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THE MARINE TURTLES IN HAWAIIAN ISLANDS

1988 REVIEW

by

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Recovery Plan for Hawaiian Sea Turtles

Prepared by
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INTRODUCTION

The preparation of recovery plans are required for all species listed under the U.S. Endangered Species Act,. unless it is determined that a species will not benefit from such action. The Act allows for the formation of recovery teams responsible for developing recovery plans. A recovery plan for threatened and endangered sea turtles in the southeastern United States (western Atlantic, Caribbean, and Gulf of Mexico) has already been prepared by a recovery team and formally approved in September of 1984.

The present draft recovery plan for Hawaiian sea turtles was prepared by a recovery team appointed in 1985. The team met on five occasions, three of which involved several days of deliberations (October 22-25, 1985, April 29-May 2, 1986; and January 20-23, 1987). In addition, a team member (Dr. Harold F. Hirth) who was unable to attend the January 1987 meeting came to Hawaii September 14-17, 1987 to work with the team leader to finalize the draft plan. The plan represents the best scientific efforts and unanimity of professional opinion by the recovery team members.

This Recovery Plan for Hawaiian Sea Turtles contains separate plans for the two species with breeding populations in the Hawaiian Islands. They cover the green turtle, Chelonia mydas, and the hawksbill turtle, Eretmochelys imbricata. In addition, there is a combined plan for the leatherback, Dermochelys coriacea, and olive ridley, Lepidochelys olivacea, both of which occur in Hawaiian water but nest elsewhere. It was the decision of the recovery team to make each plan a complete product in it self, thereby requiring some necessary repetition where equivalent problems and solutions were identified for each species. Each plan consists of a series of concise recovery actions of either a management or research nature. The ultimate goal of these actions is to secure habaitat, and restore and maintain Hawaiian sea turtle populations at levels of abundance commensurate with the carrying capacity of the habitat (i.e., a state of biological recovery).

The recovery actions in each plan have been divided into two main elements that address limiting factors based on sea turtle habitat usage in 1) the marine environment, and 2) the terrestrial environment. This method of partitioning should prove beneficial for two reasons. First, it will help to simplify a potentially complex subject and aid the reader in better understanding the scope and nature of the recovery problems identified and solutions offered. As oviparous reptiles, sea turtles have two environmental components critical to their life cycle--terrestrial nesting beaches where eggs incubate; and marine foraging and resting areas in nearshore waters or, for some life stages and species, in the pelagic zone. Secondly, since federal jurisdictional responsibilities for the protection, management, and research of sea turtles are shared along terrestrial and marine boundaries, the division used in this plan should help the National marine Fisheries Service (NMFS) and Wildlife Service (USFWS) focus their respective agency resources in the mandated cooperative approach to achieve recovery.

Because many of the other Federal and State agencies involved with Hawaiian sea turtle management and research activities do not necessarily share the same priority of recovery actions within their statutory mandates or operating procedures, these agencies are not specifically identified for each recovery action. It is intended that agencies and organizations with responsibilities or expertise within any of the listed recovery actions would consider the highest applicable rated items in each section first in their operational plans. Where it is clear that certain agencies such as the NMFS, USFWS, State of Hawaii, U.S. Coast Guard, National Park Service, and military agencies have specific jurisdictions or legal requirements, they are identified for each appropriate recovery action.

An implementation schedule was not included in the Recovery Plan since many of the management and research actions are either on-going or require supplemental funding to complete or initiate.

It was not considered necessary, nor within the scope of this plan, to provide details on how to implement each of the recovery actions. However, some priorities were established by the team for major recovery tasks for each species. These priorities, summarized in the following section, were divided into separate categories for management and research, since the two activities are complementary rather than competitive with one another. The setting of certain priorities in this manner should help all of the involved agencies in obtaining any additional funds needed to do the work.

PRIORITIES FOR THE RECOVERY OF HAWAIIAN SEA TURTLES

Priority listings by species

Due to its designation as an endangered species under federal and state law, and the inadequate knowledge of its life history and ecology, the Hawaiian hawksbill is considered to be the sea turtle species of highest priority for recovery actions.

Accordingly, the Hawaiian green turtle is designated as the next order of priority because of its listing as a threatened species.

In view of the fact that the leatherback (listed as endangered) and the olive ridley (listed as threatened) have no known historical or present breeding populations in the Hawaiian Islands, these species are given a lower priority in recovery actions.

Prioritized listings within species for important management and research actions

Baseline monitoring to ascertain population status and trends, and nesting habitat carrying capacity, is considered fundamental to all recovery actions (see Appendix 1).

Hawaiian Hawksbill

Priority Management Actions

1. Implement immediate protection of existing nests in order to maximize natural hatchling production.

2. Inform and educate the public of the endangered and protected status of the Hawaiian hawksbill.

3. Implement as appropriate the required actions to reduce or eliminate incidental mortality and injury by fishing nest.

4. Increase and enhance law enforcement efforts to protect the Hawaiian hawksbill.

5. Protect known terrestrial and marine habitats used by the Hawaiian hawksbill.

6. Initiate captive breeding efforts for conservation purposes.

Priority Research Actions

1. Identify all essential terrestrial and marine habitats used by the Hawaiian hawksbill.

2. Document the full scope and magnitude of incidental mortality and injury by fishing nest.

3. Determine the food and foraging requirements of the Hawaiian hawksbill.

4. Investigate the sources and levels of egg and hatchling predation on the beach and evaluate the potential for management action.

5. Investigate predation by sharks and evaluate the potential for management action.

Hawaiian Green Turtle

Priority Management Actions

1. Protect marine and terrestrial habitats used by the Hawaiian green turtle.

2. Inform and educate the public of the threatened and protected status of the Hawaiian green turtle.

3. Increase and enhance law enforcement efforts to protect the Hawaiian green turtle.

4. Implement as appropriate the required actions to reduce or eliminate incidental mortality and injury by fishing nest.

5. Rescue and release hatchlings trapped in the nest by soil and vegetation impediments.

6. Encourage additional captive breeding efforts for conservation purposes.

Priority Research Actions

1. Investigate the incidence, impact, and cause of tumors in Hawaiian green turtles.

2. Increase and expand efforts to identify nearshore, pelagic, and terrestrial habitats used by the Hawaiian green turtle.

3. Document the full scope and magnitude of incidental mortality and injury by fishing nest.

4. Investigate the levels of hatchling predation by ghost crabs and evaluate the potential for management action.

5. Investigate predation by sharks on all life stages and evaluate the potential for management action.

6. Determine foraging habitat characteristics as they relate to differential growth rates and age of maturity in Hawaiian green turtles.

7. Assess the impact of synthetic debris and other pollutants on Hawaiian green turtles in pelagic developmental habitat.

8. Evaluate experimental headstarting for conservation purposes using captive-bred hatchling Hawaiian green turtles.

Leatherback and Olive Ridley in Hawaiian Waters

Priority Management Actions

1. Implement appropriate actions to eliminate or reduce incidental injury and mortality by fishing activities in the pelagic zone.

2. Inform and educate the private and commercial sectors to report sightings of leatherbacks and olive ridleys in marine and terrestrial habitats.

3. If an when additional nestings occur, provide immediate protection to nests through the incubation period and supervise the safe release of hatchlings.

Priority Research Actions

1. Document and investigate all incidental mortality and injury reported.

2. Catalog all sightings of individuals at sea and on land.

3. Assess the impact of pollutants and synthetic debris on all life stages in the pelagic zone.

Biological Overview of the Hawaiian Hawksbill

A serious shortage of information exists on all aspects of the life history and ecology of the hawksbill turtle in the Hawaiian Islands. Along with the green turtle, hawksbills were well known in the early Hawaiian culture. However, unlike the green turtle, the hawksbill was apparently not esteemed as food, probably due to sporadic fatal poisonings such as have been recorded elsewhere, even to the present time. Studies on other hawksbill populations have determined the species to be primarily a spongivore. This dietary factor is believed to somehow account for its occasional toxicity. The single adult Hawaiian hawksbill thus far examined for stomach contents (from a gill-net mortality) was filled to capacity with sponges. Another dead hawksbill examined--a juvenile washed ashore from pelagic habitat--had a massive intestinal blockage caused by hundreds of small pieces of ingested plastic debris.

Hawksbill nesting only occurs in the main Hawaiian Islands, primarily on several small sand beaches along the east coast of the Island of Hawaii., Two of these sites (Halape and Apua Point) are at a remote location in the Hawaii Volcanoes National park. Not all of the presently known hawksbill beaches have turtles nesting on them each year. The most consistently used sites seem to be at Kamehame Point on Hawaii, and a black sand beach at the river mouth of Halawa Valley at the east end of Molokai. Probably not more than three hawksbills per year nest at each of these two locations. Overall, there many not be more than a dozen hawksbills nesting annually on all beaches combined. From the little information that is available, the nesting season appears to extend from July through November.

There are no modern-day records of nesting hawksbills or their occurrence in nearshore marine habitat anywhere in the Northwestern Hawaiian Islands. According to some early historical accounts, hawksbills may have occupied this region in past centuries.

None of the known nesting beaches have shred usage by both hawksbills and green turtles (or any other sea turtle species). However, certain underwater resting habitats used by green turtles in nearshore waters along the east coast of the Island of Hawaii are reported to also be occupied by hawksbills.

