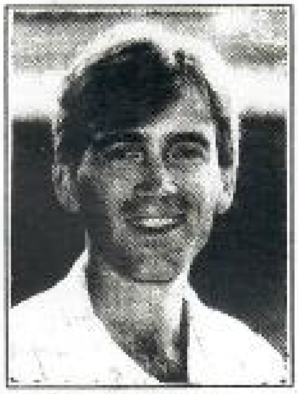
REPORTER'S CORNER



TIMOTHY HURLEY

Oh, those poor Hawaiian sea turtles.

Every time you turn around it seems someone's pointing a finger at those benevolent doe-eyed reptiles, implicating them as unwitting accomplices in a shark attack.

Kihei's Don Bloom, the victim in the June 13 shark encounter off Wailea, was the latest to make the connection in a letter to The Maui News last week. He suggested that the shark that bit him in murky water had mistaken him for a sea turtle.

It's a cry heard over and over. In recent years the Hawaiian sea turtle has taken a lot of heat — from all quarters.

Many have suggested that the gradually increasing population of sea turtles is to blame, or at least partially responsible, for the reportedly higher numbers of tiger sharks that roam our waters.

Those who raise the issue point out that the sea turtle — a mainstay on the tiger shark diet — has been legally protected by federal and state laws in Hawaii since the mid-'70s. During that time, the tiger shark population has seemingly mushroomed as well.

And the theory goes that since there are more sea turtles swimming in and around our islands, the tigers are increasingly going after them — and sometimes mistaking humans for the turtles.

Think about it from a shark's point of view: From the murky depths you spot what looks like a tasty turtle skimming the water's surface. OK, so maybe a closer examination would have revealed a fiberglass bodyboard with dangling arms and legs. But, hey, when you're hungry . . .

It's all that kind of talk that really rankles George Balazs, zoologist and leader of marine turtle research for the National Marine Fisheries Service in Honolulu.

Perhaps Hawaii's top turtle expert, Balazs says there is no evidence to suggest that a growing turtle population is the cause of increased shark sightings and attacks.

While there are indeed more turtles in our waters,

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there aren't as many out there as people think, he says. Sea turtles are simply high-profile animals and so they get the blame.

Balazs, who is also known for compiling and maintaining a list of Hawaii shark attacks, says it is true that the turtle is on the tiger shark diet. But he believes its importance on the shark's daily menu has been overestimated. Also eaten by tiger sharks are fish, crabs, lobsters, birds, other sharks, rays, squid, octopus, crabs, snails, jellyfish and even garbage.

The reason turtles are overrated as shark food, he says, is because they are found in the stomach of sharks more often. That's due to the fact they can't be broken down by stomach acids as well. Many other things a tiger shark eats digest faster.

As for the mistaken identity theory, Balazs says he doesn't buy it.

"If you're in California, the shark thinks you're a seal. If you're in Hawaii, the sharks think you're a turtle," he says. "Which one is it?"

There is no credible data to support the mistaken identity theory, Balazs insists.

"Taking things at the surface is a natural part of the tiger shark's known feeding strategy," he says. "Jean-Michel Cousteau said some sharks are more fussy than others about what they eat. Tiger sharks are known to eat almost anything and everything, and are more likely to attack anything on the surface whether it's a piece of wood, a surfboard, a boat or a bird."

A number of recent attacks in Hawaii on surfers have taken place during daylight hours in reasonably clean, clear water. It's hard to imagine that the sharks involved in those incidents mistook their victims for anything other than a potentially edible object at the surface, he says.

Balazs points to an incident in East Maui waters a couple of years ago. The passengers on a charter fishing boat witnessed — and even took photos — of a 2,000-pound bull that had fallen off a cliff into the ocean and was being mercilessly attacked by sharks.

"Did the sharks mistake that bull for a sea turtle? Perhaps, but only if they had been staring at inkblots for too long!"

Balazs says surfers and swimmers should still consider the sea turtle a friend.

"If turtles weren't out there making themselves available as a food item, the tiger shark population would simply turn to something else to eat.

"And that something else could be surfers or swimmers."

Staff writer Timothy Hurley covers the environment for The Maui News. June 27, 1995

BOOKS

The master of the underwater thriller is back with 'Shark'

By Craig Wilson
Gannett News Service

Peter Benchley, happy as a clam, is lunching on fried oysters at the Sansom Street Oyster House in Philadelphia. A man approaches his table.

"Excuse me," he says. "But aren't you an actor?"

"No, sorry," says Benchley.

"I'm sorry, but you look so familiar."

Benchley says it happens often. People can't quite place him. He loves to tell about the time someone approached him and said, "Weren't you Peter Benchley once?"

Indeed he was. Still is.

Son of novelist Nathaniel Benchley, grandson of Algonquin Round Table humorist Robert Benchley, and author of the mega-thriller "Jaws," Peter Benchley, at 54, is back with a new drama from the deep, "White Shark" (Random House, $23). On the 20th anniversary of "Jaws," Benchley is jumping back in the water.

"Even if I became pope, cured cancer and won a Nobel Prize, the music at my funeral would still be John Williams' score from Jaws," says Benchley. "There's not much I can do about it."

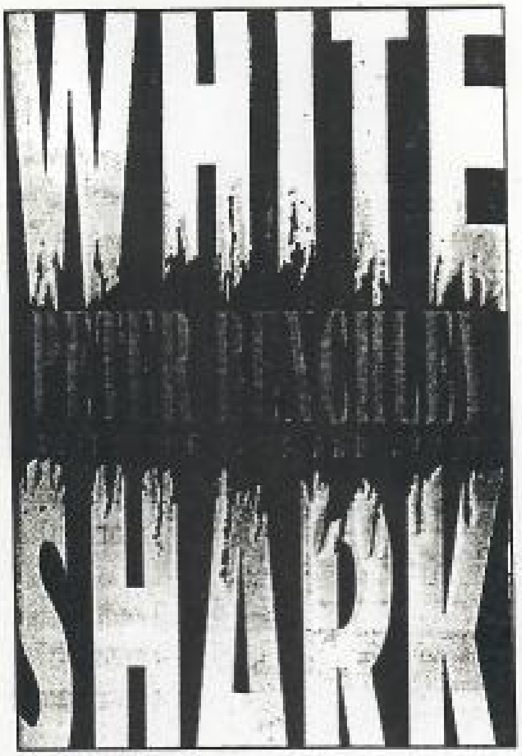
Not that Benchley is really complaining. "Jaws" made him a wealthy man, and the master of underwater thrillers.

"Jaws touched a real deep nerve in people," he admits. And Williams' music sent out its own share of shivers.

Benchley's newest page-turner revolves around a mysterious something that's disrupting life under the sea. Benchley refers to it as "It." Bodies start washing up on shore. Blood fills the sea. A hand here. A leg there. It is quintessential Benchley.

Benchley is a master at writing page-turners. Even the New York Times has called his pacing "irresistible."

"If you write for yourself, and keep yourself interested, you create it filled with unknowns and what ifs," he says. "I have a strong narrative head. I'm very impatient with stories that don't go anywhere."



"White Shark's" main character is Simon Chase, a marine biologist who loves the sea and the misunderstood sharks that swim in it. Benchley admits there are similarities with his own life.

"Every one of these characters is more or less me," he says. "A middle-age reprobate gets in trouble beyond his depth."

