conditions when the ambient ocean temperature is even cooler. For example, during the early May 1985 field work in Kahului Bay (Table 1) the offshore temperature was found to be 2° cooler or 24.5°C.

Turtles were censused from shore as they surfaced to breathe in an effort to better understand their diurnal activity patterns and behavior in the vicinity of the outfall. Due to turbid water conditions and reflection on the sea surface, the turtles could only be seen when they came up for air. This surface interval was usually very short, lasting only 1-3 s. Nevertheless, the turtles were highly visible during this brief time since, as mouth breathers, their entire head was raised out of the water. The lighter colored areas of the throat and head were especially noticeable at night under the artifical lighting from the power plant and harbor facilities. Small sharks <1 m long were sighted at the surface a few times, but they were easily distinguished from turtles.

On only a few occasions was it possible to identify and keep track of individual turtles to estimate submergence time between breaths. This interval was tentatively determined to be from 1 to 4 min. However, some turtles may have stayed down for a much longer period, as would occur in typical resting habitats. The complicating factor here is that, although some may be on the bottom in a prolonged resting phase, many others outside of the clear plume appear to be actively foraging and therefore taking more frequent breaths. The warmer water may also be an important factor, since a concomitant increase in body temperature and metabolism would necessitate more frequent respiration. To estimate the total number of turtles around the outfall at any given time, sightings made at the surface during a 1-min period would have to be multiplied by the submergence time, which in this case is assumed to be 1 to 4 min. Figure 11 shows the sightings per minute that were recorded at select times on 13 different days during April, May, and June. The highest counts obtained during this period were 12-29 per min with an average 20 per min on the night of 2 May. Using 2.5 min as an average submergence time, an estimated 50 turtles may have been present. The total number of individuals involved could be even higher if a turnover occurs and new turtles arrive and others depart throughout the night. However, this is unlikely to be a significant factor since very few turtles ever reappeared once a major disturbance, like a diver entering the water, frightened them away.

The arrival of turtles near the outfall starting at sunset, and their increase after the end of twilight, are illustrated in Figure 11:1-1C. Also shown here is the approximate 35% decline in sightings that resulted when three persons started fishing from the top of the embankment by casting beyond where the turtles were aggregated. Figure 11:2-2C illustrates a similar scenario on the following night (11 April), only this time a lone fisherman was present from before sunset standing on the boulders right next to the outfall. He departed shortly after dusk at 1930. Until the time he left the turtle sightings remained very low. However, a small but noticeable increase occurred 30-45 min later, even though several other people started fishing 50 m to the east of the outfall in a much less illuminated section of the embankment. Representative sightings taken after dark on 1 May, when no direct human disruption occurred, are shown in Figure 11:3. Similar sightings for the following night appear in Figure 11:4. However, in this case a skin diver (one of the research personnel) spent 15 min surveying the area. As shown, an almost total abandonment of the area by the turtles subsequently took place. Figure 11:5-5A again illustrates a sighting period from sunset until after dark with no human intervention. Figure 11:6-7 covers several censuses during 4-9 May, one of which revealed the near absence of turtles due apparently to two fishermen standing close to the outfall.

The floodlight that normally comes on automatically shortly after sunset was placed on manual control and left off for several hours on the nights of 17-20 June. This was done to try to increase the chances of catching turtles in nets set nightly during this period. It also provided the opportunity to see what effect this point source of illumination might have on the presence of turtles near the outfall. Figure 11:8-10 suggests that little if any response was obtained when the light was switched on. Factors that may be an important consideration here include the array of other lighs in the vicinity, and the apparently exceedingly desirable nature of the heated water to the turtles. Any aversion the turtles may have to shoreline lighting might be overcome by the thermal advantage. It should also be noted that when the floodlight is turned on, it gradually reaches full illumination over a 5-min period, rather than immediate peak intensity. However, this may be of no significance since the headlights from nearby vehicles that sometimes enter the harbor at night periodically flash across the outfall area.

Foraging Habitat Appraisal

Observations made while skin diving at night revealed that the aggregated turtles were not foraging in the warm plume of clear water next to the outfall. Instead, the turtles seen here were either lying motionless on the bottom, or drifting in the shallow water column slowly back and forth along with the wave surge and flow from the outfall. The turtles were also hovering over one another, presumably to obtain maximum use of the warmest portion of the plume. Although the turtles fled within several minutes after the diver's arrival, it was still possible to confirm the absence of any feeding activity, given the excellent underwater clarity within the plume and large numbers (up to 28) viewed each time.

There were no benthic algae growing on the rubble and boulders which comprise the bottom where the highest density of turtles occurred. However, detached pieces of Codium spp. and A. spicifera were abundant. These algae commonly grow along the bottom starting 10-20 m from the clear-water plume and extend up to 300 m from shore. Codium edule and A. spicifera, the two major species in the stomach samples, were especially abundant in a 3 m deep channel present 100-300 m from shore slightly to the west of the outfall. Other algae commonly found included Amansia, Scinaia hormoides, and Dictyosphaeria cavernosa. At dusk turtles were almost always seen surfacing here, apparently occupying or transiting the area before moving closer to the outfall. Foraging seemed likely to occur throughout this rich algal zone, although it is too far away to make observations from shore at night. Turtles that could be seen commonly surfacing in turbid water much closer to the clear plume may have also been feeding on algae growing on the bottom.

Fresh frozen bulk samples of the two principal food sources, as well as another alga, C. reediae, were analyzed to compare nutrient composition (Tables 26 and 27). Codium reediae, although abundant, was not found in any of the stomach samples. The C. edule was harvested from the channel area approximately 200 m from shore, and at a site near the clear plume. The former location was beyond the direct thermal influence of the outfall, and the latter was well within it.

On a dry matter basis, Acanthophora contained more than twice as much protein (Table 26) and iron (Table 27) as C. edule. Acanthophora also had much higher levels of copper, manganese, and zinc than C. edule, but was noticeably lower in sodium, magnesium, and potassium (Table 27). The composition of C. edule, sampled at the two sites, varied for a number of nutrients; concentrations were generally higher in the plants growing close to the outfall. Prominent among these were protein (10.7% vs. 8.2%), fiber (26.6% vs. 21.8%), calcium (5.7% vs. 1.7%), iron (918 vs. 385 ppm), and manganese (425 vs. 44 ppm). The nutritional significance and reasons for these differences are unknown. However, the higher levels of protein might be expected to produce faster rates of growth in turtles utilizing this material. The higher concentrations of certain heavy metals in algae near the outfall could be due to various metallic debris and other litter present along the bottom, or possibly an elevated content in the discharge water.

While diving about 150 m from the outfall, an abandoned gill net was located and removed from the bottom where it had become fouled on calcareous outcroppings. This net was probably the same one in which a large (70-80 cm) turtle was found entangled on 8 October 1984 (see Balazs 1985c:405). Rescuers tried to cut the net loose, but the turtle swam away with a piece of line still wrapped around it's flipper. Other debris of significance found on the bottom included the scute from the carapace of a small (45 cm) turtle.

Many areas along the seaward side of the Kahului Harbor breakwater have dense intertidal growths of Pterocladia. It is especially visible at low tide growing on the light-colored concrete on the west side of the harbor entrance. This alga, along with a band of Ulva fasciata, also occurs on the boulder embankment immediately to the east (upwind) of the warmwater outfall. Although Pterocladia is available here in considerable abundance, the turtles are apparently not utilizing it to any great extent, based on the stomach samples obtained. In an earlier study of resident green turtles at Punaluu Bay on the Island of Hawaii, the sole source of food was Pterocladia. The most rapid growth rates thus far known for green turtles in the Hawaiian Islands occur at this location (Balazs 1982).

Inside the harbor there are profuse growths of U. fasciata on the rocks and other hard surfaces interspersed along the two sand beaches. Accumulations of decomposing Ulva and other algae often occur on this shoreline. In the vicinity of the boat ramp on the harbor's west side there are large quantities of the red alga, Hypnea musciformis. This species was introduced to the Hawaiian Islands from Florida in 1976. It is now sometimes found as a dietary component of green turtles, especially around Oahu (Balazs 1980b).