Additional but limited background information available on the Hawaiian hawksbill can be found in the supporting literature shown in the bibliography.0

Hawaiian Hawksbill Recovery Actions for Limiting Factors

I. Marine Environment

A. Human Take

1. Increase surveillance and active law enforcement by developing a coordinated plan to prevent illegal capture, mortality, and trafficking. The directed capture of hawksbills takes place along with green turtles in Hawaii due to their similarity of appearance. Turtles are taken using spears, harpoons, nest, grappling hooks, firearms from shore, underwater bang sticks, nooses, and by hand capture. Elicit the cooperation of enforcement branches of the National Marine Fisheries Service, State of Hawaii, U.S. Fish and Wildlife Service, U.S. Customs Service, National Park Service, U.S. Coast Guard, country police departments, military agencies, and other authorities to apprehend and prosecute violators. Encourage the public to report suspected violations.

2. Eliminate intentional and unintentional harassment of hawksbills. Activities such as ski and scuba diving, vessel traffic, jet skis, and vessel anchoring may disturb or displace hawksbills These factors should be regulated or controlled to eliminate impacts, especially in sensitive and/or high density foraging and resting areas, nearly all of which are yet to be determined.

3. Establish networks to report incidental take. Along with (1) and (2) above, encourage reporting of incidental take of all dead or alive hawksbills resulting from nets, hooks, traps, monofilament fishing line, rope, debris ingestion and

entanglement, vessel collisions, explosives, and such illegal fishing methods as the use of "Clorox" and other chemicals. Inform fishermen and others involved in these networks how to identify the hawksbill and distinguish it from the green turtle. Special attention should be directed to documenting the incidental take of pelagic turtles by driftnets and longlines in the Hawaiian region.

4. Expand and enhance networks to report strandings. Along with (1), (2), and (3) above, promote the reporting of any hawksbill out of its element or in a physiologically distressed state. Dead turtles should continue to be salvaged for necropsies, and live turtles should be brought into captivity for possible rehabilitation. No diseased turtle should be returned to the wild.

5. Educate and inform the public on the endangered and protected status of the hawksbill in marine habaitat. The general public, including school children, fishers, scientific researchers, boat operators, military personnel, and tourists should be made aware of the fact that the hawksbill is an endangered and protected species in Hawaii, and that foraging and resting sites are sensitive and important areas worthy of protection.

6. Establish information and education programs extolling the role of the hawksbill turtle in the cultural heritage of Hawaiians and other ethnic backgrounds in Hawaii. By means of advertising and educational programs, promote the virtues of the environmental, conservation, and historical ethic.

7. Permitted research and management activities involving hawksbills may be allowed provided the benefits to the hawksbill population outweigh the costs. Permitted research and management actions involving other species and activities must be evaluated by the appropriate agencies to eliminate or minimize to acceptable levels any impacts on the hawksbill.

Hawaiian Hawksbill Recovery Actions for Limiting Factors

I . Marine Environment

B. Predation

1. Investigate the extent and severity of natural predation on hatchlings by sharks, finish, and seabirds in nearshore waters of breeding areas. Protection plans including predator control should be commensurate with the degree of predation identified.

2. Investigate the extent and severity of natural predation on juveniles in pelagic habitat. These studies are contingent upon determining the location of this marine habitat and identifying the predators involved. Protection plans, if feasible in this extensive and dynamic oceanic region, should be commensurate with the degree of predation identified.

3. Investigate the extent and severity of natural predation on immature and adult hawksbills in nearshore benthic habitat by sharks and finish. Turtles have been recorded in Hawaii amongst the stomach contents of sharks and groupers. Protection plans including predator control should be commensurate with the degree of predation identified.

Hawaiian Hawksbill Recovery Actions for Limiting Factors

I . Marine Environment

C. Disease

1. Investigate the incidence and impact of parasites and infectious agents on hawksbills. Virtually nothing is known in Hawaii about the occurrence of bacterial infections (e.g., Vibrios), virus and parasites such as blood flukes, leeches and burrowing barnacles, and possibly tumors, in the hawksbill.

2. If feasible, cooperate in investigations of the etiology of poisoning by hawksbills as it relates to human populations at other Pacific locations. In recent years, cases

involving mortality and severe illness from eating hawksbills have occurred in Tonga and Fiji. Sporadic outbreaks of poisonings are known worldwide and are thought to be due to some component of the hawksbills' prey items.

Hawaiian Hawksbill Recovery Actions for Limiting Factors

I . Marine Environment

D. Habitat Alteration

1. Maintain natural habitats. Emphasis should be placed on the maintenance of natural hawksbill ecosystems. The burden of proof, beyond a reasonable doubt, rests on the advocated in altering the natural condition.

2. Locate and assess foraging and resting habitats for the hawksbill. Foraging and resting areas are for the most part currently unknown. Baseline information is required to identify and understand natural and man-induced habitat alterations.

21. Important foraging and resting grounds should be designated for special consideration as natural preserves.

22. Shelter type, tides, temperature, salinity, and pressure they relate to depth should be investigated.

3. Eliminate adverse human induced habaitat alteration in order to maintain foraging and resting habitats.

31. Petrochemical pollution sources can range from small spills related to bilge pumping or broken transmission lines to large scale tanker spills. Spill contingency plans should be reviewed with respect to protecting foraging and resting sites.

32. Major spills or other pollution events need immediate response to determine what clean-up measures are required. Attention should be given to the clean-up measure to ensure that their impacts on hawksbills and their foraging and resting habitats are not greater than the spill itself.

33. Identify sources of synthetic debris that may entangle or be ingested by hawksbills in foraging and resting habitats,both in the nearshore and pelagic environment. Abatement programs should be initiated.

34. Prevent or mitigate impacts from dredging. Cumulative and secondary impacts, and loss of nearshore habitat, need to be quantified.

35. Assess the presence and impact in hawksbills of pesticide, herbicide, and other toxic agents used by humans that enter the coastal marine environment.

36. Minimize the effects of artificial illumination from vessels and onshore sources during the period of hatchling emergence in hawksbill breeding areas.

4. Investigate natural events that adversely impact foraging and resting habitats. For example, tsunamis have been known to hurl turtles in foraging pastures far up on shore where they died after being unable to return to the sea.

41. Compile historical information on catastrophic geological and climatological events, such as tsunamis, hurricanes, the "El Nino effect," lava flows, acid rain, coastal forest fires, and earthquakes. Such data will be used to determine the potential impact of future catastrophic events.

42. As for items for the hawksbill become known, investigate natural fluctuations in abundance and distribution.

43. Investigate the dynamics of oceanic currents, gyres, and zones of convergence as they relate to pelagic life stages and recruitment to nearshore benthic habaitat. Studies have suggested that the hawksbill passes through a pelagic stage of development similar to the green turtle and other sea turtle species.

Hawaiian Hawksbill Recovery Actions for Limiting Factors

II. Terrestrial Environment

A. Human Take

1. Increase surveillance and active law enforcement by developing a coordinated plan to prevent illegal capture, mortality, and trafficking. Elicit cooperation of enforcement branches of the U.S. Fish and Wildlife Service, U.S. Customs Service, National Park Service, U.S. Coast Guard, National Marine Fisheries Service, State of Hawaii, country police departments, military agencies, and other authorities to apprehend and prosecute violators and to encourage the public to report suspected violations.

2. Eliminate uninterntional and intentional harassment of hawksbills. Aircraft should not land nor fly low over nesting sites. Campers, hikers, beach combers, fishers, and other recreationists should be informed to report, but not disturb, nests, nesting turtles and hatchlings.

21. Egg nests and hatchlings are susceptible to crushing and hatchlings are disoriented by vehicles on nesting beaches. Hatchlings may also be deterred by tire tracks from reaching the ocean, thereby increasing their exposure to desiccation and predation. Adult females may be struck while ascending or descending the beach or while nesting. Elicit cooperation of appropriate law enforcement agencies and other public and private entities, including landowners, to eliminate vehicles on known nesting beaches.

22. Shoreline development resulting in increased human interactions with hawksbills on the beach should be controlled or eliminated to reduce adverse impacts.

23. Military exercises and other military activities should be evaluated regarding the potential to disturb nesting hawksbills. Consultations should occur at the earliest possible time with the agencies involved in eliminating or mitigating potential impacts.

3. Educate and inform the public about the endangered and protected status of the hawksbill on the nesting beach. The general public, including school children, fishers, scientific researchers, boat operators, military personnel, and tourists should be made aware of the fact that the hawksbill is an endangered species in Hawaii, and that nesting beaches are sensitive and important areas worthy of protection.

4. Permitted research and management activities involving hawksbills may be allowed provided the benefits to the hawksbill population outweigh the costs. Permitted research and management actions involving other species and activities must be evaluated by the appropriate agencies to eliminate or minimize to acceptable levels any impacts on the endangered hawksbill.

5. Experimental breeding efforts for conservation purposes should be encouraged using to the extent possible turtles presently in captivity. An adult female of known Hawaiian ancestry is currently in captivity at Sea Life Park which offers, in part, the potential for captive breeding for restocking purposes. A small number of wild hatchlings, preferably those rescued from natural entrapment in nests or otherwise doomed circumstances, should be raised in captivity should ideally be related at known nesting beaches on the following night Head starting with captive-bred hatchlings to a size appropriate for release into coastal foraging pastures is also encouraged for experimental restocking purposes. All turtles released into the wild must be certified free of disease.

Hawaiian Hawksbill Recovery Actions for Limiting Factors

II. Terrestrial Environment

B. Predation

1. Investigate the severity of egg loss by predation. The extent of this predation by ghost crabs, mongooses, cats, dogs, birds,

and possibly rats and feral pigs, needs to be determined. Studies should also be made on whether ghost crab burrows provide access to eggs for other organisms (e.g., ants, flies, and their larvae) or changes in the microenvironment of the incubation chamber (e.g., desiccation of eggs). Egg protection and predator control by government and private entities should be commensurate with degree of predation identified.