Get Benchley going on sharks, and he soon puts down his fork and forgets about the plate of cherrystone clams before him. He is very protective of the species that made him famous. But he also understands their intrigue.

"It's a safe danger. It's why kids love them. They're fun to watch and fun to learn about. It's not a fear one needs to worry about.

"For every shark attack on a human, there are 4.5 million sharks killed by man," he says. It seems his life is spent educating the public to the fact that a shark will not attack a human unless it's confused. "Every shark attack is an accident."

Unfortunately, admits Benchley, a human sitting on a surfboard looks exactly like a sea lion to a hungry shark swimming below, and sea lions are sharks' favorite meal.

"What are they going to do after they've ripped your leg off by mistake? asks Benchley. "Say I'm sorry?"

Even though Benchley's books are great beach reading, he says they also serve another purpose. They are filled with facts about sea life.

"My hope is I'll give you a good time says Benchley, "but I'm going to force you to learn something too . . . It doesn bother me if you want to call it a good beach read, but if I heard from a scientist that I've made a mistake in there, *that* would bother me."

Will "White Shark," like "Jaws," mak the silver screen?

Maybe. The book has been optioned, and Benchley has already written and rewritten the screenplay. "But you never know what Hollywood is going t do," he says. "Never."

Peter Benchley at a glance:

- **Home:** Princeton, N.J., complete with a pool with a shark painted on the bottom.
- **Family:** Wife, Wendy. Three children: Tracy, 27; Clay, 25; Christopher, 7.
- **His novels:** Jaws, 1974; The Deep, 1976; The Island, 1979; Q Clearance, 1986; Rummies, 1989; Beast, 1991.
- **Writing habits:** Every morning from 8 until 1, "unless some producer pays for me to go someplace exotic."
- **Favorite author:** Canadian novelist Robertson Davies. "As fast as he writes, I read."
- **About reviews:** Family friend John Steinbeck told him never to read reviews of his books. "The pain of the bad ones is far worse than the pleasure of the good ones." Benchley followed the advice, except once, when he read a devastating New York Times review of his novel, "The Deep." "I can still quote from it," says Benchley.

Monday June 23 1997 B1

The Honolulu Advertiser

Hawaii's Environment

JAN TENBRUGGENCATE

What do big sharks eat? Anything!

Tiger sharks are associated with most shark attacks on humans in Hawaiian waters, but studies of shark behavior and eating habits suggest the species isn't out there looking for people, but is simply biting what looks interesting.

A study of stomach contents of 281 tiger sharks collected in a shark control program from 1967 to 1969, and from a shark catching program in 1976, shows that tiger sharks aren't selective feeders.

"Tiger sharks may be opportunistic feeders that prey heavily on abundant, easy-to-capture prey," wrote the authors of a report on the study, published last year. The authors are Christopher Lowe, Bradley Wetherbee, Gerald Crow and Albert Tester.

They found that tiger shark diets appear to change as they get larger, and that the bigger tigers are more likely than smaller ones to pose a threat to humans, since they tend to take prey of about the same size as humans.

Among small sharks up to 6 feet in length, bony fish and eels (as opposed to fish with cartilage instead of bones, such as sharks and rays) were found in the stomachs of 89 percent. Twenty-two percent had bird remains in their stomachs, and there were smaller amounts of squid and crabs. A small shark had eaten a cat.

Among medium-sized sharks of 6 to 9 feet in length, fish were still common, but not as common as among smaller sharks. Many of these sharks had eaten lobsters, other sharks, turtles, dolphins, goats and sheep.

Large sharks, identified as more than three meters (about 10 feet) long, had been eating a much broader array of foods, so that no single food category formed a majority. The two fishing programs caught 135 sharks in this size range, of which 22 percent had empty stomachs.

Here's how the eating habits of the rest of the big sharks were itemized:

- ■ 40 percent had eaten fish. Puffers and porcupine fish were the most common, as they were in the fish diets of the smaller sharks.
- ■ 37 percent of the sharks' stomachs contained remains of sharks and a few rays.
- ■ 35 percent had eaten crustaceans, mainly lobsters.
- ■ 25 percent had birds in their bellies. Sharks regularly swallow seabirds resting on the ocean's surface.
- ■ 16 percent had mammal parts, mainly dolphins, but three had eaten goats, two had eaten dogs, two rats and one a mongoose. One of the big tigers' stomachs contained human remains.
- ■ 15 percent had eaten turtles.
- ■ 10 percent had eaten octopus, squid or related animals.

About 21 percent of the big sharks had consumed sticks, tin cans, clothing, kitchen scraps, aluminum foil and plastic bags.

Jan TenBruggencate is The Advertiser's Kauai bureau chief and its science and environment writer. You can call him at (808) 245-3074 or email him at tenb@aloha.net.

The Honolulu Advertiser 6/5/97
A1

Giant shark seen off Niihau, Lehua

By Jan TenBruggencate
Advertiser Kauai Bureau

LIHUE, Kauai — Kauai residents have reported a huge shark, possibly a great white, in the waters off Niihau and Lehua.

A group of free divers was frightened out of the water near Lehua recently by a very large shark, according to people operating diving companies.

And Bruce Robinson, manager of Niihau Ranch, saw a large shark two weeks ago off Lehua from the Niihau Helicopters aircraft.

"This thing was huge. I'm pretty sure it was a white," he said. "It had a conical head and was 20 to 25 feet long, but whether it was a gray nurse or a blue, I don't know. I know it wasn't a whale shark. I've seen plenty of those."

Robinson, who is also a diver, said he has come face to face with a 6-foot white shark in the water off Niihau, and identified a small white caught by Niihau residents while they were fishing.

"No question in my mind, they're there," he said.

Marine experts warn against any effort to kill off large sharks. The big shark hasn't bothered anyone, and wiping out large predators can cause more problems than it solves, experts say. For one thing, they are the major predators of nearshore shark species, whose numbers rise when the big sharks are removed.

Big sharks have been seen in the area before. Linda Bail, co-owner of Bubbles Below Scuba Charters, said she saw an immense shark there two years ago. But despite an active diving schedule, she hasn't seen it since. She didn't get a good look at the head and couldn't identify it, she said.

"It was a very, very large shark. The shark is out there, and I can't guarantee what it

See Shark, Page A5

"You've got to have a lot of prey to keep biomass of that size going."