Turtles are reported to only rarely occur inside the harbor. None was observed during the present study. One person interviewed said that the same large turtle, identifiable by the pattern of barncles on its carapace, has been occasionally seen inside the harbor for the past several years.

Resting Habitat Appraisal

The warmwater area closest to the outfall can, to some extent, be considered resting habitat since most of the turtles seen there were in an inactive "resting" state. The principal motivation for occupying this site, however (other than for nearby foraging) is almost certainly for thermoregulation. That is, to elevate body temperature to accelerate metabolic processes such as digestion, growth, and reproduction. The complete absence of turtles in the vicinity of the outfall during the daytime strongly suggests that resting habitat of a more typical nature is being utilized elsewhere.

Other than the dredged harbor and entrance channel, the nearshore waters of the power plant are relatively shallow, and there is no structural relief along the bottom where turtles might find shelter to rest. Extremely high turbidity and hazardous conditions from vessel traffic prevented scuba diving along the channel entrance to search for resting sites. However, no turtles were seen at the surface in this area, as usually occurs where they rest in numbers along the bottom.

Besides the harbor channel, the nearest area of deep water to the power plant is located 1.0-1.3 km seaward, in a northerly direction beyond the breakers (Fig. 9). Significant resting habitat was identified here which is almost certainly being used by the turtles present at the outfall. The normally strong onshore tradewinds, high turbidity, and wind-driven swell made this area difficult to examine. However, for several hours following sunrise on 9 May 1985 calmer conditions prevailed which allowed a scuba survey to be undertaken.

The bottom outside the breakers was hard and relatively featureless in depths of 4-8 m. However, slightly farther offshore, there was a series of sheer-walled canyons with sand bottoms at depths of 20-25 m. One of these canyons that was no more than 15 m wide was examined by following it along the bottom for about 100 m. Three large turtles >82 cm were encountered resting under or within calcareous recesses in the canyon wall. One turtle was seen as it rapidly swam off, leaving a large cloud of suspended sand. The other two remained in their protective shelters, where they were positioned somewhat sideways and well aware of a diver's presence. One turtle moved a short ways farther into its resting place when the diver touched its flippers to confirm the absence of tags. Due to their large size, no attempt was made to catch the turtles by hand. Outside the canyon, another turtle was lying motionless between outcroppings on the bottom at a depth of 23 m. A fifth turtle was sighted in a shallower area (10 m) between two small live coral heads, but it was alert and immediately swam away. While at anchor and motoring through this offshore area, several turtles were also seen floating at the surface.

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Table 1.--Continued.

Date 1985	No. of personnel	Activity	No. of turtles captured (when attempted) Total	Recoveries
		Kahului Bay, Maui		
10-12 Apr.	2	Nocturnal census and observational studies from shore at warmwater outfall of the Maui Electric Plant. Diurnal skin diving survey.	--	--
1-10 May		Nocturnal census and observational studies from shore at warmwater outfall. One night of sampling with tangle nets. Bone biopsy and stomach sample collected. Nocturnal skin diving surveys. Diurnal scuba (to 19.8 m (65 ft)) and skin diving surveys using an inflatable boat.	1	0
17-21 June		Nocturnal sampling with tangle nets at warmwater outfall. Diurnal and nocturnal skin diving surveys. Nocturnal census and observational studies from shore. Bone biopsy, stomach, and blood samples collected. Deep-body temperatures recorded.	9	1
(20 days)		Subtotal	10	1
		Maunalua Bay, Oahu		
30 Apr.	3	Diurnal scuba surveys to a depth of 7.6 m (25 ft) involving 3 man-hours of bottom time. Stomach sample collected.	1	0
15 May	3	Diurnal scuba surveys to a depth of 10.7 m (35 ft) involving 3 man-hours of bottom time. Blood, bone biopsy, and stomach samples collected.	2	0

Table 9.--Epizoites sampled from four green turtles on Oahu, Molokai, and Maui.

Tag No.	Straight carapace length (cm)	Location	Epizoites
8495-96	44.9	Kawela Bay, Oahu	Sphacelaria tribuloides Polysiphonia tsudana Melobesia sp. Platylepas hexastylos (harmless skin barnacle) Small clawed shrimp larva
8545-46	52.2	Palaau, Molokai	S. tribuloides P. scropulorum Lyngbya semiplena
7917-18	57.4	Palaau, Molokai	S. furcigera P. tsudana P. setacea Pilinia rimosa Calothrix sp. Melobesia sp. Platylepas hexastylos
8479-81[1]	71.8	Kahului Bay, Maui	Chaetomorpha brachygona Melobesia sp. Polysiphonia sp. Platylepas hexastylos

[1]The burrowing barnacle, Stephanolepas muricata, was found along the anterior edge of the front flippers on six of the other turtles captured at this site. In addition, two turtles caught here had several Chelonibia testudinaria on their carapace and plastron. This nonburrowing, harmless barnacle is commonly found on green turtles at some locations in Hawaii, but not at the principal study sites covered in this report.

Table 13.--Deep-body temperatures of nine green turtles sampled at Kawela Bay, Oahu, and Kahului Bay, Maui.

Tag No.	Straight carapace length (cm)	Date 1985	Approximate time of capture	Deep body temperature (°C)
		Kawela Bay, Oahu		
8502-04	67.7	28 June	0030	26.7
8499-8500	60.9	28 June	0200	26.2
8497-98	47.6	28 June	0430	25.6
8495-96	44.9	28 June	0630	24.8
8761, 8763, 8505	64.9	2 July	2200	25.9
8506-07	67.0	3 July	0100	26.3
8510-11	50.2	3 July	0230	24.8
		Kahului Bay, Maui		
8468-71	92.0	18 June	2230	28.8
8479-81	71.8	19 June	0030	27.6

Ambient temperature on the west side of Kawela Bay at high tide was 26.5°-27.5°C. At low tide (0530-0700) it was 23°-24°C due to the greater influence of freshwater discharge from the spring.

Temperature in the outfall plume where the turtles were captured was 30°C. Farther from shore beyond the direct influence of the outfall the ambient temperature was 26.5°C.

Table 21.--Results of turtle netting effort near the warmwater outfall in Kahului Bay, Maui.

Field study date 1985	Duration in hours	Length of nets (m)	Netting effort (meter-hours)	No. of turtles captured	Meter-hours per turtle
7 May	5	9	45	1	45
17 June	7	18	126	1	126
18 June	6	36	216	[1]2	108
19 June	6	36	216	[1]0	--
20 June	6	55	330	[2]4	82
Overall	30	--	930	8	117

[1]An additional turtle was captured by hand on each of these nights while skin diving in the warmwater outfall.

[2]Includes the recapture of a turtle originally tagged on 18 June 1985.

Table 22.--Biometrics of nine green turtles sampled near the warmwater outfall in Kahului Bay, Maui.

	Carapace length		Carapace width					
Tag No.	Straight (cm)	Curved (cm)	Straight (cm)	Curved (cm)	Plastron length (cm)	Tail length/ sex (cm)	Head width (cm)	Front flipper width (cm)
8456-57	44.8	47.0	35.7	41.5	35.4	6.5(?)	7.0	7.8
8479-81[1]	71.8	76.0	55.9	69.0	56.8	12.5(?)	10.5	12.9
72/0-72	78.3	82.5	59.3	77.5	64.2	25.0(M)	10.7	13.6
8476-78	80.4	--	62.3	--	66.9	13.7(F?)	11.5	12.9
8482-85	86.0	--	65.5	--	68.4	20.3(F)	11.8	15.5
8464-67	86.2	90.5	--	--	70.4	40.2(M)	12.2	14.8
8472-75	90.2	--	63.9	--	71.2	22.0(F)	11.8	14.8
8468-71[1]	92.0	--	69.2	--	72.7	20.0(F)	12.3	14.6
8486-88[2]	96.5	--	73.0	--	78.0	28.0(F)	14.1	16.6

[1]Captured by hand while skin diving at night near the warmwater outfall.