2. Investigate severity of hatchling predation. The extent of predation by ghost crabs, mongooses, cats, dogs, birds, rats and feral pigs needs to be determined. Hatchling protection and predator control should be commensurate with the degree of predation identified.

Hawaiian Hawksbill Recovery Actions for Limiting Factors

II. Terrestrial Environment

C. Disease

1. Investigate the incidence and impact of mosquitos and other blood sucking insects capable of transmitting disease to hawksbills on land. Adult females and hatchlings on the beach are exposed to a number of insects, including ones introduced to the main Hawaiian Islands, that are potential carriers of pathogens.

Hawaiian Hawksbill Recovery Actions for Limiting Factors

II. Terrestrial Environment

D. Habitat Alteration

1. Maintain natural habitats. Emphasis should be placed on the maintenance of natural hawksbill ecosystems. The burden of proof, beyond a reasonable doubt, rests on the advocates interested in altering the natural condition.

2. Maintain nesting beaches to eliminate adverse human-induced habitat alteration. Hawksbill beaches should be designated for special consideration as natural preserves. The nesting sites known at present are on Molokai at Halawa Beach, on Hawaii at Kamehame, Punaluu/Ninole, Kawa, Orr's Beach, Harry K. Brown Beach, and Halape in the Hawaii Volcanoes National Park; and on Oahu at Malaekahana. Other nesting sites may become known when efforts are undertaken to locate them.

21. Shoreline development plans, such as for roads, harbor construction, buildings, lighting, military installations, erosion control, and sand mining, should be evaluated at an early stage for their potential adverse impact on turtles. Developers and regulatory agencies should cooperate to eliminate or mitigate the adverse impacts identified.

22. Maintain suitable vegetation types to prevent erosion, foster successful nesting, and promote hatchling production. Manage shoreline plant communities to maximize hawksbill hatchling production.

23. Create a contingency plan. The State of Hawaii, country governments, the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, and the National Park service should have a contingency plan to counter the inevitable demands that the growing tourist industry will make regading access to coastal areas with nesting beaches.

24. Control artificial illumination. A plethora of scientific research has shown that artificial illumination (from domiciles, street lights, vehicles, flashlights, etc.) will disturb nesting females and disorient hatchlings. The quantity of light should be controlled by limiting access and, where necessary, shoreline development. The quality of light present on natural nesting beaches needs investigation. Studies should be made on the intensity and color of light that has minimal effect on turtles of all sizes.

25. Prevent the introduction of exotic plants and animals. Some nesting turtles are adversely impacted by the

presence of certain types of vegetation and their root systems which respectively inhibit digging the body pit and egg chamber. Exotic vegetation may also alter the natural sun/shade mosaic on the nesting beach and thus produce abnormal ratios of males-females, as well as alter the duration of incubation. The ecesis of opportunistic animals, like rats and mongooses, must be prevented as they are predators of eggs and hatchlings. Control programs will be contingent upon and commensurate with the nesting beach and exotic plant or animal involved.

26. Monitor litter and pollution on the nesting beaches. Baseline studies should be made at least annually on the extent of pollution (plastic nets, fishline, tar balls, etc.) washed up on hawksbill nesting beaches. If warranted, methods should be developed to clean it up. Solid debris may obstruct or injure nesting females and inhibit hatchlings crawling to the sea. Volatile and water-soluble contaminants on the beach during the incubation period should be investigated as these contaminants can be absorbed into the egg and embryo. Sources of pollution and the polluters should be identified.

27. Major spills or other pollution events need immediate response to determine what clean-up measures are required. Attention should be given to the clean-up measures to ensure that their impacts on nesting habitat are not greater than the spill itself.

3. <u>Study natural processes on the hawksbill nesting beaches</u>. It is imperative to monitor, investigate and, where necessary and feasible, alleviate some of the important natural population control mechanisms.

31. Study impacts of basalt and calcareous chunks in the nesting beaches. Female turtles sometimes abandon their nest digging when they encounter large rocks or other debris. Hatchlings sometimes become entrapped when attempting to emerge from the nest. If warranted, these obstacles should be removed. Clutches should be exhumed after natural emergence and trapped hatchlings rescued and released at night.

32. Assess the vulnerability of nests to erosion. Conduct studies throughout the nesting season to determine the number of hawksbill nests damaged or lost to storms and beach erosion. Transplant doomed clutches on the berm shortly after oviposition. Establish egg hatcheries at a nearby protect6ed location, if data become available to show that such action is essential.

33. Investigate the effect of rain and salt water inundation on hatchability of eggs. Schedule benign experimental studies on the effect of rainfall (intensity, periodicity) and effect of salt water indunation (amount, duration0 on the gas diffusion within the egg chamber, on development of embryos, hatchability of eggs and entombment of hatchlings.

34. Assay the sand for bacterial content. Measure the build up of the bacteria and fungus in the sand in order to determine if bacterial/fungal action accounts for mortality.

35. Investigate the thermal profile of egg clutches to determine natural sex ratios. Temperature dependent sex determination is the norm among all sea turtle genera. Cooler incubation temperatures yield more males, and warmer temperatures produce more females. The natural sex ratios of hatchling Hawaiian hawksbills need to be determined.

36. Investigate the incidence and extent of natural catastrophic alteration of nesting habitat resulting from tsunamis, storm waves, hurricanes, lava flows, coastal forest fires, and earthquakes. For example, tsunamis have been known to wash away egg clutches on nesting beaches. Where feasible and necessary, mitigating actions should be taken (e.g., egg translocation, beach restoration). nesting hawksbills have been known to die by becoming entrapped, overturned or falling down inhospitable beach terrain. Hatchlings have suffered similar mortality from natural

geological features when they attempt to crawl to the sea. Management actions should be directed at eliminating or reducing these problems to the extent feasible.

Hawaiian Hawksbill

III. Criterion for Recovery

Recovery of the Hawaiian hawksbill population has been reached when nesting on all currently used nesting beaches, known and unknown, has been restored and maintained at carrying capacity. #"carrying capacity" is defined as the number of nesting females that results in the maximum average hatchling production. Carrying capacity is therefore synonymous with "optimum nesting population."

The first step in this recovery process will be to reduce and overcome limiting factors affecting the immediate survival of the population to the extent that it is no longer in danger of becoming extinct (e.g., reclassified from endangered to threatened status).

Biological Overview of the Hawaiian Green Turtle

The Hawaiian green turtle is a long-range migrant breeder and herbivore that spends most of its life foraging and resting in nearshore benthic habitat. Adult females undertake reproductive migrations at intervals of 2 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 (Fig. 1). French Frigate Shoals, along with Nihoa, Necker, Gardner Pinnacles, Laysan, , Maro Reef, and Pearl and Hermes Reef in the Northwestern Hawaiian Islands, is 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 foraging areas where they reside throughout the Hawaiian Archipelago, as well as from Jonston Atoll 800 km to the south.

At last 90% of all reproduction by green turtles in the Hawaiian Islands occurs at French Frigate Shoals, mainly on East Island. Due top their small size, nesting occurs throughout the interior of these islets, and not just along the shoreline beaches. The remaining 10% of nesting takes place at Laysan, Lisianski, and Pearl and Hermes Reef. Also, in recent years, a very low level of nesting by green turtles has occurred in the main Hawaiian Island.

Figure 1. Long distance migrations of adult green turtles (Chelonia mydas) in the Hawaiian Archipelago, as determined by tag and recapture studies. French Frigate Shoals is the major breeding colony.

The breeding season at French Frigate Shoals 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 1.80 at 11- to 18-day intervals (mean 13) within each season. During the internesting intervals, they actively avoid further mating attempts by makes, but remain in shallow water near their nesting beach or, along with males, crawl out on the beach. Land 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, resting, and possibly for protection from the tiger shark, *Galeocerdo cuvieri*, an important predator of the green turtle.

Hatchling Hawaiian green turtles measuring 5 cm in straight shell 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 rarely 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 in shell length are virtually never found in coastal waters of the Hawaiian Islands. The size of 35 cm is therefore assumed to be the minimum at which recruitment occurs to nearshore habitat from the pelagic environment.

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 >82cm reside in the nearshore habitat of these eight islands. Factors responsible for this distribution include the greater amount of available habitat, and abundance of certain marine vegetation (algae and seagrass) preferred for food, and oceanic currents that appear favorable in transporting young turtles to the main islands for recruitment into coastal habitat. The nearshore benthic habitat surrounding the main islands is, however, limited in scope since great depth generally occur just a few kilometers from shore.

Although green turtles, like all sea turtles, only spend a small portion of their lives on land most research worldwide has been focused on the terrestrial phase of their life cycle. 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 underwatrer habitat.

Immature Hawaiian green turtles living in the wild have been found to grow at a slow rate. From 10 to 60 years (mean 25) may be needed to reach sexual maturity. Based on 10 years of tagging data, the total number of adult females nesting at French Frigate Shoals has been estimated at approximately 750. Comprehensive biological and historical information on these and other major aspects of the Hawaiian green turtle population can be found in the supporting background literature shown in the bibliography.

Hawaiian Green Turtle Recovery Actions for Limiting Factors

I. Monitoring and Assessment of the Population

Overall objective: To continue the development of numerical models and population estimation procedures (See Appendix 1).