— JOHN NAUGHTON
RESEARCHER, NATIONAL MARINE FISHERIES SERVICE

Great White Shark

Carcharodon carcharias

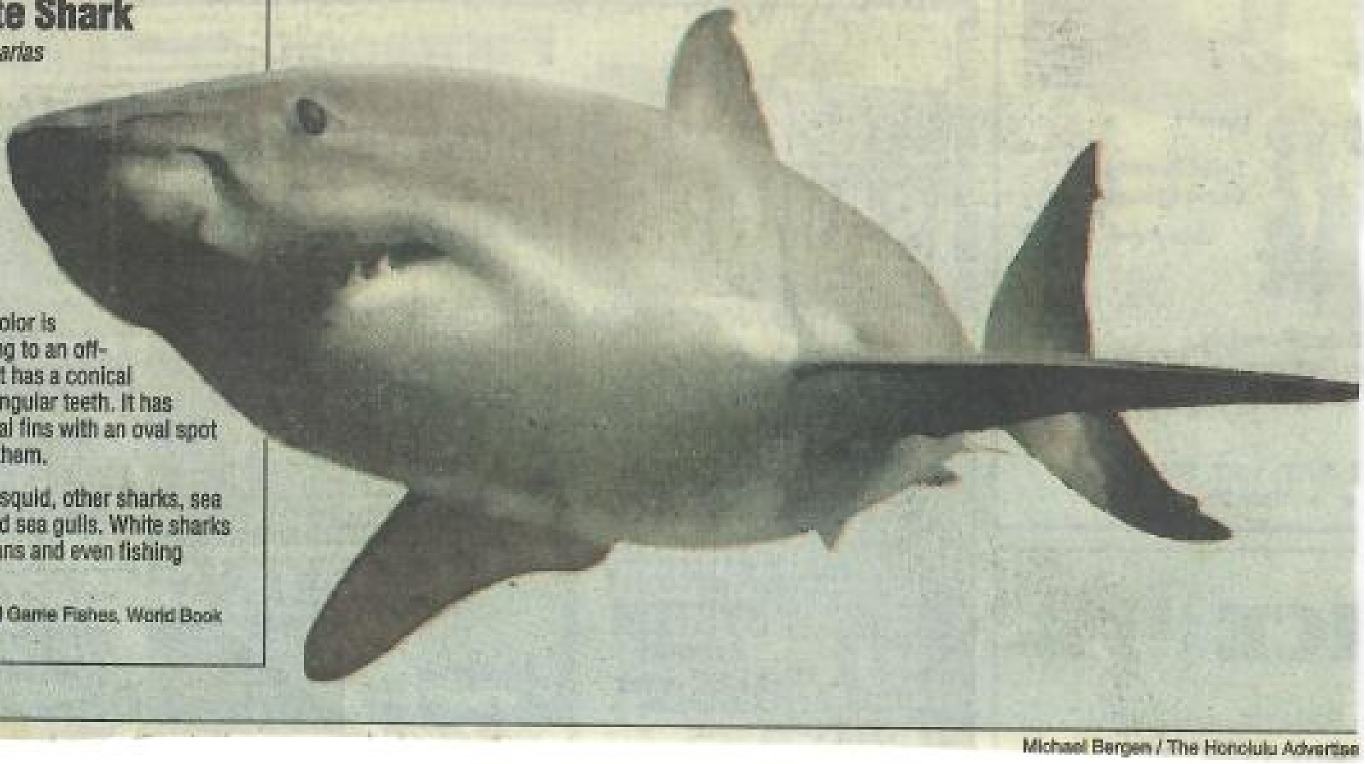
Length: Adults are 11-14 feet; can grow as long as 21 feet.

Habitat: Cool temperate to tropical waters.

Description: Skin color is grayish brown fading to an off-white on the belly. It has a conical snout and large triangular teeth. It has black-tipped pectoral fins with an oval spot on the body above them.

Diet: Includes fish, squid, other sharks, sea turtles, sea lions and sea gulls. White sharks have attacked humans and even fishing boats.

Source: World Record Game Fishes, World Book Encyclopedia



Michael Bergen / The Honolulu Advertise

Shark: Great white may be cruising off Niihau

FROM PAGE ONE

was," Bail said. "It was very fat. Its width was what was impressive."

A National Marine Fisheries Service researcher, John Naughton, said his discussion with Bail indicates she almost certainly saw a great white. He said these are rare, but not unknown, in the Hawaiian Islands.

Naughton said a young great white might be confused with other species, but with age, "a white gets very thick."

Bail said she believes the big shark she saw was passing through. It was June 1995, a period when Hawaii's ocean water temperature was much colder than usual and could have attracted a species normally found in colder waters, she said.

Following the food

Waikiki Aquarium shark expert Jerry Crow said a big great white might have trouble finding enough to eat around Hawaii and might be following a food source.

"It could possibly be following the migration of humpback whales from Alaska to Hawaii, but that's unknown," he said. The shark could also feed on porpoises, which the species is known to do in the Mediterranean, Naughton said. Crow added: "It would probably feed more on weak and injured animals."

Naughton said great white sharks normally frequent areas with a lot of prey, such as seal and sea lion rookeries.

Hawaiian monk seals have established a small but growing population at Niihau, but Naughton said that would probably not provide enough food to meet the needs of a giant great white.

"You've got to have a lot of prey to keep biomass of that size going," he said.

Naughton reported that seals around the Northwestern Hawaiian Islands show a healthy respect for big sharks, including whites.

"In all the years I've been working, including shark fishing, I've only seen two. One was when we were diving at Laysan (one of the Northwestern Hawaiian Islands). We had a huge one swim over us — it was at least 14 or 15 feet — and the seals obviously knew it was there. They dove into caves to hide," he said.

The shark did not bother the human divers, he said. Naughton said neither great whites nor tigers, the more common big Hawaiian sharks, normally attack divers far below the surface or on the bottom. They more commonly go after seals or other prey on the surface, he said.

Waikiki Aquarium's Crow said, though, that great whites are not predictable.

"White sharks have carried off divers off Australia... If they're in a feeding mode, they take very large prey. They usually come from behind and you usually don't see them," Crow said.

Great whites are rarely caught, but Naughton said he is aware of three cases in which white sharks were caught by anglers, mainly along the Big Island's Kona coast. Crow said during shark-control fishing in Hawaii in 1959 and 1960, two whites were caught off the Big Island, an 11-footer off Oahu's North Shore and a 9-footer off East Oahu. (Reference books say the white sharks can grow as long as 21 feet.)

Shark populations reduced

State-sponsored shark fishing programs have shown that Hawaii's population of big sharks is readily reduced through concerted fishing pressure.

Researchers found that when large tiger shark populations dropped, the smaller nearshore sharks that tiger sharks eat increased in numbers. These sharks put more pressure on the shoreline fish supply.

Many shark species, tigers and whites included, are long-lived and produce few young. Because they don't reproduce quickly, their populations can remain depressed for a long time after heavy fishing pressure.

"Most of the sharks of the world are soon going to be on the endangered species list," Bail said.

Naughton said white sharks are now protected in many parts of the world because they've nearly been fished out. Bail said she hopes the large Niihau shark, like other parts of the marine ecosystem, is left alone.

"The last think I want is people scared or someone over there trying to catch it," Bail said.

The only confirmed great white shark attack in Hawaii occurred in 1969 off Oahu, shortly after a dead whale had been removed from a nearby beach. The shark was identifie from its tooth imprints in a surfboard.

Date: 25 Apr 96 17:57:27 EDT
From: Don@dar.CCMAIL.CompuServe.COM
To: gbalazs@honlab.nmfs.hawaii.edu,
/DV=INTERNET#c#TENB#l#a#r#ALOHA.NET/DT=ID/PRMD=CSMAIL/ADMD=COMPUSERVE/C=US@C
Subject: Wailua shark attack? case or sightings

Dear George-
The reported "shark siting" protocol with DAR is still handled by our I&E program (apparently since "sharks" are more "information" than they are fishery "biology"; here's what I was able to glean on my own:

A visitor saw something and called Kauai Police Dept., KPD then called one of our DOCARE enforcement officers (Tarey Lowe) who then called me at home the Sunday morning of the sighting, the discussing went something like this:
TL: Don, a large 7-8 foot shark was reported (to KPD by a visitor) to have been seen off of Wailua Bay near "Horner's" (the surf spot where Silva was attached 2? years ago); what should we do?
DH: If no one was bitten, chased out of the water, or threatened by the shark in any way, and there is no evidence of "bait" or stimuli in the water that could attract or invoke a shark attack (like a dead turtle, whale, etc.) then the visitor should consider themselve lucky to have seen one of these important elements of the coral reef ecosystem! Based on the information provided, I would not recommend putting up "Shark Signs", irregardless of the fact that it is a 3-day weekend.