[2]Numerous small tumors present on most skin surfaces and both eyes. This turtle was found dead of unknown causes at Nehe Point, 23 July 1986, 2.2 km north of where it had been tagged on 20 June 1985.

Table 23.--Identification of stomach contents sampled from seven green turtles near the warmwater outfall in Kahului Bay, Maui.

Tag No.	Straight carapace length (cm)	Sample contents (%) T = trace	
8456-57	44.8	*Pterocladia* sp.	T
		Laurencia sp.	T
8479-81	71.8	*L. nidifica*	50
		Amansia glomerata	25
		Acanthophora spicifera	25
		Chondrococcus hornemanni	T
		Ceramium sp.	T
		Codium edule	T
		Dictyota sp.	T
		Small crab	
		Terrestrial grass fibers	
		Sand	
7270-72	78.3 (M)	*C. edule*	99
		Antithamnion sp.	T
		Climacosphenia sp.	T
		Synedra sp.	T
8476-78	80.4 (F?)	*Codium edule*	99
		Acanthophora spicifera	1
		Amansia glomerata	T
		Champia parvula	T
		Laurencia nidifica	T
		Jania capillacea	T
		Pterocladia sp.	T
		Acrochaetium seriatum Boerg.	T
8482-85	86.0 (F)	*Acanthophora spicifera*	99
		Amansia glomerata	T
		Codium phasmaticum	T
8464-67	86.2 (M)	*C. edule*	95
		Acanthophora spicifera	T
		Hypnea musciformis	T
		Halimeda discoidea	T
		Red-orange paint chips	
		Small crab leg and eyes	
8472-75	90.2 (F)	*C. edule*	99
		A. spicifera	1
		Amansia glomerata	T
		Ahnfeltia concinna	T
		Hypnea pannosa	T
		Ceramium sp.	T

Table 24.--Injuries and abnormalities found on five green turtles near the warmwater outfall in Kahului Bay, Maui.

Tag No.	Straight carapace length (cm)	Description
8479-81	71.8	Hole in first right lateral likely caused by a spear or harpoon.
7270-72	78.3	Partially healed indentation 4.5 cm in diameter in third central scute of carapace. Possibly a gunshot wound that impacted underwater, or blow by a dull instrument.
8464-67	86.2	Thick mound of scar tissue around 1 cm diameter hole in right ventral region of neck. A likely spear puncture.
8468-71	92.0	Blind in right eye due to completely atrophied eyeball. Healed piece missing from right hind flipper.
8486-88[1]	96.5	Numerous tumors (fibropapillomas) on both eyes as well as the inguinal and axial regions. Healed pieces missing from the trailing edge of left front flipper.

[1]This turtle was found dead of unknown causes at Nehe Point on 23 July 1986, 2.2 km north of where it had been tagged on 20 June 1985.

Table 25.--Percent injuries and abnormalities found on different size classes of green turtles sampled on Oahu, Molokai, and Maui.

Location		Size class - straight carapace length (cm)					
		35-45	45-55	55-65	65-75	75-85	>85
Kawela Bay, Oahu	N = 34	14%	14%	0%	33%	0%	--
Palaau, Molokai	N = 133	0%	11%	8%	16%	67%	--
Kahului Bay, Maui	N = 9	0%	--	--	100%	50%	60%

Table 26.--Percent nutrient composition[1] of benthic algae collected near the warmwater outfall at Kahului Bay, Maui.

Algae (source)	Dry matter	Crude protein[3]	Ether extract	Ash	Neutral detergent fiber	[2]Acid detergent fiber	
						Permanganate lignin	Cellu-lose
Codium edule (near warmwater outfall)	7.4	10.7	0.5	57.0	26.6	3.4	6.9
C. edule (from channel 200 m offshore)	5.6	8.2	0.6	60.1	21.8	3.5	6.2
C. reediae (near warmwater outfall)	5.3	12.2	0.8	53.5	23.8	2.5	5.6
Acanthophora spicifera (near warmwater outfall)	6.8	23.2	0.1	45.3	23.1	6.8	8.9

[1]Reported on a dry matter basis as determined by the "proximate analysis" method commonly used for terrestrial animal forage.

[2]Present in benthic algae as a complex polysacchride; not true lignin or cellulose as found in terrestrial plants.

[3]Nitrogen × 6.25.

Table 27.--Mineral composition[1] of benthic algae collected near the warmwater outfall in Kahului Bay, Maui.

Algae (source)	Percentage					Parts per million			
	Ca	P	K	Mg	Na	Fe	Cu	Mn	Zn
Codium edule (near warmwater outfall)	5.68	0.11	2.88	1.84	>8.75	918	13	425	10
C. edule (from channel 200 m offshore)	1.68	0.09	4.45	1.98	>8.75	385	10	44	9
C. reediae (near warmwater outfall)	1.15	0.14	1.13	1.60	>8.75	251	34	244	21
Acanthophora spicifera (near warmwater outfall)	4.38	0.29	1.44	0.80	0.95	1,838	198	1,036	67

[1]Dry matter basis. Ca = Calcium; P = Phosphorus; K = Potassium; Mg = Magnesium; Na = Sodium; Fe = Iron; Cu = Copper; Mn = Manganese; Zn = Zinc.