1. Adults

11. Nesting females. Continue annual censuses and tagging during the peak nesting season at French Frigate Shoals. Undertake saturation tagging for several consecutive years at French Frigate Shoals. Study the cause of cyclic variation in the annual number of nesting turtles at French Frigate Shoals. This phenomenon is known but as yet unexplained in sea turtle populations.

12. Non-nesting females in basking habitat. Monitor while basking by tagging and other observations.

13. Males in basking habitat. Monitor while basking by tagging and other observations. Continue documenting the breeding cycles of males which varies from those of females.

14. Explore the application of the archival microchip tag to further elucidate reproductive migratory patterns between foraging pastures and nesting beaches.

15. Continue to evaluate skeletochronological aging techniques to estimate age at maturity.

2. Subadults and adults in nearshore resident habitat. Identify high density forging and resting sites and institute a permanent monitoring program, especially with respect to documenting natural growth rates.

3. Juveniles and hatchlings in pelagic habitat. Continue the development and testing of hatchling tags for estimating growth, mortality, and dispersal.

4. Eggs and hatchlings on the nesting beach. Continue to support mitochondrial DNA studies to genetically discriminate the Hawaiian green turtle from other geographically separated breeding populations of green turtles.

Hawaiian Green Turtle Recovery Actions for Limiting Factors

II. Marine Environment

A. Human Take

1. Increase surveillance and active law enforcement by developing a coordinated plan to prevent illegal capture, mortality, and trafficking. Elicit cooperation of enforcement branches of the National Marine Fisheries Service, State of Hawaii, U.S. Fish and Wildlife Service, U.S. Customs Service, National Park Service, U.S. Coast Guard, country police departments, military agencies, and other authorities to apprehend and prosecute violators. Encourage the public to report suspected violations.

2. Eliminate intentional and unintentional harassment of green turtles. Activities such as skin and scuba diving, vessel traffic, jet skis, and vessel anchoring may disturb or displace green turtles. These factors should be regulated or controlled to eliminate these impacts, especially in sensitive and/or high density foraging and resting areas, some of which are yet to be determined.

3. Establish networks to report incidental take. Along with (1) and (2) above, encourage reporting of incidental take of all dead or alive green turtles resulting from nets, hooks, traps, monofilament fishing line, rope, debris ingestion and entanglement, vessel collisions, explosives, and such illegal fishing methods as the use of "Clorox" and other chemicals. Special attention should be directed to documenting the incidental take of pelagic turtles by driftnets and longlines in the Hawaiian region.

4. Expand and enhance networks to report strandings. Along with (1), (2), and (3) above, promote the reporting of any green turtle out of its element or in a physiologically distressed state. Dead turtles should continue to be salvaged for necropsies, and live turtles should be bought into captivity for possible rehabilitation. No diseased turtle should be returned to the wild.

5. Educate and inform the public on the threatened and protected status of the green turtle in marine habitat. The general public, including school children, fishers, scientific researchers, boat operators, military personnel, and tourists should be made aware of the fact that the green turtle is a threatened species in Hawaii, and that foraging and resting sites are sensitive and important areas worthy of protection.

6. Establish information and education programs extolling the role of green turtles in the cultural heritage of Hawaiian and ethnic backgrounds in Hawaii. By means of advertising and educational programs, promote the virtues of the environmental, conservation, and historical ethic.

7. Permitted research and management activities involving green turtles may be allowed provided the benefits to the green turtle population outweigh the costs. Permitted research and management actions involving other species and activities must be evaluated by the appropriate agencies to eliminate or minimize to acceptable levels any impacts on the green turtle.

8. Catalog and tag all live green turtles being held in captivity. Legally acquired green turtles currently in privately owned ponds, commercial display facilities, and other captive environments should be inventoried and tagged to discourage the illegal take of live turtles from the wild.

Hawaiian Green Turtle Recovery Actions for Limiting Factors

II Marine Environment

B. Predation

1. Investigate the extent and severity of natural predation on hatchlings by sharks.

finfish, seabirds, and possibly monk seals in nearshore waters of breeding areas. Protection plans including predator control should be commensurate with the degree of predation identified.

2. Investigate the extent and severity of natural predation on juveniles in pelagic habaitat. These studies are contingent upon determining the location of this marine habitat and identifying the predators involved. Protection, if feasible in this extensive and dynamic oceanic region, should be commensurate with the degree of predation identified.

3. Investigate the extent and severity of natural predation on immature and adult turtles in nearshore benthic habitat by sharks and finfish. Turtles have been recorded in Hawaii amongst the stomach contents of sharks and groupers. Protection plans including predator control should be commensurate with the degree of predation identified.

4. Investigate the extent and severity of natural predation on remigrating adults in pelagic habitat. Large sharks and killer whales are likely predators in this environment. Protection plans should be commensurate with the degree of predation identified.

Hawaiian Green Turtle
Recovery Actions for Limiting Factors

II. Marine Environment

C. Disease

1. Investigate the incidence, impact and cause of fibropapillomas (tumors) in green turtles. Debilitating fibrous tumors are known to occur in Hawaiian and other populations of green turtles (i.e., Caribbean). However, the incidence of this disease appears to be increasing in Hawaii. Its etiology and effects as they relate to the viability of the population are presently unknown.

2. Investigate the incidence and impact of parasites and infectious agents on green turtles.

21. Determine the extent, impact, and mode of transmission, including intermediate hosts, of blood flukes and other internal parasites.

22. Determine the extent, impact, and mode of transmission of leeches (Ozobranchus) and burrowing barnacles (Stephanolepas) and other external parasites.

23. Determine the extent and impact of certain bacteria (i.e., Vibrios) and other infectious agents.

Hawaiian Green Turtle
Recovery Actions for Limiting Factors

II. Marine Environment

D. Habitat Alteration

1. Maintain natural habitats. Emphasis should be placed on the maintenance of natural green turtle ecosystems. The burden of proof, beyond a reasonable doubt, rests on the advocates interested in altering the natural condition.

2. Inventory and assess extensively utilized foraging and resting habitats. Baseline information is required to identify and understand natural and man-induced habaitat alterations.

21. Important foraging and resting grounds should be identified for special consideration as natural preserves.

22. Shelter type, tides, temperature, salinity, and pressure as they relate to depth, should be investigated.

3. Eliminate adverse human induced habitat alteration in order to maintain foraging and resting habitats.

31. Petrochemical pollution sources can range from small spills related to bilge pumping or broken transmission lines to large scale tanker spills. Spill contingency plans should be reviewed with respect to protecting foraging and resting sites.

32. Major spills or other pollution events need immediate response to determine what clean-up measures are required. Attention should be given to the clean-up measures to ensure that their impacts on foraging and resting habitats are not greater than the spill itself.

33. Identify sources of synthetic debris that may entangle or be ingested by green turtles in foraging and resting habitats, both in the nearshore and pelagic environment. Abatement programs should be initiated.

34. Prevent or mitigate impacts from dredging. Cumulative and secondary impacts, and loss of nearshore habaitat, need to be quantified.

35. Assess the presence and impact in turtles of pesticide, herbicide, and other toxic agents used by humans that enter the coastal marine environment.

36. Investigate the ecological aspects of sedimentation on foraging and resting habitats.

37. Investigate the effects of altering natural freshwater infusion from both springs and surface flow into foraging pastures.

38. Continue to minimize the effects of artificial illumination from vessels and onshore sources during the period of hatchling emergence in turtle breeding areas.

4. Investigate natural events that adversely impact foraging and resting habitats. For example, tsunamis have been known to hurl turtles in foraging pastures far up on shore where they died after being unable to return to the sea.

41. Compile historical information on catastrophic geological and climatological events, such as tsunamis, hurricanes, the "El Nino effect," lava flows, acid rain, coastal forest fires, and earthquakes. Such data will be used to determine the potential impact of future catastrophic events.

42. Investigate fluctuations in natural and introduced forage on resident pastures as they relate to recruitment, growth rates, and remigration intervals.

43. Investigate the dynamics of oceanic currents, gyres, and zones of convergence as they relate to pelagic life stages and their recruitment to benthic habitat. Recent studies have suggested that the green turtle's pelagic stage is longer than previously thought, hence the increased importance of this life cycle phase.

5. Continue to monitor and investigate the foraging assemblage of green turtles near the newly constructed and potentially dangerous nerve gas/chemical munitions incineration plant at Johnston Island. Implement management and research measures previously recommended as the result of earlier published studies.

Hawaiian Green Turtle Recovery Actions for Limiting Factors

III. Terrestrial Environment

A. Human Take

1. Increase surveillance and active law enforcement by developing a coordinated plan to prevent illegal capture, mortality, and trafficking. Elicit cooperation of enforcement branches of the U.S. Fish and Wildlife Service, National Park Service, National Marine Fisheries Service, U.S. Customs Service, state of Hawaii, U.S. Coast Guard, country police departments, military agencies, and other authorities to apprehend and prosecute violators and to encourage the public to report suspected violations.

2. Eliminate unintentional and intentional harassment of green turtles. Aircraft should not land nor fly low over nesting and basking sites. Residents, tourists, and military personnel should be informed to report, but not to disturb, nesting and basking turtles. Military activities on Midway, Kure, Kahoolawe, and elsewhere throughout Hawaii should be

programmed to mitigate disturbance of sea turtles.