5 am next day Monday: Listening to radio on way to work- announcer states "Yesterday a 20 foot shark was reported off of Wailua Beach!" (my mental response= sounds like a fish story to me; if it was this large it could only be one of four possibilities: a whale shark, a great white, a basking shark that's lost, or the viewer saw manta rays basking at surface and mistook them for a large shark)

7am - I received call from Orlando Anaya, Chief Life Guard for Kauai County Parks and Recreation stating:

OA: Don, I was just down at Wailua Bay and saw two large Manta Rays, each about 12' wide (pec to pec), I think these fish are what the person saw that reported seeing a large shark. Why would these fish be in Wailua Bay close to shore?

DH: Mantas are planktivores and eat small organizms that float in the plankton; the bay receives relatively high levels of nutrients and suspended organic materials that are discharge into the bay from the Wailua River, one of the largest watersheds in the state. The bay is often "green" which indicates relatively high primary productivity, lots of plankton, and the mantas are simply there because of the relatively concentrated food source.

True story about mantas basking in Kihei, Maui in 1968 or 69:
I (DH) was working for a pluming company (Leis Company) with a fellow employee (Wally Chung-Ki) and we were

plumbing the top floor of the "Hale Pau Hana", the first condo to be built in Kihei; we were pluming the top floor before the roof was put on and Wally and I were in adjancent rooms when I heard Wally yell---"Shark, Shark, Shark....."; I ran over to Wally and said where, where? Wally pointed frantically, right there! It took me about 2 seconds to assess the situation--- all the while swimmers were scrambling to the beach, (I should note her that although I was not a professional fishery biologist at the time, I've always had a keen interest in marine biology and was an avid diver)---I said to Wally, "That's not a shark its a large manta ray sunning itself, see it's sunning and swimming parallel to beach and one of the two pectorals in black (top surface) and the other is white (under surface). It took me almost 15-20 minutes to convince Wally who by now had stopped yelling "shark"; finally the manta starting swimming towards us and you could see the tips of pectorals going up and down, up and down, and it finally swam to a position where we could see the entire ray. Wally finally was convinced (learned) how to differenciate a Manta from a shark.

The moral of this story, even residents born and raised in Hawaii can mistake Mantas for sharks...just think what someone, like Dorthy, visiting from Kansas might do!

George, John Naughton called me mid-morning the Monday after the "shark" sighting in Wailua was reported and I told him this same true story. Aloha, dh

RECORDS OF WHITE SHARK-BITTEN LEATHERBACK SEA TURTLES ALONG THE CENTRAL CALIFORNIA COAST

DOUGLAS J. LONG

Department of Biology, Saint Mary's College, P.O. Box 4507, Moraga, CA. 94575, U.S.A.

Running Header: WHITE SHARK FEEDING ON SEA TURTLES

ABSTRACT

White sharks Carcharodon carcharias are alleged to feed on sea turtles, but little documented evidence exists. Presented here are two cases of white sharks feeding on the leatherback sea turtle Dermochelys coriacea, based on white shark bite wounds inflicted on two sea turtle carcasses collected along the central California coast. Direct predation or post-mortem scavenging could not be discerned. These records are among the few cases documenting white sharks feeding on sea turtles, including the first records from the Pacific.

Key words: Carcharodon, Dermochelys, predation, scavenging, sea turtle, white shark

INTRODUCTION

Adult white sharks Carcharodon carcharias feed on fishes and marine mammals, and are suspected of preying on sea turtles. Bigelow & Schroeder (1948) and Compagno (1984) list sea turtles as dietary items of white sharks, but did not identify the species of turtles eaten, nor did they cite specific examples or give further information. In addition, analyses of gut contents of white sharks (Bass et al. 1975, Stevens 1984, Klimley 1985, Cliff et al. 1989, Bruce 1992) did not list sea turtles as prey items. The only published accounts of a white shark feeding on a sea turtle is Coles' (1919) observation of a large (ca. 550 cm) white shark attacking a live adult loggerhead sea turtle Caretta caretta off the coast of North Carolina, U.S.A, but additional published records of white sharks feeding on sea turtles do not exist. In this report, two shark-bitten leatherback sea turtles Dermochelys coriacea from the central

California coast add to the few records of white sharks feeding on sea turtles. These accounts are the only such records from the Pacific range of the white shark, and constitute the first report of white sharks feeding on the leatherback sea turtle.

METHODS AND MATERIALS

Sea turtles in United States waters are federally protected, thus all live and dead turtles that strand along the west coast are investigated and documented (see Seagars & Joziwak 1991, and Long et al. this volume). Between January 1991 and December 1994, seven stranded leatherback sea turtles were examined and documented from the coast of central California, including two sea turtles showing evidence of feeding by sharks. Wounds were examined and evaluated, following criteria used by Long & Jones (this volume), and Long et al. (this volume), to determine the source of the wounds.

RESULTS

On 16 February 1992, an adult female leatherback sea turtle (158 cm total carapace length) was collected on the beach at Halfmoon Bay, San Mateo County, California (37° 28' N, 122° 27' W, Fig. 1-1). Both the left front and right hind flipper were bitten off near the bases. Examination of the wounds showed punctures, cuts, and serration marks attributable to an adult white shark (Fig. 2A). Portions of this specimen were retrieved, and it is curated at the California Academy of Sciences.

On 11 August 1993, another adult female (162 cm estimated total carapace length) washed ashore on Brighton Beach, Bolinas, Marin County, California (37° 54' N, 122° 43' W, Fig. 1-2). The turtle had the posterior end of the carapace and the left hind flipper bitten off, and a large bite (about 48 cm wide) had removed the right central section of the carapace (Fig. 2B). Based on jaw measurements by Long & Jones (this volume), the size of the white shark was estimated to be an adult between 500 and 550 cm total length. Portions of this turtle were collected, and it is curated into the University of California, Berkeley, Museum of Vertebrate Zoology.

DISCUSSION

Based on the characteristically large, deep bites and wide tooth punctures observed on the leatherback turtle carcasses, the wounds were unmistakably inflicted by white shark. Unfortunately, both turtles had been dead for several days prior to examination, so it was difficult to confirm if white shark predation was the direct cause of death for the turtles, or if the bites were inflicted after death. Post-mortem examinations of the carcasses however, did not reveal death from more common causes such as disease, drowning from net entanglement, trauma from boat collision, or complications from ingestion of plastics. In any case, the presence of large bites and removal of large portions of tissue from the carcasses are direct evidence of feeding (either predation or scavenging) by white sharks on leatherback sea turtles.

These records are important in several respects. First, the large bites taken out of the sea turtles shells attest to the strength and bite force of the white shark. Unlike most sea turtles whose shell is covered with large bony plates, the leatherback turtle has a thick shell composed of small, bony tile-like plates covered with a thick later of cartilage and skin (Marquez 1990). While not as solid as the shells of other sea turtles, the leatherback's shell is still very tough. The bites that penetrated both the carapace and plastron in the second turtle specimen showed that a great amount of force was needed. The tooth morphology of tiger sharks Galeocerdo cuvieri are believed to be adapted for preying on sea turtles (Witzell 1987), and they are a common food item of this shark species (Randall 1992, Simpendorfer 1992, Stevens & McLoughlin 1992).