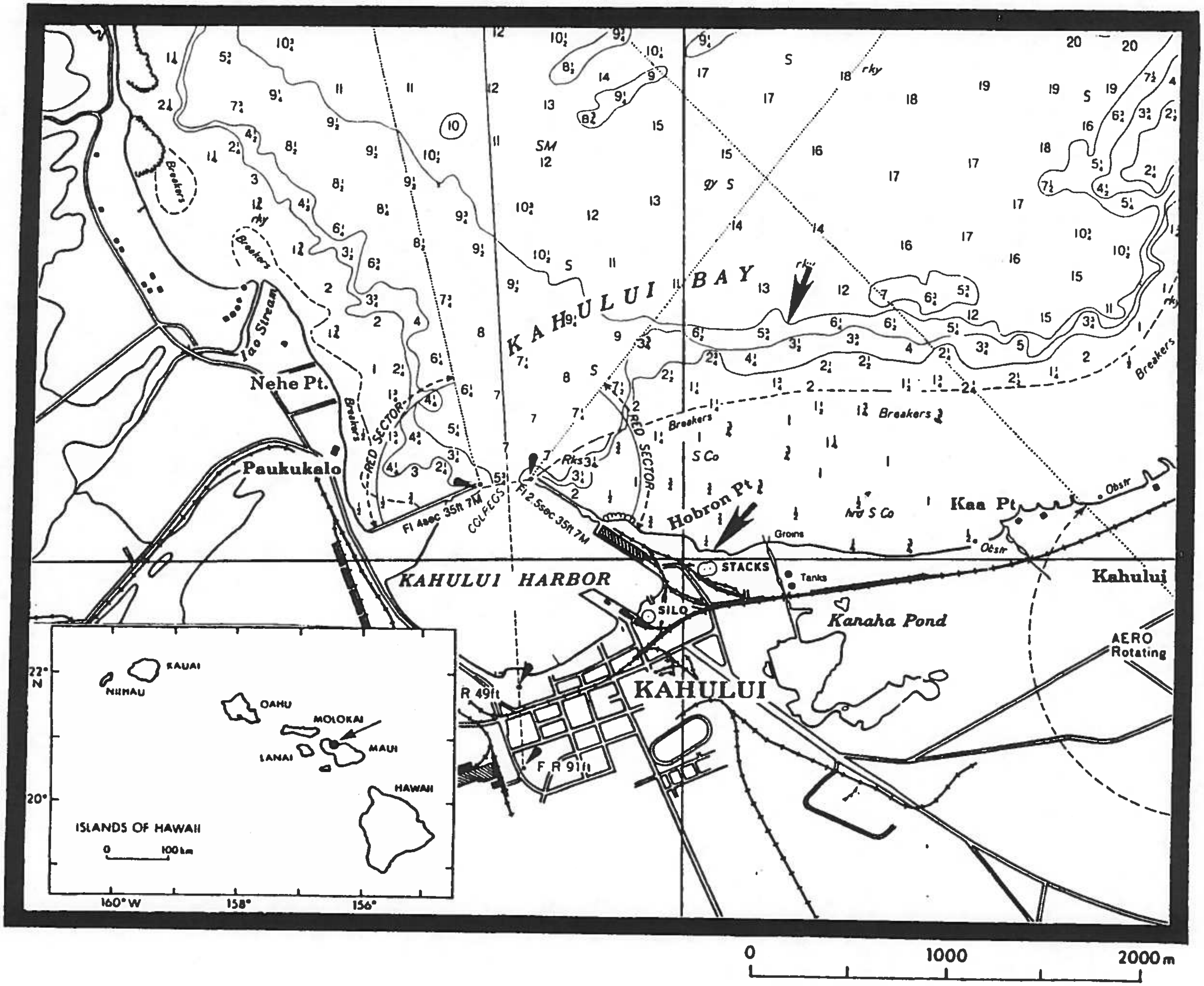


Figure 9.--Kahului Bay, Maui, lat. 20°54'N, long. 156°28'W. Adapted from NOAA chart 19342 (depth in fathoms).

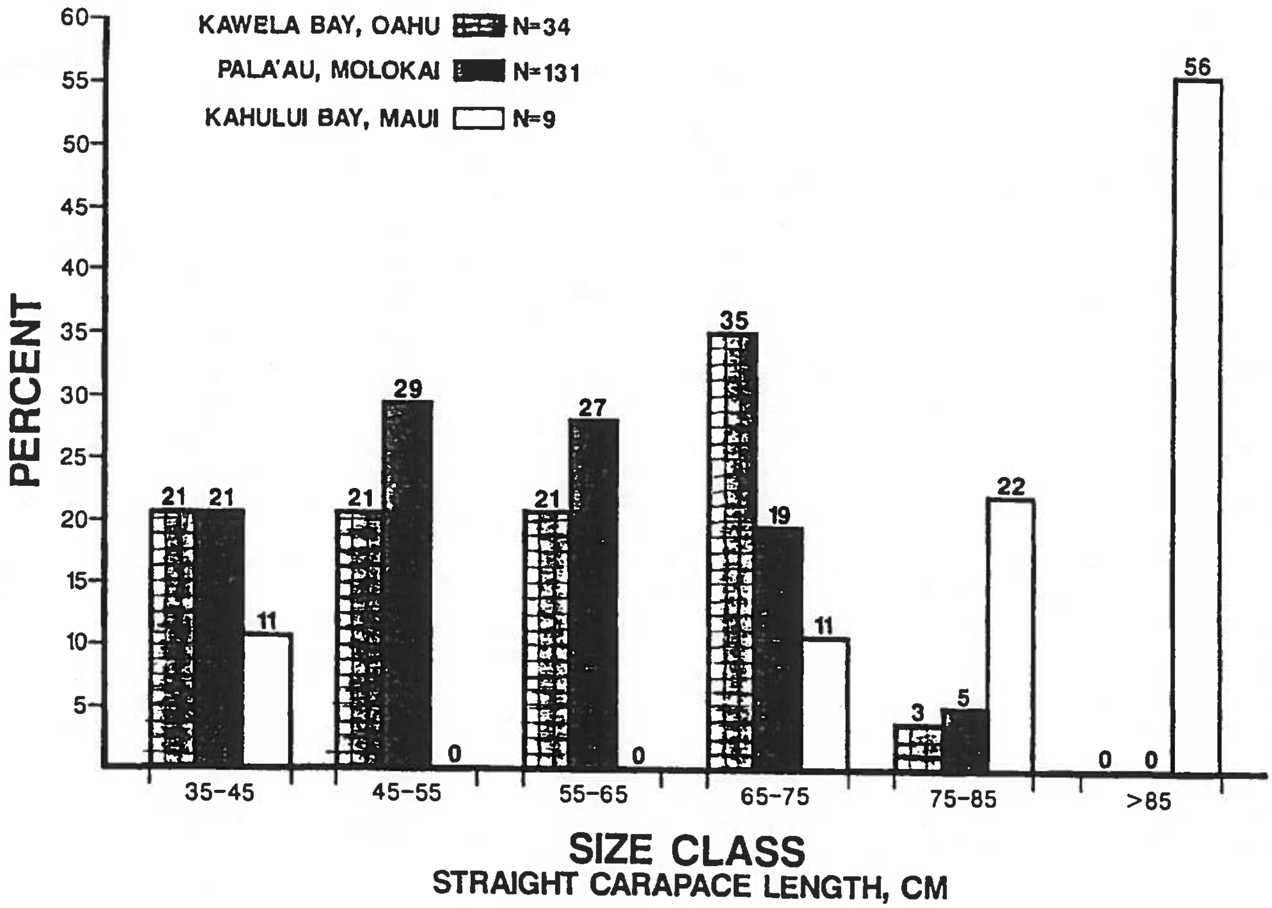
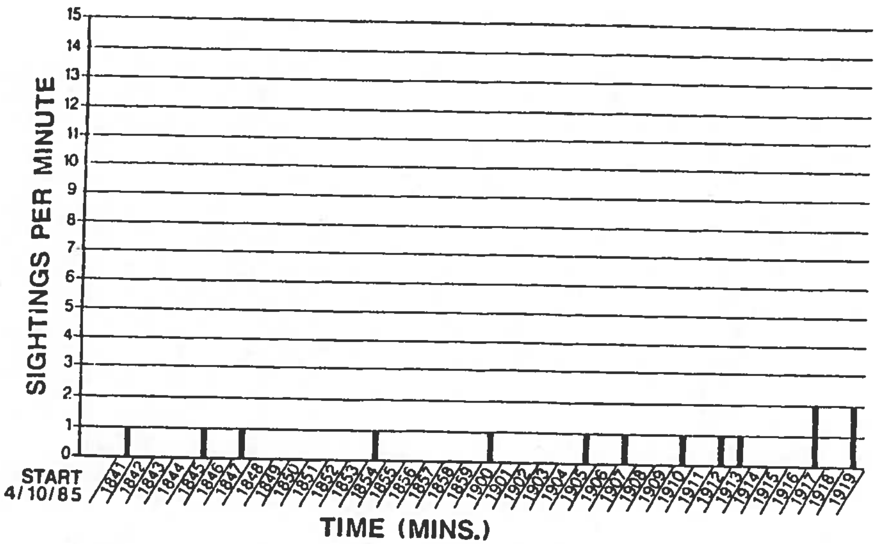
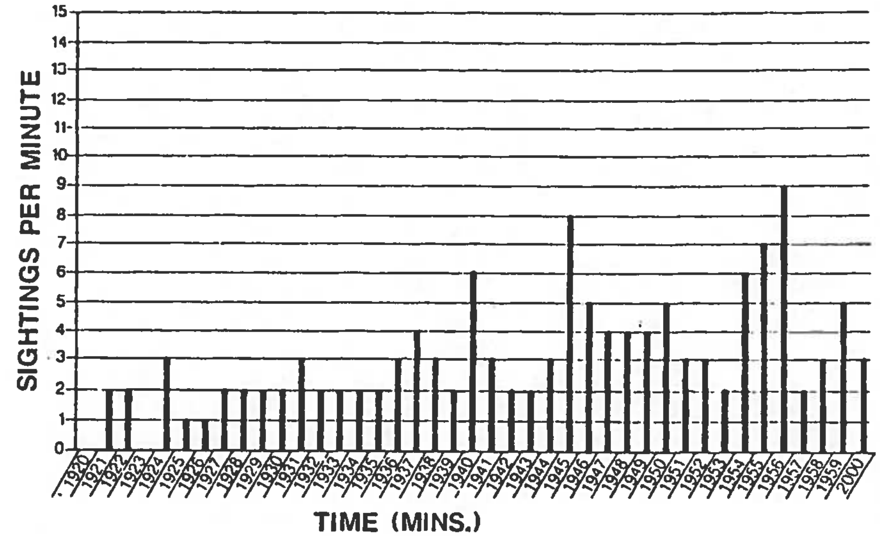


Figure 10.--Size classes in 10-cm increments of green turtles sampled at Kawela Bay, Oahu; Palaau, Molokai; and Kahului Bay, Maui.