21. In the main Hawaiian Islands egg nests and hatchlings are susceptible to crushing and hatchlings are disoriented by vehicles on nesting beaches. Hatchlings may also be deterred by tire tracks from reaching the ocean thereby increasing their exposure to desiccation and predation. Adult females may be struck while ascending or descending the beach or while nesting. Elicit cooperation of appropriate law enforcement agencies and other public and private entities, including landowners, to eliminate vehicles on known nesting beaches.

3. Educate and inform the public on the threatened and protected status of the Hawaiian green turtle. The general public, including school children, fishermen, scientific researchers, boat operators, military personnel, and tourists should be made aware of the fact that green turtles are threatened species in Hawaii and that nesting and basking beaches are sensitive and important areas worthy of protection.

4. Establish information and education programs extolling the role of green turtles in the cultural heritage of Hawaiians and other ethnic backgrounds in Hawaii. By means of advertising and educational programs point out the virtues of the environmental, and conservation and historical ethics.

5. Permitted research and management activities involving green turtles may be allowed provided the benefits to the green turtle population outweigh the costs. Permitted research and management actions involving other species and activities must be evaluated by the appropriate agencies to eliminate or minimize to acceptable levels any impacts on the green turtle. Permitted research involving tagging and censuses during the peak nesting season at East Island, French Frigate Shoals, should receive priority over the permitted activities at this critical site for the green turtle population. This research, which has been carried out continuously since 1973, is the basis for monitoring and assessment of the population through numerical models for population estimates and trends. There are no alternate times of the year or other sites where this work can be conducted.

6. Breeding effects for conservation purposes using turtles presently in captivity, such as conducted at Sea Life Park, should be encouraged. Healthy hatchlings produced in captivity should be encouraged. healthy hatchlings produced in captivity should ideally be released at known nesting beaches on the following night. Head starting with a portion of the *captive-bred hatchlings* to a size appropriate for tagging and release into coastal foraging pastures in encouraged for *experimental* restocking purposes. all turtles released into the wild must be certified free of disease.

Hawaiian Green Turtle
Recovery Actions for Limiting Factors

III. Terrestrial Environment

B. Predation

1. Investigate severity of egg destruction and predation. Previous work on East Island has shown that ghost crabs do not prey upon turtle eggs but studies should be made on whether crab burrows cause eggs to desiccate or provide access for other potentially harmful organisms)e.g., ants, flies, and their larvae).

11. Quantify egg destruction by abnormal nesters. Amputee nesters sometimes inadvertently break their own eggs during oviposition and concealment of the nest, and sometimes phenotypically normal females unconsciously destroy some of their own eggs during nesting.

12. Quantify egg destruction by nesters. In some areas because the nesting beach is limited, late nesters dig up eggs of earlier nesters, while in a few places (viz., Heron Island, Australia) density-dependent nest destruction exists. These phenomena should be analyzed in relation to the carrying capacity of the habitat.

13. Quantify egg destruction incidental so shearwater burrowing.

Preliminary observations of this occurrence at East Island should be augmented with statistical studies.

2. Investigate the severity of egg loss by predation. In the main Hawaiian Islands the extent of this predation by ghost crabs, mongooses, cats, dogs, birds, and possibly rats and feral pigs, needs to be determined. Egg protection and predator control by government and private entities should be commensurate with degree of predation identified.

3. Investigate severity of hatchling predation. Earlier work indicates that ghost crabs at french frigate Shoals prey on hatchlings. The extent of this predation needs to be documented. Likewise, the occurrence and extent of predation by frigate birds needs to be studied. Hatchling protection and predator control should be commensurate with the degree of predation identified.

31. Investigate severity of hatchling predation in the main Hawaiian Islands. The extent of predation by ghost crabs, mongooses, cats, dogs, birds, rats and feral pigs needs to be determined. Hatchling protection and predator control should be commensurate with the degree of predation identified.

Hawaiian Green Turtle Recovery Actions for Limiting Factors

III. Terrestrial Environment

C. Disease

1. Investigate the incidence and impact of ticks and other blood sucking insects capable of transmitting disease. Ticks (*Ornithodoros*) are present in the soil of all the islets at French Frigate Shoals where they periodically undergo population explosions. Seabirds are the principal blood sources for these ticks, however, they are also known to parasitize nesting turtles, monk seals, and humans. Their ability to transmit virus and other potentially harmful pathogens to nesting and basking turtles, as well as cause anemia to hatchlings in the nest, needs to be determined.

Hawaiian Green Turtle Recovery Actions for Limiting Factors

III. Terrestrial Environment

D. Habitat Alteration

1. Maintain natural habitats. Emphasis should be placed on the maintenance of natural green turtle ecosystems. The burden of proof, beyond a reasonable doubt, rests on the advocates interested in altering the natural condition.

2. Maintain nesting and basking beaches to eliminate adverse human-induced habaitat alteration. One of the main objectives of the green turtle recovery plan is to restore, and then maintain at carrying capacity, a natural number of nesting females on the existing Hawaiian nesting beaches. In addition, if feasible, depopulated beaches should be restored where green turtles historically nested in hawaii. The principal nesting sites are French frigate Shoals, Laysan Island, Lisianski Island, and Pearl and Hermes Reef. French Frigate Shoals is presently by far the most important since it hosts over an estimated 90% of all nesting by green turtles in the Hawaiian Islands. Within the past 5 years a few green turtles have nested sporadically on several beaches in the main Hawaiian Islands. The main sites of this activity include Lawai kai, Kipu Kai, and Kaupea on Kauai Kahuku on Oahu, and Moomomi on Molokai. Basking takes place at all of the nesting beaches in the Northwestern Hawaiian Islands, as well as at Kure Atoll and on lava rock ledges on Necker Island and Nihoa Island. Basking also occurs at a low level on the NaPali coast of Kauai. All of these nesting and basking beaches should be protected to eliminate or exclude undesirable habitat alteration.

21. Nesting and basking beaches in the main Hawaiian Islands should be designated for special consideration as natural preserves.

22. Control access to the nesting and basking beaches. The U.S. Fish and Wildlife Service regulates legal access to French Frigate Shoals through a permit system. It is essential that current levels of protection afforded by on-site management personnel at Tern Island be maintained as a deterrent against turtle poachers and other trespassers. The U.S. Fish and Wildlife Service should also continue to limit entry and strictly regulate human activities at other islands and reefs used by green turtles in the Hawaiian Islands National Wildlife Refuge. Other agencies (e.g., State of Hawaii, country governments, U.S. Navy, U.S. Coast Guard) should actively cooperate with the Fish and Wildlife Service and enforce regulations within their own jurisdictions.

23. Create a contingency plan. The State of Hawaii, country governments, the U.S. Fish and Wildlife Service, and the National Marine Fisheries Service should have a contingency plan to counter the inevitable demands that the growing tourist industry will make regarding access to the islands and coastal areas with nesting and basking beaches.

24. Control artificial illumination. A plethora of scientific research has shown that artificial illumination (from domiciles, lanterns, flashlights, flashbulbs) will disturb nesting females and disorient hatchlings. The quantity of light should be controlled by limiting access and, where necessary, shoreline development. The quality of light present on natural nesting beaches needs investigation. Studies should be made on the intensity and color of light that has minimal effect on turtles of all sizes.

25. Prevent the introduction of exotic plants and animals. Some nesting turtles are adversely impacted by the presence of certain types of vegetation and their root systems which respectively inhibit digging the body pit and egg chamber. Exotic vegetation may also alter the natural sun/shade mosaic on the nesting beach and thus produce abnormal ratios of males - females, as well as alter the duration of incubation. The ecesis of opportunistic animals, like rats and mongooses, must be prevented in the Hawaiian Islands National Wildlife Refuge as they would prey upon eggs and hatchlings. Control programs will be contingent upon and commensurate with the nesting beach and exotic plant or animal involved.

26. Remove human debris from East and other islets as French Frigate Shoals. For example, abandoned antenna wire is inhibiting normal nesting behavior of some female turtles on East Island. The U.S. Fish and Wildlife, State of Hawaii, and National Marine Fisheries Service, and military personnel should work together to clean up this debris. The hardpacked terrain and sheet-pile seawall at Tern Island limit the availability of terrestrial habitat for nesting and basking and are known to disorient and trap turtles on land. This necessitates on-site management personnel to rescue and release these turtles.

27. Implement improved garbage and human waste disposal methods on the nesting beaches. Garbage should be packaged and removed from French Frigate Shoals. Organic garbage dumped into the sea may attract sharks which may prey upon turtles also attracted on the debris. Plastics discarded into the sea can be ingested by or entangle sea turtles. Burying garbage on nesting beaches changes soil chemistry with potential negative impact on embryonic or hatchling imprinting. Proper disposal of toilet wastes from researches on the small islets at French Frigate Shoals that has the least impact on nesting turtles needs to be determined.

28. On-site management personnel need to be maintained at Tern Island to discourage illegal entry by vessels into French Frigate Shoals which could result in greater numbers of groundings, wreckage, and pollution.

29. Monitor litter and pollution on the nesting beaches. Baseline studies should be made annually on the extent of pollution (plastic nets, fishline, tar balls, etc.) washed up on the nesting and

basking beaches. If warranted, methods should be developed to clean it up. Solid debris may obstruct or injure nesting females and inhibit hatchlings crawling to the sea. Volatile and water-soluble contaminants on the beach during the incubation period should be investigated as these contaminants can be absorbed into the egg and embryo. Sources of pollution and the polluters should be identified.

3. Study natural processes on the nesting and basking beaches. It is imperative to monitor, investigate, and, where necessary and feasible, alleviate, some of the important natural population control mechanisms.