The morphology and microstructure of white shark teeth are also designed to penetrate and cut hard objects with application of heavy forces (Preuschoft et al. 1974, Frazzetta 1988), including mammal bones and turtle shells. Therefore, attacks would not be prevented by the turtle's carapace, and predation on sea turtles should not seem unusual.

Secondly, turtles have not previously been reported as dietary items from white sharks in the eastern North Pacific (Klimley 1985). It is not surprising that these new feeding records came from central California, as this area has a high incidence of white shark predation on marine mammals (Le Boeuf et al. 1982, Klimley 1985, Long & Jones, this volume, Long et al. this volume). Additionally, leatherbacks are the most common sea turtle along central California, and are most frequently seen offshore or recovered as dead stranded individuals in the summer and fall (Starbird et al. 1993). It is interesting that while one of the carcasses was collected in August, the other was collected in February, during a season when both leatherbacks are rare and white shark predation on pinnipeds is low (Klimley et al. 1992, Starbird et al. 1993, Long et al. this volume).

Lastly, these are the first records of the white shark as a possible predator on the leatherback sea turtle. Off southern Australia, Cropp (1979) described what he believed to be a leatherback's defensive behavior in the presence of a white shark, a behavior that included erratic diving, rolling on the surface of the water, and violent flailing of the turtle's flippers as it floated on its back. The shark attempted no attack, however, and thus predation by white sharks on this species could not be confirmed. Killer whales Orcinus orca are the leatherback's only positively confirmed predator (Caldwell & Caldwell 1969), but tiger sharks are also suspected as predators (Keinath & Musick

1993). From the evidence presented here, white sharks are also likely predators on the leatherback sea turtle.

Since so few records documenting shark predation on sea turtles exist, little can be said regarding trends in predatory dynamics. Sea turtles are probably uncommon dietary items for white sharks because sea turtles are not abundant in temperate seas frequented by white sharks (Compagno 1984, Marquez 1990). Alternatively, the seeming rarity of sea turtles in the diet of white sharks may be due to the turtles' possible low food value when compared to that of marine mammals. Klimley (1994), and Long & Jones (this volume) discuss the shark's preference for prey with high fat content; it is possible that the sea turtles in this study were attacked and rejected after several bites. Only additional records and further observations of white shark / sea turtle interactions can lead to more concrete assumptions on the nature of their predatory interactions.

ACKNOWLEDGEMENTS

Data on the leatherback sea turtles were collected by myself and other volunteer personnel from the National Marine Mammal Stranding Network under the auspices of the National Marine Fisheries Service and the National Oceanographic and Atmospheric Administration. I would like to thank R.E. Jones (Museum of Vertebrate Zoology, University of California, Berkeley), S. Webb and K. Hansen (Point Reyes Bird Observatory), R. Bandar (California Academy of Sciences, San Francisco).

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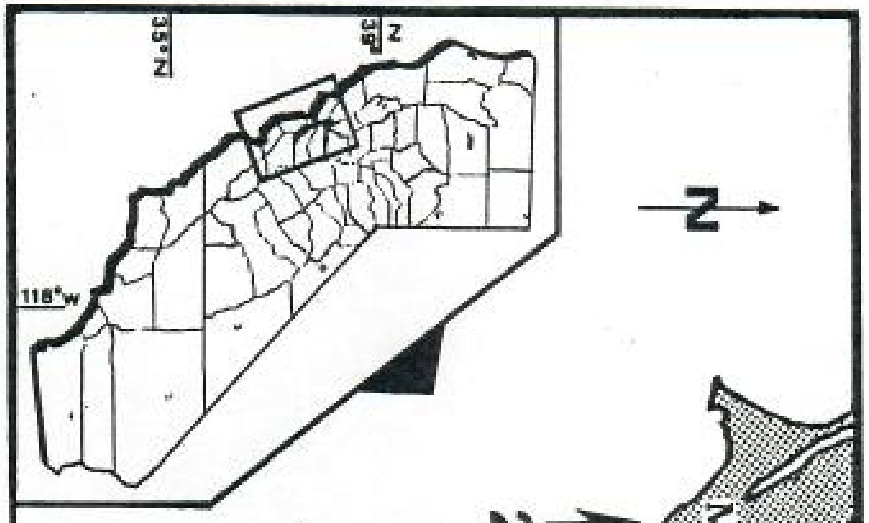
FIGURE CAPTIONS

Figure 1. The central California coast showing the locations where the two white shark bitten leatherback sea turtles were recovered. Numbers on the map correspond to the specimen case numbers used in the text.

Figure 2. Illustrations of the two leatherback sea turtles showing location, position, and shape of the shark bites (shaded areas). Arrows point to individual tooth punctures and cuts: A) adult female from Halfmoon Bay (specimen 1); B) adult female from Bolinas (specimen 2).

FIG. 1


35°N
38°N
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N
1
2
S.F.
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SOLANO
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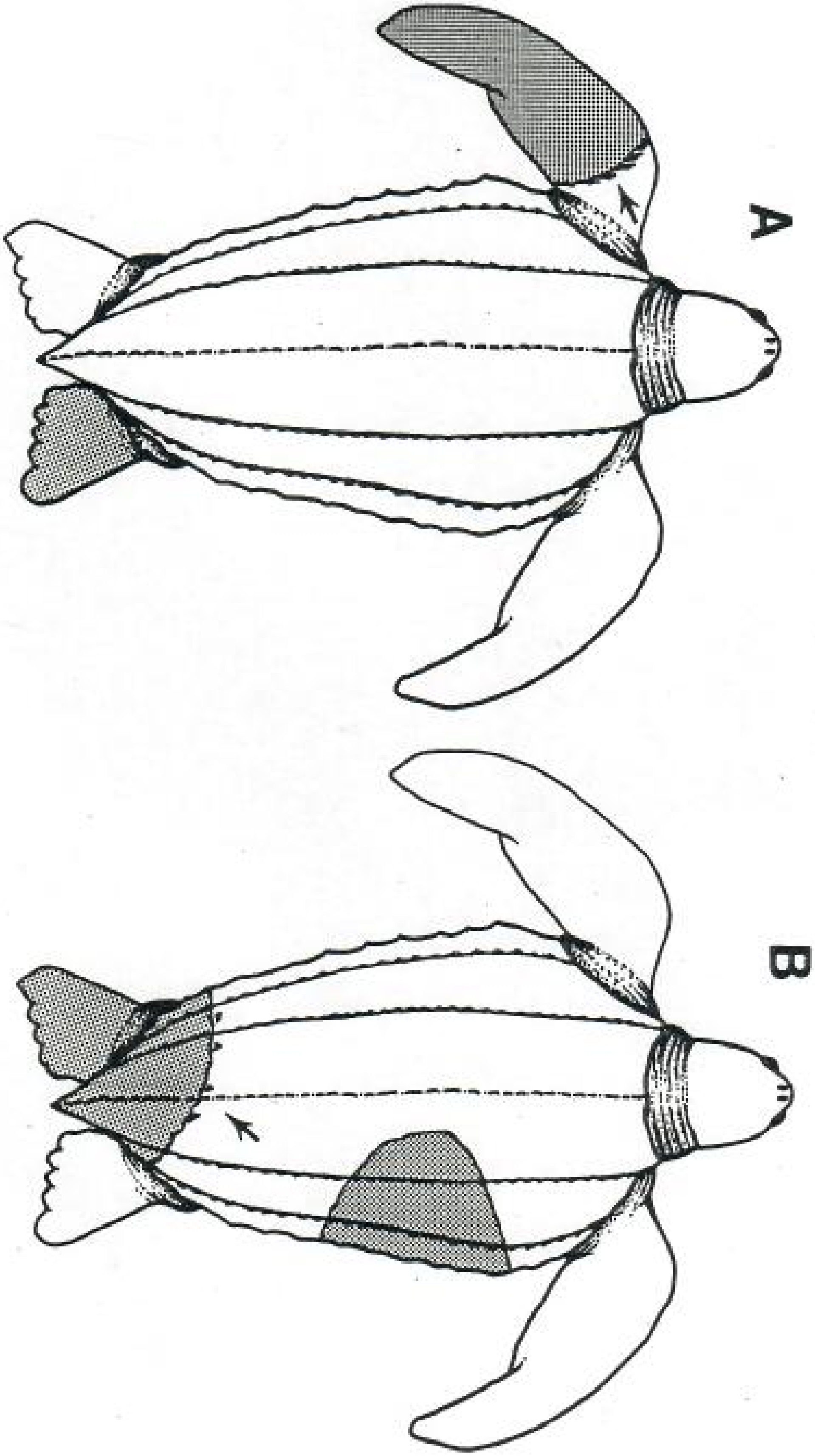
SANTA CLARA
SANTA CRUZ