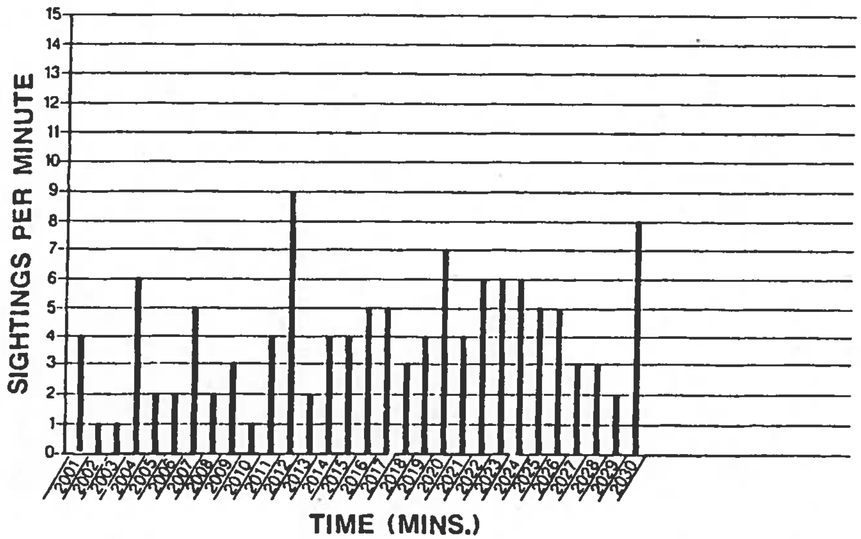
1

Sunset at 1850. Floodlight on at 1900. Brisk onshore tradewinds and choppy seas.



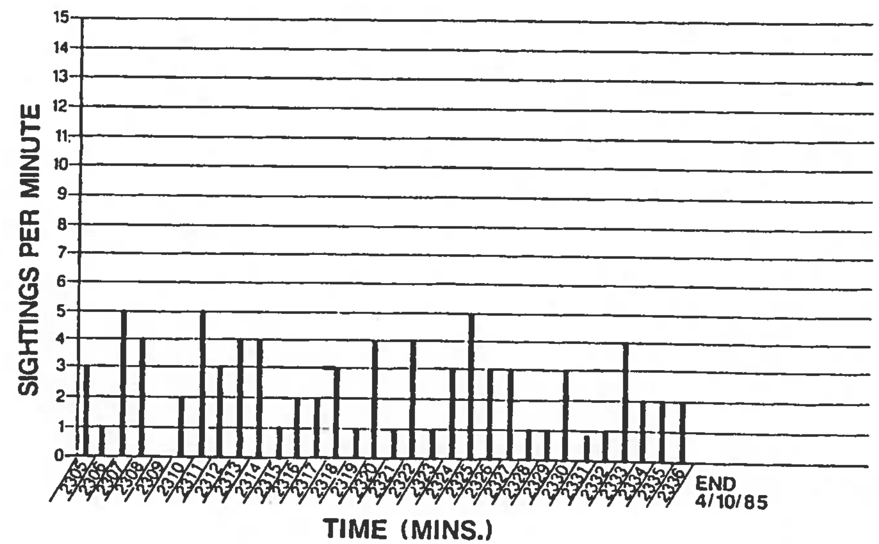
1a

End of observable twilight at 1930. High tide of 0.6 m (1.9 ft) at 2000.



1b

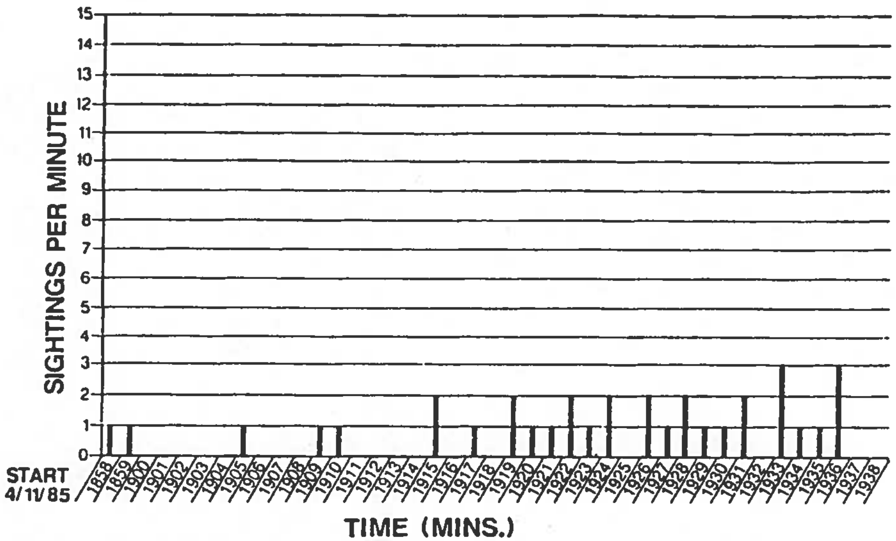
Three persons with rods and reels arrived at 2030 and commenced fishing from the elevated boulder embankment above the warmwater outfall. Counts not made from 2031 to 2304.



1c

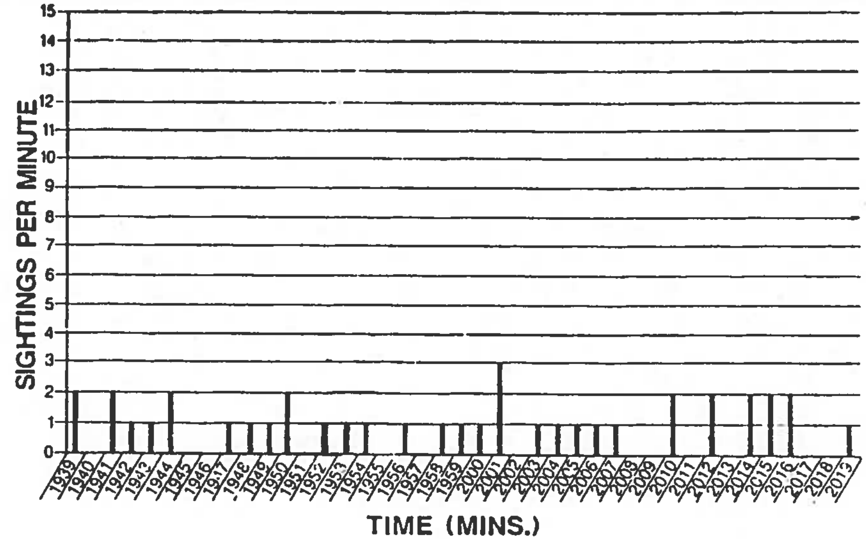
Fishermen departed at 2330.

Figure 11.--Sightings of green turtles surfacing to breathe near the warmwater outfall in Kahului Bay, Maui.