31. Removal of calcareous chunks from the nesting beaches. Female turtles at French Frigate Shoals sometimes abandon their nest digging when they encounter large pieces of limestone. Hatchings sometimes become entrapped when attempting to emerge from the nest. These obstacles should be removed along with the wire and other debris. Clutches should be exhumed after natural emergence and trapped hatchlings rescued and released at night.

32. Asses the vulnerability of nests to erosion. Conduct studies throughout the nesting season on the major beaches at French Frigate Shoals to determine the number of nests damaged or lost to storms and beach erosion. Transplant doomed clutches on the berm shortly after oviposition. There is no need to establish egg hatcheries on French Frigate Shoals at this time.

33. Investigate the effect of rain and salt water inundation on hatchability of eggs. Schedule experimental studies on the effect of rainfall (intensity, periodicity) and effect of salt water indunation (amount, duration) on the gas diffusion within the egg chamber, on development of embryos, hatchability of eggs, and entombment of hatchlings.

34. Assay the sand for bacterial content. Because of the presence of green turtles, seabirds, monk seals, and other biota at French Frigate Shoals for millennia, it is important to measure the build up of the bacteria and fungus in the sand in order to determine if bacterial/fungal action accounts for some of the egg mortality here.

35. Investigate abortive nesting attempts. Conduct studies on why up to one-half or more of the emerging females on any one night at French Frigate Shoals (especially East and Whale-Skate Island) may fail to lay eggs. Prevailing hypotheses which need further investigations revolve around insufficient soil moisture or rootlets, limestone chunks, and amputated hind flippers. Investigators should also look for evidence of sand-smelling and false crawls which are indicative of the accuracy of nest-site selection and reproductive readiness.

36. Investigate the thermal profile of egg clutches to determine natural sex ratios. Temperature dependent sex determination is the norm among all sea turtle genera. Cooler incubation temperatures yield more males, and warmer temperatures produce more females. The natural sex ratios of hatchlings produced at French Frigate Shoals need to be determined.

37. Investigate the incidence and extent of natural catastrophic alteration of nesting habitat resulting from tsunamis, storm waves, lava flows, coastal forest fires, and earthquakes. For example, tsunami have been known to wash away egg-clutches on nesting beaches. Where feasible and necessary, mitigating actions should be undertaken.

Hawaiian Green Turtle

IV. Criterion for Recovery

Recovery of the Hawaiian green turtle population has been reached when nesting on all currently used nesting beaches, known and unknown, has been restored and maintained at carrying capacity. "Carrying capacity" is defined as the number of nesting females that results in the maximum average hatchling production. Carrying capacity is therefore synonymous with "optimum nesting population."

This does nit imply that currently unused nesting beaches which have been identified as historical nesting sites must necessarily be restored to carrying capacity as part of the Recovery Criterion. There may be restored to carrying capacity as part of the Recovery Criterion. There may be existing or historic factors which preclude the successful occupation of these sites and, realistically these areas should not be considered. However, there may be nesting sites that are now being used at less than carrying capacity which have not been discovered and should e included within the definition.

Biological Overview of the Leatherback and Olive Ridley in Hawaiian Waters

There are no historical records or other evidence from the early Hawaiian culture that breeding populations of the leatherback or olive ridley ever occurred in the Hawaiian Islands. The only known nesting of these species at present consists of a single egg-clutch laid by an olive ridley on Maui in September of 1985; and for the leatherback, a false nesting attempt on Maui in August of 1982 and a reported but not verified successful nesting on Kauau in December of 1986. There is, however, considerable indication that the pelagic zone surrounding the Hawaiian Islands constitutes regularly used foraging habitat and/or migratory pathways for both species.

Leatherbacks are commonly seen by fishermen in Hawaiian offshore waters, generally beyond the 100-fathom curve but within sight of land. Two areas where sightings often take place are off the north coast of Oahu and the West (Kona) coast the Island of Hawaii. Further to the north of the Hawaiian Islands, a high seas aggregation of leatherbacks is known to occur at lat. 35° - 45° N, long. 175° - 180° W. Incidental capture in this region has been reported to take place in pelagic drift nets deployed by foreign fishing vessels.

Available information suggests that the olive ridley also regularly uses the Hawaiian pelagic region for foraging and/or developmental migrations. Sightings of olive ridleys are fewer, but this is likely due to its small size in contrast with the larger and far more distinctive leatherback. It is not unusual for olive ridleys in reasonably good health to be found entangled in scraps of net or other floating synthetic debris. Small crabs, barnacles and other marine life often reside on the debris and likely serve as a food attraction to turtles.

Subadult leatherbacks, as well as juvenile and subadult olive ridleys, are among the life stages known to be present in Hawaiian waters. The significance of this finding rests in the fact that, for both species worldwide, very little information exists on the developmental ecology of the immature life stages. Such turtles are rarely ever seen in the wild, starting from the time they leave the beach as hatchlings until they return to nest as adults.

The leatherback is listed as an endangered species (since 1970), and the olive ridley as a threatened species (since 1978), except for east Pacific breeding populations in Mexico and in Surinam where they are listed as endangered. Olive ridleys in Hawaiian waters are herein considered as endangered because their derivation is most likely to be from the Pacific coast of Mexico.

Additional information on the leatherback and olive ridley can be found in the supporting background literature shown in the bibliography.

Leatherback and Olive Ridley Recovery Actions for Limiting Factors

I . Marine Environment

A. Human Take

1. Increase surveillance and active law enforcement by developing a coordinated plan to prevent illegal capture, mortality, and trafficking. Elicit the cooperation of enforcement branches of the National Marine Fisheries Service, State of Hawaii, U.S. Fish and Wildlife Service, U.S. Customs Service, National Park Service, U.S. Coast Guard, country police departments, military agencies, and other authorities to apprehend and prosecute violators. Encourage the public, especially offshore fishermen, to report suspected violations.

2. Establish networks to report incidental take. Along with (1) above,encourage reporting of incidental take of all dead or alive leatherbacks and olive ridleys resulting from pelagic driftnets, longlines, hooks, traps, lines, debris ingestion and entanglement, and vessel collisions. Inform fishermen and others involved in these networks how to identify the leatherback and olive ridley and distinguish them from the hawksbill and green turtle.

3. Expand and enhance networks to report strandings. Along with (1) and (2) above, promote the reporting of any leatherback

and olive ridley out of its element or in a physiologically distressed state. Dead turtles should continue to be salvaged for necropsies, and live turtles should be brought into captivity for possible rehabilitation. No diseased turtle should be returned to the wild. healthy turtles that are released should be tagged, photographed, measured, and weighed.

4. Educate and inform the public on the endangered and protected status of the leatherback and olive ridley in marine habitat. The general public, including school children, fishers, scientific researchers, boat operators, military personnel, and tourists should be made aware of the fact that the leatherback and olive ridley are endangered and protected species in Hawaiian waters.

5. Permitted research and management activities involving the leatherback and olive ridley may be allowed provided the benefits to the leatherback and olive ridley populations outweigh the costs. Permitted research and management actions involving other species and activities must be evaluated by the appropriate agencies to eliminate or minimize to acceptable levels any impacts on the leatherback and olive ridley.

Leatherback and Olive Ridley Recovery Actions for Limiting Factors

I . Marine Environment

B. Predation

1. Investigate the extent and severity of natural predation on adults, subadults, and juveniles in pelagic habitat. These studies are contingent upon determining the location of this marine haabaitat and identifying the predators involved. Protection plans, if feasible in this extensive and dynamic oceanic region, should be commensurate with the degree of predation identified.

Leatherback and Olive Ridley Recovery Actions for Limiting Factors

I . Marine Environment

C. Disease

1. Investigate the incidence and impact of parasites and infectious agents on the leatherback and olive ridley. Virtually nothing is known in Hawaii about the occurrence of bacterial infections (e.g., Vibrios), virus, parasites such as blood flukes, leeches and burrowing barnacles, and possible tumors, in the leatherback and olive ridley.

Leatherback and Olive Ridley Recovery Actions for Limiting Factors

I. Marine Environment

D. Habitat Alteration

1. Eliminate adverse human induced habitat alteration in order to maintain pelagic habitats.

11. Petrochemical pollution sources can range from small spills related to bilge pumping or broken transmission lines to large scale tanker spills. Spill contingency plans should be reviewed with respect to protecting pelagic habitats.

12. Major spills or other pollution events need immediate response to determine what clean-up measures are required. Attention should be given to the clean-up measures to ensure that their impacts on pelagic habitats are not greater than the spill itself.

13. Identify sources of synthetic debris that may entangle or be ingested by leatherbacks and olive ridleys in pelagic habitats. Abatement programs should be initiated.

14. Asses the presence and impact in turtles of pesticide, herbicide, and other toxic agents used by humans that enter the pelagic environment.

2. Investigate natural events that adversely impact pelagic habitats.

21. Compile historical information on catastrophic events, such as hurricanes, and the "El Nino effect." Such data will be used to determine the potential impact of future catastrophic events.

22. As food items for the leather back and live ridley become known, investigate natural fluctuations in abundance and distribution.

23. Investigate the dynamics of oceanic currents, gyres, and zones of convergence as they relate to pelagic to pelagic life stages.

Leatherback and Olive Ridley Recovery Actions for Limiting Factors

II. Terrestrial Environment

1. The point of origin (nesting beaches) for leather backs and live ridleys in Hawaiian water should be determined.

11. Additional nesting within the Hawaiian Islands should be documented. The egg clutches should be protected and hatchlings cataloged prior to release.