FIG. 2



CAS ICHTHYOLOGY

6 JAN 1996

California
Academy
of Sciences

DEAR GEORGE -

THANKS FOR YOUR INTEREST IN MY RESEARCH. UNFORTUNATELY, MY PAPER IS BASICALLY AN EXTENDED NOTE ON TWO INSTANCES OF WHITE SHARKS FEEDING (AND POSSIBLY PREYING) ON LEATHERBACK SEA TURTLES, BUT I HOPE IT IS OF SOME USE TO YOUR RESEARCH. THE PAPER IS DUE OUT, AS PART OF THE WHITE SHARK BOOK, IN AUGUST. I AM INTERESTED IN SEA TURTLES AND WOULD LOVE REPRINTS OF YOUR RESEARCH. IN ADDITION, I WOULD BE INTERESTED IN FUTURE RESEARCH POSSIBILITIES, INVOLVING SHARK / SEA TURTLE INTERACTIONS, WITH YOUR GROUP (AND THE TIGER SHARKS IN YOUR AREA!). FOR FUTURE CORRESPONDENCE YOU CAN REACH ME AT THE DEPT. OF ICHTHYOLOGY, CALIFORNIA ACADEMY OF SCIENCES (BELOW).

SINCERELY, DOUGLAS LONG

California Academy of Sciences Golden Gate Park San Francisco, California 94118-4599 415/ 221-5100
Home of Steinhart Aquarium and Morrison Planetarium

Temporal and Spatial Distribution of Catches of Tiger Sharks, *Galeocerdo cuvier*, in the Pelagic Longline Fishery Around the Hawaiian Islands

JEFFREY J. POLOVINA and BOULDERSON B. LAU

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ABSTRACT—Thirty-five tiger sharks, Galeocerdo cuvier, *have been reported caught in pelagic longline gear from 25 to 265 n.mi. off the Hawaiian Archipelago during December 1990-May 1993. Fifteen sharks were caught farther than 50 n.mi. offshore, indicating that tiger sharks do occur well offshore and removed from benthic topography. About 89% of the sharks were caught during October-March, while only 56% of the fishing effort occurred during that period.*

Introduction

The tiger shark, *Galeocerdo cuvier*, has a circumglobal distribution in tropical and temperate oceans (Randall, 1992). While considered a nearshore shark, returns of tagged tiger sharks from the east coast of the United States show that they can move considerable distances. The Cooperative Shark Tagging Program of the NMFS Northeast Fisheries Center's Naragansett Laboratory tagged 2,257 tiger sharks during 1977-89 and have data from the recoveries of 135 tags (Randall, 1992). Fifty-seven tags were recovered at least 100 n.mi. away from the tagging sites. The greatest distance between the tag and recovery sites was 1,853 n.mi. (Randall, 1992). Generally, this movement is believed to be alongshore movement over the continental shelf.

Less is known about tiger shark movement in the oceanic Hawaiian Islands. In one tagging study only four tagged tiger sharks have been recovered, and only one showed any significant movement, 45 n.mi., from the north to the south of the Island of Oahu (Tester, 1969). Sonic tracking of a tiger shark in the Northwestern Hawaiian Islands over two 24-hour periods found the shark remained within 7 km of the reef (Tricas et al., 1981).

As a result of recent apparent increases in tiger shark attacks on humans in Hawaii (Balazs, In press), there is considerable interest in long-term movement patterns of tiger sharks around the Hawaiian Islands. Information on the movement of tiger sharks around the Archipelago would provide a useful biological background to assess the impact of management actions such as localized shark fishing.

Since November 1990, the Honolulu Laboratory of the NMFS Southwest Fisheries Science Center has collected logbooks from vessels fishing in the pelagic longline fishery around the Hawaiian Archipelago. Occasionally, catches of tiger sharks are recorded in the logbooks and these records provide unique information on the offshore occurrence of tiger sharks around the Hawaiian Islands. Here, we present a spatial and temporal analysis of catches of tiger sharks from the longline fishery logbooks.

Data

Fish are caught by longline gear with baited hooks on hundreds of branch lines attached to a single long main line often stretching 30 n.mi. The main line is buoyed at regular intervals by float lines connected to surface floats. The depth of the hooks alters the gear efficiency in catching different species. Each longline set requires most of a day or night to set, soak, and retrieve. Recently, because of the development of the swordfish fishery, the longline fleet has grown dramatically, and many vessels often make from 30- to 40-day trips, traveling 400-1,000 miles north of Hawaii. The longline fishery around the Hawaiian Archipelago typically targets swordfish and bigeye tuna but catches a wide range of fishes occasionally including tiger sharks. Longline sets targeting tunas are usually day sets; gear is deployed early in the morning and retrieved late in the afternoon. Sets targeting swordfish are night sets; gear is set late in the afternoon and retrieved early in the morning. Since November 1990, all longline vessels fishing around the Hawaiian Islands are required to report by set: Location of the set, number of hooks, and number of fish caught for the 15 most common species, including three species of oceanic sharks. Tiger sharks are not one of the species specifically identified in the logbooks; they are entered as "other" on the log sheets.

Logbooks from December 1990 to May 1993 were examined for reports of tiger shark catches. During this 30-month period, longlining within 50 n.mi. of the main Hawaiian Islands was prohibited for about 20 months (from mid-June to mid-December 1991 and from March 1992 to May 1993) to resolve gear conflicts.

Results

An examination of longline logbooks from December 1990 to May 1993 found 35 catches of tiger sharks recorded from 4,350 fishing trips (Table 1, Fig. 1).