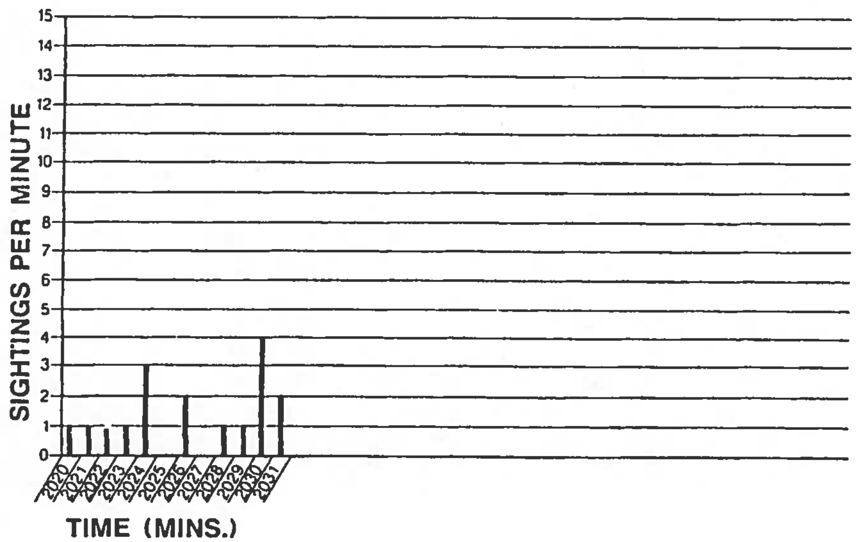
2

Sunset at 1850. Floodlight on at 1900. Gentle offshore winds and calm seas. Moon in last quarter. Fisherman casting from boulders at sea level right next to warmwater outfall.



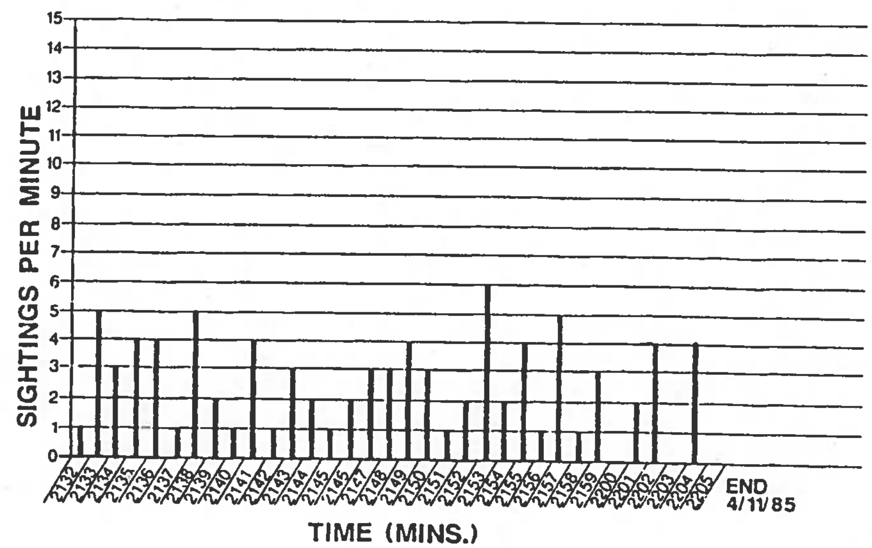
Fisherman departed. High tide of 0.5 m (1.8 ft) at 2045. End of observable twilight at 1930.

2a



No counts made from 2032 to 2131.

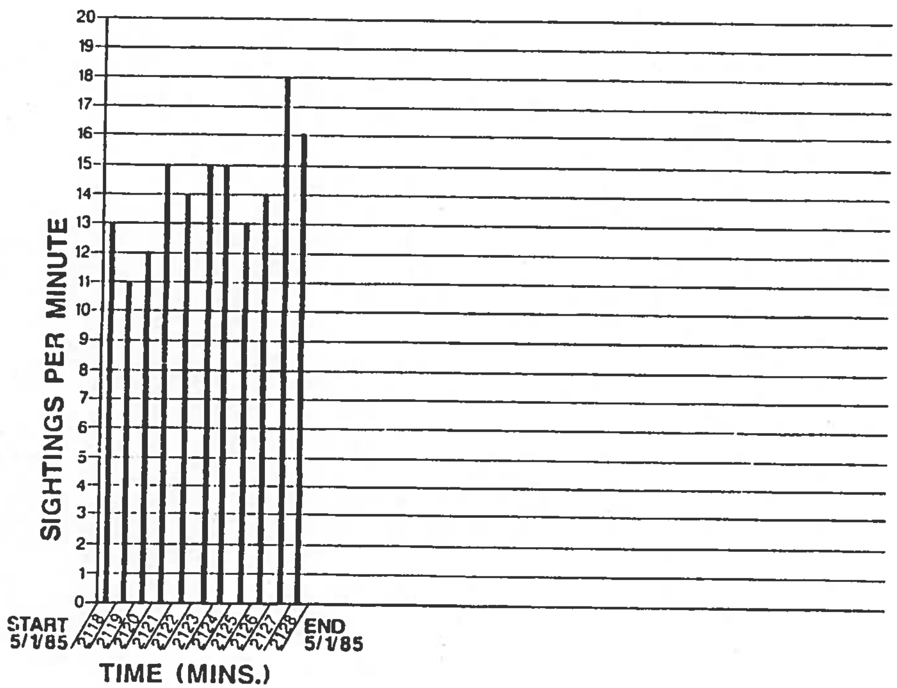
2b



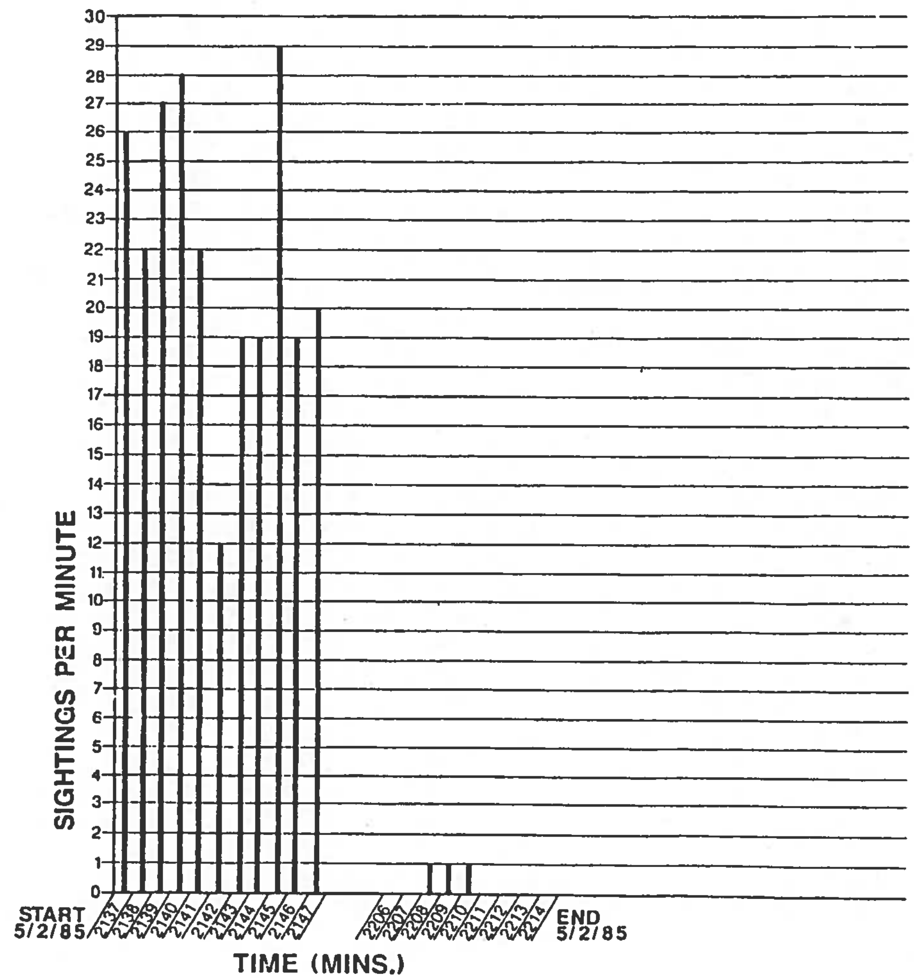
Several people fishing from elevated embankment 50 m to the east of warmwater outfall.