Leatherback and Olive Ridley

III. Criterion for Recovery

A determination of conditions for the recovery of the leatherback and olive ridley in Hawaiian waters will only be possible when adequate knowledge becomes available on their life history and ecology, especially the exact locations and conservation status of the nesting beaches. Recovery actions will then have to be heavily focused on international cooperative efforts, since there are no known nesting colonies of these two species under U.S. jurisdiction in the Pacific region.

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APPENDIX 1

Considerations for Population Assessment and Monitoring of the Hawaiian Green Turtle

Prepared by Jerry A. Wetherall

This appendix examines several topics germane to the monitoring and assessment of Hawaiian green sea turtles, expanding on points raised in the main text of the Recovery Plan. Items discussed include monitoring objectives, basic concepts and information needs for population modeling, and strategies and procedures for nesting population assessment. In the last sections, the methods currently used to monitor nesting females at East Island are described, estimates of East Island nesters are presented, and critical areas for further research are identified.

I . Population Assessment and Monitoring Objectives

According to the Recovery Plan, the "recovery" of the Hawaiian green sea turtle population will be realized when the annual average number of nesting females on each currently used nesting beach, known or unknown, is restored to the beach's biological carrying capacity, and maintained at that level.

Three actions are necessary to implement the recovery rule. First, an inventory of "currently used nesting beaches, known or unknown" must be completed. Second, the !biological carrying capacity: of each beach must be estimated. Third, a standard procedure for assessing the status of nesting females on each beach must be developed.

The recovery criterion provides a very specific focal point for population monitoring and assessment activities. However, the scope of recovery program objectives should probably be somewhat broader. The set of important objectives might include the following:

(1) Monitor changes or trends in population abundance

In accord with the chosen recovery criterion, a basic requirement of the recovery program is a means of producing regular estimates of the size of the population of nesting females, or an index of its abundance. A long time series of abundance estimates (or indices) based on consistent survey and estimation procedures is required to reveal patterns of variability against which the significance of trends can be judged.

(2) Predict population size and recovery rate or time

Under ideal circumstances, in addition to monitoring nesting population levels, we would be able to predict the size of each cohort at various ontogenetic stages, given a model of the population dynamics and management action scenarios. Further, we would be able to estimate the time to recovery of the total population for a proposed set of management actions, within known limits of precision. This capability would require a sound knowledge of biological parameters of reproduction, (fairly readily available), maturation rates (still unknown), remigration rates (known) and survival rates (unknown at all stages from hatchling onwards), and their response to various management actions.

(3) Evaluate the effectiveness of recovery actions

Assessing performance of recovery actions requires having a defined measure of success (the recovery criterion), the ability to decide when success is achieved, and ultimately the ability to detect whether success was due to management actions or to other (natural) events.

Our present capabilities support objective (1) to some degree, with respect to the population of nesting females at East Island, French Frigate Shoals. Objective (2) can be attempted only roughly; we can substitute educated guesses for firm estimates of population parameters and project rates of population growth. To allow for uncertainty in the underlying assumptions, we can repeat the projections for a range of parameter scenarios. Objective (3) is important to recovery program management, but separating the effects of recovery actions from natural population changes will be extremely difficult.

II. Model of Population Dynamics

The second recovery objective, predicting population trends, requires a long-term program of biological research and analysis leading to a model of population dynamics.

Green turtle population dynamics may best be treated by considering discrete life stages, each characterized by a unique set of attributes with respect to habitat, behavior, and accessibility. A reasonable way to begin is to define the population of nesting females in a given year. This provides a starting point for a distinct cohort of offspring. At any point in time, a model of the total population dynamic can be constructed by tracing the history of each such cohort over its lifespan, and integrating over all cohorts still present in the population. The information needed for modeling the population dynamics varies among the stages, as follows:

(1) Nesting females

For modeling purposes, the key attributes of nesting females at a particular nesting beach are the distribution of their first arrival times at the nesting beach, the multiplicity of nesting episodes (number of clutches of eggs deposited per female0, the distribution of time intervals between successive nesting emergences (interesting interval), the distribution of the duration of each nesting episode (number of nights required to successfully deposit a clutch of eggs), and the distribution of clutch size (number of eggs deposited per nest). With such information, identification and enumeration of individual nesters (or their nests) during a beach survey allow estimation of the number of females nesting that season, the total number of nests dug, and the number of eggs deposited in the beach. Further, if neophytes can be distinguished from remigrants (e.g., by saturation tagging over several seasons), recruitment can also be estimated.

(2) Hatchlings

Knowledge of the distribution of hatching success among nests on a beach allows estimation of the probability of survival from deposition to hatching, and the total number of hatchlings produced during the season. Rates of predation during the crawl to the sea can also be observed, so the size of the cohort at the beginning of its sea life can be computed.

(3) Early juvenile pelagic stage

The parameters we need to know for this stage are growth rate and survival rate. A model of distribution dynamics, including rates of dispersal, range of movement, spatial patterns, social structure, and feeding behavior would also be valuable.

(4) Subadults

To develop complete models of this stage we will have to be able to age turtles, so we can compute growth rates, survival rates and maturation rates (distribution of ages at maturity and first nesting). Further, we need top find out how these processes are affected by such factors as forage type and abundance. Ultimately, we also need to know the rates of immigration of the smallest subadults to the inshore habitat, and rates and patterns of movement of the various subadults among different inshore areas.

(5) Adult males and non-nesting females

For turtles in these categories we need to know the growth and survival rates, and the distribution dynamics, i.e., the size- or age-specific migration patterns, habitat residence times, and so on. For the adult females in between nesting seasons, we need to know the factors affecting the reproductive cycle and the remigration interval (regenerative period).

III. Population Assessment Strategy

A. Constraints and Limitations

Several factors impinge on the options available for green turtle populationb assessment. The most important of these are:

(1) Limited access

Of the life stages outlined above, only the first and second can be monitored with reasonable ease and completeness. They involve land-based surveys (although aerial surveys of nesting activity are sometimes done on beaches in the Caribbean and elsewhere), compressed both geographically and temporally. The other stages allow only partial observation, with the difficulty of at-sea observation over widespread habitats and extended time periods.

(2) Lack of aging method

A major impediment to building turtle population models is lack of age composition information. Aging capability would lead directly to estimates of growth and survival rates in all life stages, and a complete model of population size (cohort life history). In lieu of age composition data, we must rely on an index or proxy for total population abundance; this is provided by estimating the number of nesting females.

(3) Remigration behavior

Even without the ability to age sea turtles, we could use standard tag-and-recapture methods to estimate survival rates were it not for the multi-year regenerative period and cyclic remigration behavior. These result in the confounding of adult survival probabilities and remigration probabilities in tag-recapture models. To estimate the survival rates we have to make assumptions about remigration rates, and vice versa; we cannot get separate and independent estimates of the two. Fortunately, this problem does not affect estimation of nesting population size.

It is clear from these constraint that the only feasible strategy for monitoring recovery trends is the one embodies in the recovery criterion, i.e., to regularly estimate the number of females nesting at East Island and other beaches. Any other criteria would require a much better grasp of population dynamics than we now possess and greater resources than are now available to the recovery program.

An unavoidable drawback of this strategy is that management actions taken now to increase survival of eggs, hatchlings and juveniles may not affect the nesting population for several decades. Even then their impacts may be difficult to isolate due to smoothing effects and natural background variability. Similarly, current trends in the nesting population may e due as much to undocumented events decades ago as to any recent recovery actions.,

B. Estimating the Nesting Population

(1) Basic approaches

There are various approaches to estimating nesting populations. All of them involve surveying nesting habaitat during part of the nesting season (or the entire season if sufficient resources are available), and calculating the number of females hauling out to nest during the survey period(s). If only part of the season is surveyed, the number of nesters for the total season is computed by applying raising factors to expand the survey statistics.

The methods vary in the way the number of turtles nesting during the survey period is computed. In some green turtle colonies of the South Atlantic and Caribbean, surveyors count fresh nests or turtle tracks (excluding false crawls) each day during the survey period. Then daily counts of new nests are summed over the survey period or season, and the total counts a divided by the average number of nests per female. The latter quantity is determined by tagging turtles and resighting them on subsequent emergences. In other colonies, such as the one nesting at East Island, the number of females nesting during the survey period is determined directly, by examining each turtle hauling out and applying numbered tags to establish individual identities. Below, the East island method is described in detail.

(2) The East Island method

(a) Census counts

During the survey period (or periods), a complete count of turtles hauling out to nest on the beaches at East Island is made. Each turtle encountered is examined for the presence of an identifying flipper tag. If a turtle is tagless, one or more tags is attached and the tag number(s) recorded. Multiple tags assure that the turtle's identity will be known on subsequent encounters, and allow estimation of tag shedding rates.

The survey period(s) is chosen to coincide with the assumed peak of nesting activity, usually during a 2- or 3-week interval in June and July. The length of the nesting season at East Island has been determined through periodic visits to the island over many years, and the within-season distribution of nesting activity has been estimated from comprehensive surveys in 1974 and 1975. A 2-week census period is just long enough that turtles nesting during the first nigh of the survey will be resighted once, on average. During longer surveys, turtles may be observed during several successive nesting episodes. Although resight intervals provide additional information on nesting behavior, they do not figure directly in the population estimation; only the initial encounter matters.

(b) Coverage rate model

The most critical part of the estimation procedure is the raising factor, the number multiplied by the census counter to compute the total season's nesting population. The raising factor is the reciprocal of the coverage rate, or the overall probability that a turtle nesting that season will be encountered during the specified survey period(s).