Tiger sharks were caught both on day longline sets targeting tunas and night longline sets which target swordfish (Table 1). Fifteen of the catches occurred both south and north of the Archipelago beyond 50 n.mi. offshore, with the farthest at 365 n.mi. offshore (Table 1, Fig. 1). Eighteen occurred within 45 n.mi. of the north side of Maui between November 1992 and January 1993 (Table 1, Fig. 1). About 89% (31 of 35) of the sharks were caught during the 1st and 4th quarters (October–March), while only 56% of the fishing trips occurred during this period (Table 2). Based on a chi-squared test the catches of tiger sharks in the 1st and 4th quarters are greater than would be expected if catches were proportional to fishing trips (*P*<0.0001). When the catch is examined based on distance offshore we find that 60% of those caught beyond 50 n.mi. offshore are caught in the 1st quarter (Table 2).

Table 1.—Reports of catches of tiger sharks from pelagic longline logbooks[1]. The coordinate for each location is the mean between set location and haul location. Distance is from the nearest shore of the Hawaiian Archipelago.

Record	Haul date	Set time	Haul time	Location Lat.	Location Long.	No. of tiger sharks	Distance from nearest shore (n.mi).	Quarter
1	930307	0700h	1800h	21° 56'	164° 41'	1	95	1
2	930304	0700	1800	21 46	164 37	1	105	1
3	930303	0730	1700	21 57	164 43	2	201	1
4	930119	0830	1730	18 54	160 20	1	165	1
5	930117	0900	1730	18 54	159 52	2	170	1
6	930117	0700	1730	21 12	155 47	1	30	1
7	921223	0750	1500	19 07	159 46	1	150	4
8	921222	0735	1430	19 27	160 41	1	104	4
9	921201	0800	1600	21 38	156 08	1	45	4
10	921126	0700	1600	21 32	156 01	1	35	4
11	921117	0800	1600	21 16	155 45	5	30	4
12	921116	0830	1600	21 17	156 00	4	25	4
13	921114	0800	1600	21 18	155 58	3	25	4
14	921113	0800	1600	21 22	155 51	3	35	4
15	920829	0630	1450	19 40	158 52	1	105	3
16	920811	1800	600	27 06	157 28	1	315	3
17	920209	830	1630	21 28	160 38	1	30	1
18	920117	610	1610	20 30	160 45	1	240	1
19	910626	1800	730	27 24	163 31	1	250	2
20	910617	1830	730	26 45	166 02	1	180	2
21	910329	1845	1030	28 19	159 05	1	365	1
22	910129	1400	0800	23 05	162 54	1	45	1

[1] Data provided by the Pelagics Fishery Management Plan of the Western Pacific Regional Fishery Management Council and compiled by the Fishery Management Research Program, SWFSC Honolulu Laboratory.

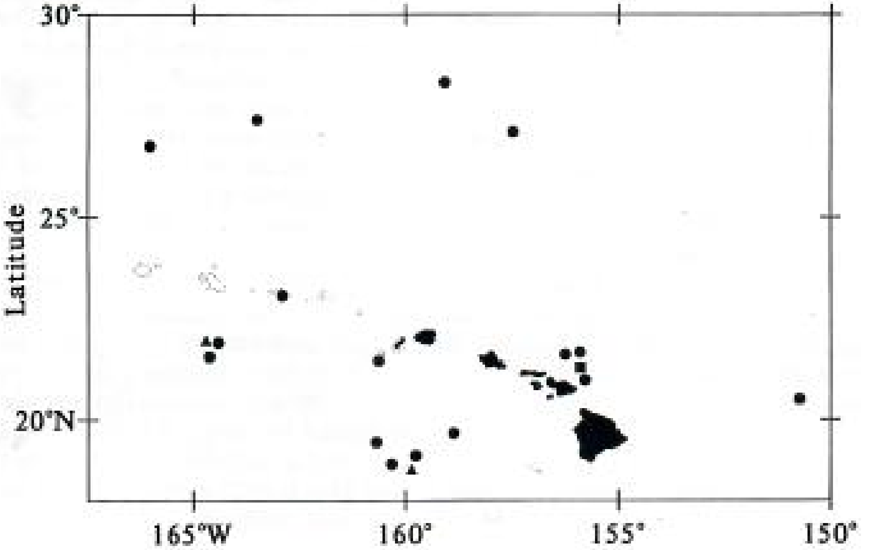

Figure 1.—Locations of tiger sharks caught by the longline fishery based on longline logbooks during December 1990-May 1993. Dots represent catches of a single tiger shark per longline set, triangles represent catches of more than one tiger shark per longline set, and the square represents four sets each with a catch of more than one tiger shark.

Discussion

Since tiger sharks are rarely caught on longline gear and since reporting requires that the incident be entered on the log sheet, it is likely that the reported catches underestimate actual catches. In fact, discussions with captains of vessels not reporting tiger shark catches in the logbooks confirm that other vessels have caught tiger sharks, but they have not specifically reported the catch. We cannot confirm that all tiger sharks reported were actually tiger sharks, but since tiger sharks are easily identified, it is likely that anyone interested enough to take the time to note the catch of a tiger shark would be able to correctly identify the species.

The reported catches show that tiger sharks can be found far offshore and well away from topographic features. Bottom depths even just 25 n.mi. off most of the islands exceed 4,000 m. Certainly, movement along the entire length of the Hawaiian Archipelago would be possible given these offshore movements. The higher catches of tiger sharks during the 1st and 4th quarters and, specifically, the higher catches of tiger sharks beyond 50 n.mi. during the 1st quarter suggest some seasonal offshore movement pattern. However, a more rigorous experimental design is needed to evaluate this hypothesis. The catches of 18 tiger sharks within 45

Table 2.—Tiger shark catches and fishing trips by quarter from the pelagic longline logbooks, December 1990–May 1993.

	Quarter of the Year 1	2	3	4
Fishing Trips	1,569	1,207	689	885
Tiger Sharks				
less than n.mi. offshore	3	0	0	17
more than 50 n.mi. offshore	9	2	2	2
Total Tiger Sharks	12	2	2	19

Data provided by the Pelagics Fishery Management Plan of the Western Pacific Regional Fishery Management Council and compiled by the Fishery Management Research Program, Honolulu Laboratory.

n.mi. of the north side of Maui between November 1992 and January 1993 and, particularly, the catches of 15 tiger sharks during 13-17 November 1992 indicate that incidental tiger shark catches by the longline fishery can have significant local impact on the tiger shark population.

While information of the size of the tiger sharks caught is not reported, discussions with vessel captains reporting catches indicate the sizes of tiger sharks caught on the longline gear range from 5 to 17 feet.

The reported catches of 35 tiger sharks by the longline fishery over the past 2 years indicate that tiger sharks may be attracted to longlines either because of the bait, or to prey on fish caught by the longline. Thus, there may be significant links between the longline fishery and tiger shark populations. A nearshore longline fishery may provide forage to support a tiger shark population, but may also inflict some fishing mortality on the population. Thus, temporal and spatial trends in fishing effort of the pelagic longline fishery may have an impact on the tiger shark population and, ultimately, tiger shark and human interactions.

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Honolulu Star-Bulletin A2

Hammerhead shark meat an ancient Hawaii treat

OCEAN WATCH

By Susan Scott

9/5/94

HAMMERHEAD shark. Those two words conjure up a vivid image. Add to that a beached female hammerhead giving birth in the sand, as happened recently in Ewa Beach, and the picture is even more striking.