2c

Figure 11.--Continued.

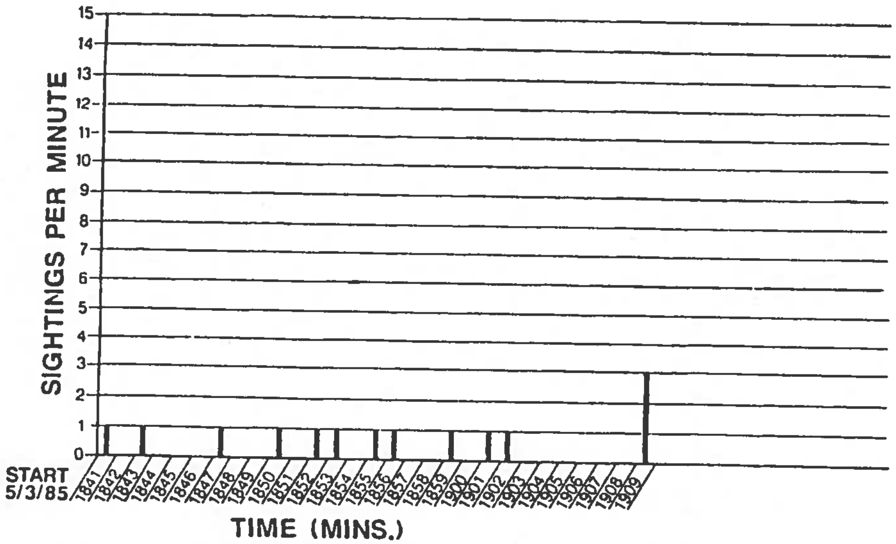


Floodlight on. High tide of 0.4 m (1.3 ft) at 2330. Low tide of 3 cm (0.1 ft) at 1815. **3**



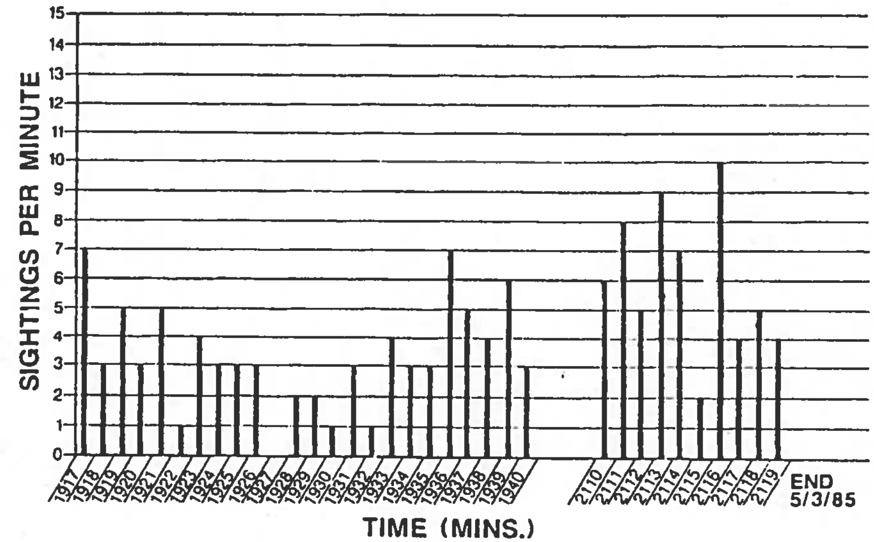
Floodlight on. High tide of 0.4 m (1.4 ft) at 0030 (3 May). Low tide of 0 m at 1900 (2 May). Light winds and calm seas. Skin diving survey was made by one person in the warmwater outfall from 2148 to 2205. **4**

Figure 11.--Continued.



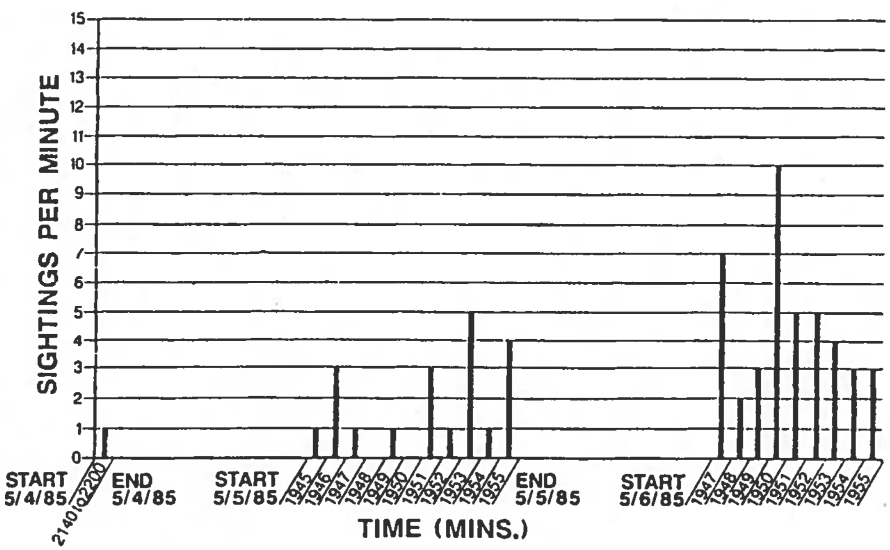
Sunset at 1900. Floodlight on at 1910. Low tide of 3 cm (0.1 ft) at 1930. Full moon occurred on the following night (4 May).

5



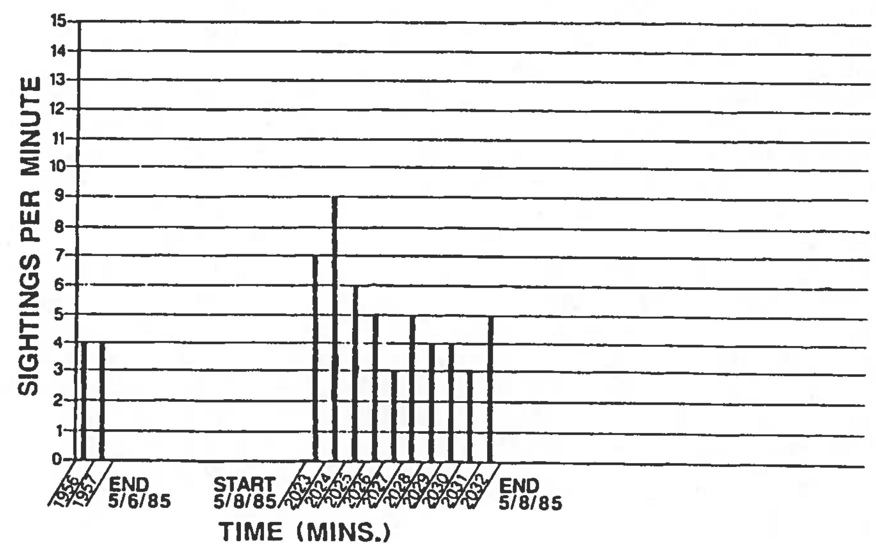
Moderate onshore winds with choppy seas. End of observable twilight at 1940. Counts not made from 1941 to 2109.

5a



Two fishermen right next to warmwater outfall on 4 May. Floodlight on. Only one sighting made during 20 min of observations. Fishermen likely present earlier in the evening on 5 May. Light winds and calm seas on 5 and 6 May. Floodlight on both nights.