The coverage rate is computed from a stochastic model of residence time that takes into account the within-season distribution of arrival times (date of first haul out by a nester), the distribution of the number of nests completed per nester during the season, the distribution of the interval between separate nesting episodes (internesting interval)Z and the distribution of the duration of a nesting esisode. Each of these component distributions is itself a probability distribution estimated from data collected during the comprehensive surveys of 1974 and 1975, and other observations.

There are two ways to compute the coverage rate for a survey. One (the stochastic method) involves accounting for all possible combinations of events, i.e., all possible combinations of arrival time, number of nests, duration of nest-building activity, and internesting interval, that could produce the observed count of nesting turtles. This involves an enormous amount of nesting turtles. This involves an enormous amount of computation. An easier approach (the deterministic method) is to estimate the coverage rate using the average or expected values of the component distributions. As long as the underlying distributions are reasonably symmetrical, the "quick-and-dirty" method should produce estimates close to those of the exhaustive approach.

(c) Raising factor and East Island nesting population estimate

The nesting population at East Island is estimated by dividing the survey count by the coverage rate, or first computing the raising factor and multiplying this by the count.

(d) Statewide nesting population estimate

Surveys of other nesting beaches at French Frigate Shoals, or elsewhere in the Hawaiian Islands have been infrequent. The general assumption is that East Island is the key green turtle nesting habitat in the archipelago, accounting for roughly 55% of the total French Frigate Shoals nesting. The French Frigate Shoals nesting population, in turn, is thought to make up about 90% of the statewide nesting population. Until regular surveys can be established at other nesting beaches, a rough estimate of the annual number of females nesting in Hawaii may therefore be computed by doubling he East Island census figure.

In addition, for every female nesting in a given year, there are probably three or four mature, veteran nesters not breeding that year. The total statewide population of mature females may therefore be about six-eight times the number nesting each season at East Island. Expansion of this estimate to the total adult population, and to immature stages, would require knowledge of sex ratios and age composition; neither is available. Obviously, such extrapolations must be viewed circumspectly. Until better information is acquired on population structure, the sensible alternative is to focus only on the nesting population estimates for those beaches which are surveyed, and to compare these levels with carrying capacities, as the recovery criterion stipulates.

(e) Precision of the population estimate

Because the survey counts at East Island are assumed to be exact (determined without error), reliability of the population estimate is a function of uncertainty in the coverage rate only. This in turn depends on natural and sampling variation in the underlying component probability distributions. Intrinsic interannual variation in the arrival time distribution, for example, will contribute to uncertainty in a population estimate based on average conditions or on an assumed constant arrival distribution. Likewise, sampling error in estimating the underlying distributions will add to uncertainty in the final population estimate, even if the haul-out schedules and nesting behavior are constant from year to year.

Precision (and statistical bias) of the deterministic population estimate can be estimated by the method of bootstrapping. This is a computer-intensive method which will produce estimates of standard errors of nesting population estimates, and confidence intervals for population size. It has not yet been applied to the East Island data. Similar, but prohibitively expensive, bootstrap procedures could be used with the stochastic estimates.

IV. Recent Trends in the East Island Nesting Population

Historical records are insufficient to allow estimates of the number of green turtles nesting annually at East Island or other nesting beaches in the years prior to 1973.

However, since 1973, systematic surveys of East Island have been conducted. These studies, including comprehensive tagging of all turtles encountered (whether basking or nesting) were most extensive in 1974and 1975, when detailed data on nesting behavior and other biological parameters important to monitoring and population modeling were collected.

Using a coverage rate model developed from the detailed biological information, the number of females nesting annually at East Island has been computed for a 15-year period, 1973-87 (Fig. l). In most years, surveys were confined to a 2- or 3-week interval during the assumed peak of the nesting season. Coverage rates ranged from 84% in 1974 to 25% in 1977.

In general, the surveys show an increase in the nesting population over the 125-year period, with considerable variation. During the first 8 years of the monitoring period, the average annual nesting population was 127 turtles. During the second 7-ear interval, the average was 196 turtles, an increase of 54%. If the extremely low estimate for 1983 is excluded from the second series of years, the increase amounts to 73%. The twofold variation among annual estimates evident during the first 8 years decreased considerably during the second 7-ear period (excluding the 1983 data).

The factors underlying the apparent increase in the East Island nesting population and the year-to-year variability are not understood. The rising trend in the population may be due to a reduction in harvest of mature turtles and subadults; green turtles have been fully protected in Hawaii since September 1978.

The increase in variability may have a number of causes. The cyclic nature of the regeneration and remigration process contributes to some of the systematic interannual variability, and this can be compounded by environmental perturbations. For example, a delay in reproductive development due to subnormal nutrition could conceivably generate a "bust" and "boom" situation. (Note that in late 1982, the year prior to the lowest recorded nesting population, inshore turtle forage may have been adversely affected by hurricane Iwa.)

Another source of variability in the nesting population estimates is interannual variation in the residence time distribution. In the extreme (but unlikely) case that the nesting population is constant, variability among nesting population estimates will be determined entirely by variation in the processes determining residence time probabilities, and their departure from the 1974-1975 conditions.

Finally, as noted before, variability in the nesting population may arise from variations in recruitment, due in turn to vagaries of egg or hatchling survival half a century earlier.

V. Research Needed for Monitoring and Modeling Population Dynamics

Monitoring procedures and models of green turtle population dynamics can be improved by field experiments or analysis in several areas. Some of these are mentioned in the main text of the Recovery Plan, but are repeated here for emphasis.

(1) Bias estimation and reduction

The utility of the annual estimates for monitoring population trends depends on their consistency, i.e., any biases in the estimates must be proportionally constant. For more demanding analyses requiring knowledge of the absolute population size, biases must be reduced to negligible levels. In either case, further research is needed to define the types and magnitude of systematic biases affecting the population estimates generated by current procedures and assumptions.

A major potential source of systematic bias is in the assumptions concerning arrival time distribution and nesting behavior. Failure of such key assumptions will invalidate the coverage rate estimates. There are two problems. First, the parameters of some of these processes have been estimated from very little data. Second, although they are assumed to be constant, the underlying processes may vary from year to year in unknown ways. To measure interannual variability in the arrival distribution and nesting behavior, nesting activity at East Island must be observed in detail over several complete nesting seasons. The two seasons already studied in detail (and these not fully covered) are insufficient. Only through a series of such complete surveys will it be possible to assess the reliability of population trend assessments. During these comprehensive surveys, observations should be made on the various aspects of nesting behavior important in coverage rate estimation. In addition, studies of clutch size and egg and hatchling survival on the beach should be done.

(2) Estimate of precision

To evaluate the effectiveness of recovery actions and the statistical significance of observed changes in nesting population size, the precision of population estimates must be determined. The bootstrap analyses described above should be conducted using current assumptions on arrival time and nesting behavior distributions. Once this is done, it will be possible to estimate the number of years required to detect a specified change in the population size with a stated level of confidence.

Estimates of precision, as well as the level of precision itself, can be improved by conducting the complete surveys mentioned above in reference to bias estimation and reduction. In particular, the relative importance of intrinsic variation and sampling variation can be judged. When sources and levels of bias and variance are better understood, census design parameters (e.g., survey interval) can be optimized with respect to specified monitoring objectives and cost constraints.

(3) Census of other nesting grounds

Present assumptions on the contribution of East Island nesting activity to the total population's reproductive output should be tested by conducting complete surveys of other nesting grounds, at french Frigate Shoals and elsewhere. Such studies will also provide useful ancillary information on remigration intervals and site fidelity (straying).

(4) Monitoring of turtles in inshore habitats

While estimating the number of nesting females is currently the best way to judge total population trends, and the focal point for measuring recovery success, sections of inshore habitat should be established for long-term annual monitoring of juveniles and non-nesting adults. Inshore habitat census procedures should be developed and standardized. Survey sections should encompass several regions of primary inshore habitat, and areas of marginal habaitat infrequently used. Besides turtle densities, the surveys should measure the character and quality of the habitat, e.g., forage density and composition.

(5) Estimating recruitment by saturation tagging

One result of a complete survey of the east Island nesting population would be the tagging of the year's entire cohort of recruits, remigrants which had not been encountered on earlier surveys, and any remigrants which had been tagged previously but had shed their tag(s). If each turtle is identified by multiple tags, the probability that it will be tagless during its next nesting season, 2-65 years hence, will be negligible. Thus, if saturation tagging with multiple tags is done for several consecutive years, eventually the only untagged turtles encountered during a survey will be neophytes, and the ratio of recruits to veteran nesters can be estimated.

However, to estimate recruitment annually would require complete coverage of nesting activity and saturation tagging each year, an unlikely possibility.

(6) Developing aging methods

(7) Estimating growth, mortality, and population size by tag-and-resight

Experiments to estimate growth and mortality rates should be conducted by releasing large cohorts of tagged hatchlings from the East Island beaches, and subsequently monitoring resights. Tag design studies should first be done by captive hatchlings. Release of tagged cohorts over two more consecutive years, coupled with an intensive resight program in nearshore waters, will permit estimates of survival rates during the early pelagic stage and inshore juvenile life. Tag resight data can also be used to estimate the contribution of East Island nesting to annual statewide reproductive output, and to estimate the aggregate nesting population.

(8) Modeling distribution dynamics using archival tags

When available, archival tags should be applied to nesting females, and to basking males and females at East Island, to monitor their movements and habitat usage.

(9) Analysis of population size and structure using tag-and-resight data for basking turtles.

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