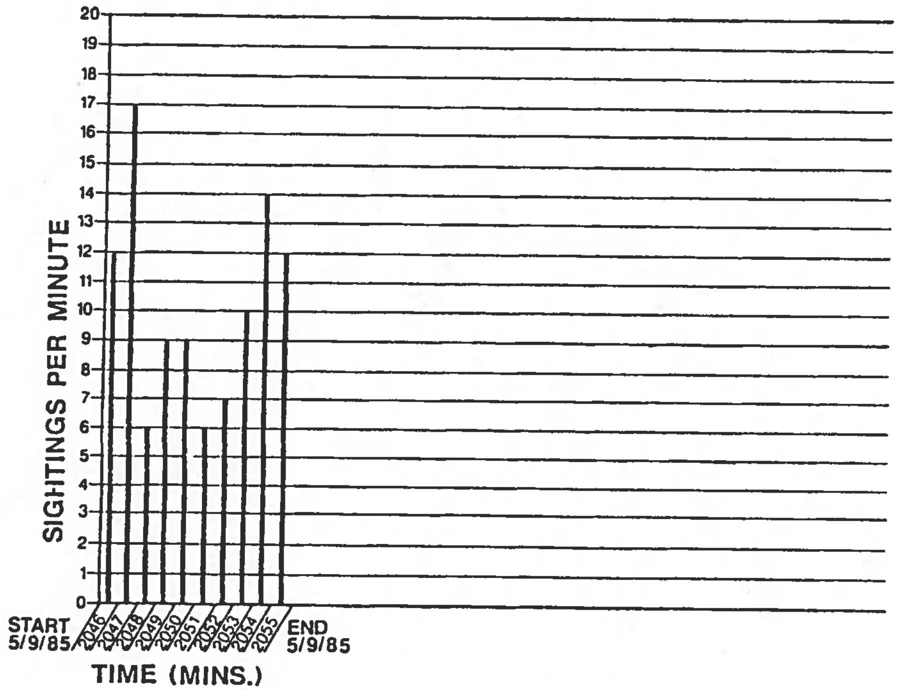
6



Moderate onshore tradewinds on 8 May. Floodlight on.

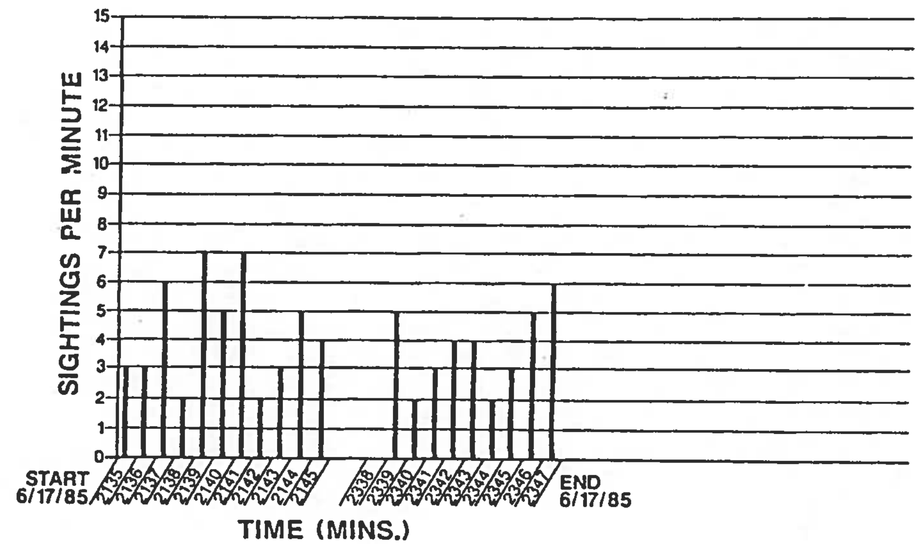
6a

Figure 11.--Continued.



Floodlight on. Brisk onshore tradewinds. High tide of 0.6 m (1.9 ft) at 1900. Moon in last quarter.

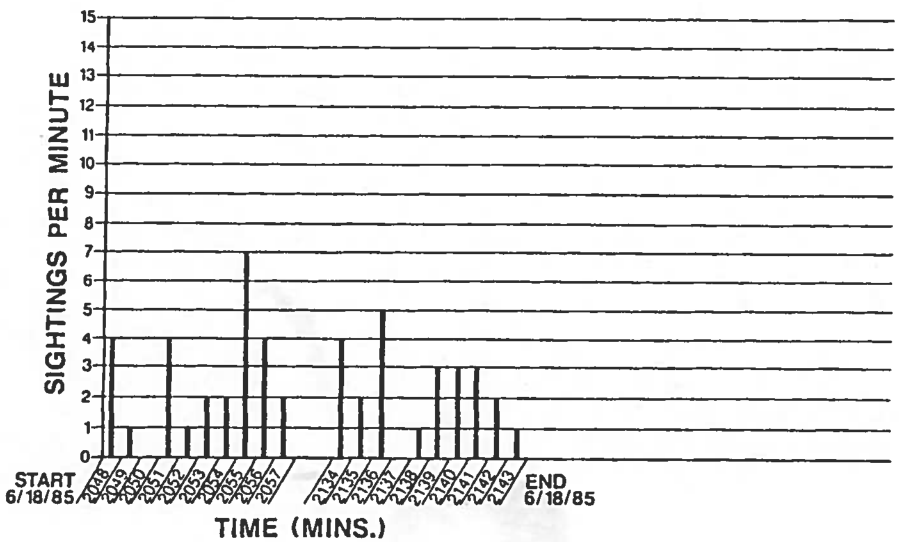
7



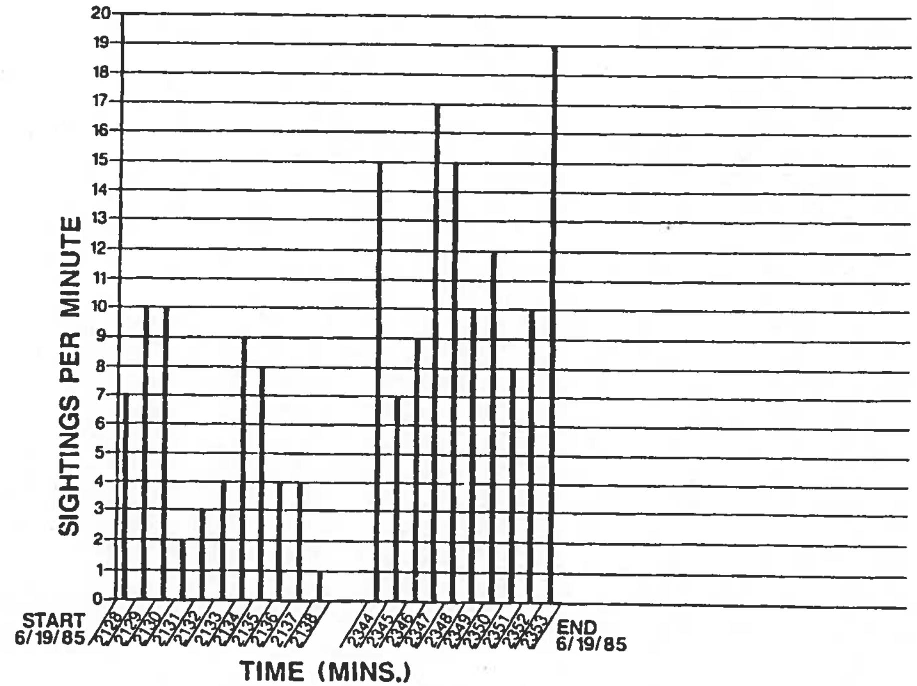
Large-mesh tangle net set by warmwater outfall from 1800 17 June to 0100 18 June. One turtle captured. Floodlight not turned on until 2335. No counts made from 2146 to 2337. Low tide of 0.6 m (0.2 ft) at 2200. Brisk onshore tradewinds.

8

Figure 11.--Continued.



Large-mesh tangle net set by warmwater outfall from 1800 to 2400. Two turtles captured. Floodlight not turned on until 2130. No counts made from 2058 to 2133. Brisk onshore tradewinds. **9**



Large-mesh tangle net set by warmwater outfall from 1830 to 0108 (20 June). No turtles captured. Floodlight not turned on until 2340. No counts made from 2139 to 2343. Low tide of 6 cm (0.2 ft) at 2300. Brisk onshore tradewinds. **10**

Figure 11.--Continued.