Hammerheads are not your average fish. Besides that weird-shaped head, members of this shark family have a sophisticated method of reproduction not seen in most fish.

This method, called viviparity, involves giving birth to live young that were nourished inside the mother via an umbilical cord.

Sound familiar? Humans are viviparous too, as are nearly all other mammals, many reptiles and several other fish.

The big difference between mammals and other viviparous animals is the feeding of milk to the young after birth.

The resemblance of hammerheads to mammals stops with the umbilical cord and birthing.

Neither these sharks, nor any others, feed their young after birth.

But hammerheads do give their babies, up to 30 per litter, a bit of a head start by delivering them in the protection of shallow bays and inlets.

Kaneohe Bay is such a place. Female hammerheads come into the bay each spring and summer to have their pups.

The youngsters, about 2 feet long, live the early part of their lives in schools in the turbid shallows of the bay where they forage along the bottom, mostly at night. As they grow, they migrate to deeper waters of the outer reef.

HAMMERHEADS mostly eat live fish, occasionally dining on members of their own kind. They also eat invertebrates such as crabs, shrimp and octopus.

And what's the deal with that weird head? The fish bear one eye and one nostril on each side of their mallet-shaped heads.

Researchers believe the widely separate eyes increase depth perception; the separate nostrils are probably useful in locating diluted smells.

Also, small pits on the underside of the head are sensitive to electric fields. This helps the shark find living creatures, such as rays, hidden in the sand.

Still another theory holds that the flat head shape provides some lift as the fish swims forward.

Hammerhead sharks live in all warm waters of the world, preferring water 75 degrees Fahrenheit and above.

Two kinds of hammerheads are found here: the scalloped hammerhead and the common, or smooth, hammerhead.

Both names describe the front edge of the head, and both are known as mano kihikihi (angular shark) in Hawaiian.

IN ancient Hawaii, people commonly ate hammerhead sharks. Since Hawaiians did not eat sharks that attacked humans, hammerheads apparently were not considered a threat.

Not everyone in old Hawaii ate hammerheads, as they were forbidden people whose aumakua, or family god, was that species.

To those who could eat them, the catching of a hammerhead was a joyous occasion.

After skinning the fish, the meat was dried, then broiled or cooked. No one in ancient Hawaii ate shark meat raw.

Although ancient Hawaiians didn't consider hammerheads vicious, there have been occasional incidents in modern times. At least three nonfatal attacks on swimmers in Hawaii have been blamed on hammerheads over the years.

In the French Pacific, local spear fishermen stop spearing, but remain in the water, when hammerheads are in the vicinity. After the sharks have passed they resume fishing.

Susan Scott is a marine science writer and author of three books about Hawaii's environment. Her Ocean Watch column appears Monday in the Star-Bulletin.

Scalloped hammerhead sharks, or manu kihikihi, grow to over 12 feet long.

Pacific Science (1994), vol. 48, no. 2: 95–115

A Review of Shark Control in Hawaii with Recommendations for Future Research[1]

BRADLEY M. WETHERBEE,[2] CHRISTOPHER G. LOWE,[2] AND GERALD L. CROW[3]

ABSTRACT: In an attempt to allay public fears and to reduce the risk of shark attack, the state government of Hawaii spent over $300,000 on shark control programs between 1959 and 1976. Six control programs of various intensity resulted in the killing of 4,668 sharks at an average cost of $182 per shark. The programs furnished information on diet, reproduction, and distribution of sharks in Hawaii, but research efforts of the programs had a number of shortcomings. Analysis of the biological data gathered was not directed toward the tiger shark, *Galeocerdo cuvier* (Peron & LeSueur), which is responsible for most attacks in Hawaii. Reliable estimates of shark populations in Hawaii cannot be made based on catch data from control programs because of sampling biases. Most of the information gained from the control programs was not published in reviewed journals and is not readily available to the scientific community. The ability of the control programs to reduce shark populations and to remove large sharks from coastal waters appears to have been stated with more confidence than is warranted, considering seasonal changes observed in shark abundance and variable fishing effort. Shark control programs do not appear to have had measurable effects on the rate of shark attacks in Hawaiian waters. Implementation of large-scale control programs in the future in Hawaii may not be appropriate. Increased understanding of the behavior and biology of target species is necessary for evaluation of the effectiveness of small-scale control efforts, such as selective fishing after an attack. Acoustic telemetry, conventional tagging, and studies on population dynamics concentrating primarily on the tiger shark may be used to obtain data about activity patterns, distribution, and population parameters, providing information useful for reducing the risk of shark attack in Hawaii and elsewhere.

AS THE HUMAN POPULATION in Hawaii has risen, ocean resources have become increasingly exploited. In addition, Hawaii's increasing resident and tourist populations have placed a high priority on coastal recreation. Expanded recreational use of the ocean brings the potential for increasing shark-human interactions. Fear of shark attack, coupled with socioeconomic pressures of tourism, prompted the state of Hawaii to establish a shark control program in 1959 (Ikehara 1961), which was followed by other programs in 1966–1969 (Tester 1968, 1969, Norris and Harvey 1969), 1971 (Fujimoto and Sakuda 1971), and 1976 (Naftel 1976, Naftel et al. 1976). Two recent fatal shark attacks in Hawaii have prompted calls for reinstitution of a large-scale shark control program.

Because of the limited availability of data from past control programs and continued debate over the appropriateness of shark control in Hawaii, this paper provides a summary and critical review of past shark control programs in Hawaii with regard to: (1) objectives of the programs; (2) results and new information gained; (3) evaluation of success. This paper also assesses the potential for future shark control programs and provides suggestions for further research to increase under-

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standing of shark behavior and to provide information that may be useful for reducing shark-human interactions.

PAST SHARK CONTROL PROGRAMS IN HAWAII

The Billy Weaver Shark Research and Control Program, 1959–1960

On 13 December 1958 a teenage surfer, Billy Weaver, was fatally attacked by a shark off Lanikai, Oahu (Tester 1960). To minimize the hazard to surfers and swimmers posed by sharks, Hawaii's first shark control program (the Billy Weaver Shark Research and Control Program) was established. The intent of the program was to reduce shark populations in coastal waters around Oahu and to compile data for future use in controlling shark abundance. The Hawaii Board of Agriculture and Forestry was assigned to direct and supervise fishing operations and collection of biological and ecological data (Ikehara 1961).

TABLE 1

FISHING EFFORT, CATCH, AND CATCH PER UNIT EFFORT (CPUE) DURING EACH SEASON FOR EACH ISLAND FROM EACH CONTROL PROGRAM

	NO. OF HOOKS SET				NO. OF SHARKS CAUGHT				SHARKS PER 100 HOOKS (CPUE)				
ISLANDS	Wi	Sp	Su	Fa	Wi	Sp	Su	Fa	Wi	Sp	Su	Fa	TOTAL CPUE
Niihau													
Tester 1967–1969	192	360	1,272	344	10	90	180	42	5.2	25.0	14.1	12.2	14.8
												OA =	14.8
Kauai													
Tester 1967–1969	216	0	496	72	12	0	54	12	5.5	0	10.9	16.7	9.9
1971	0	288	288	0	0	13	8	0	0	4.5	2.8	0	3.6
1976	0	0	0	585	0	0	0	35	0	0	0	6.0	6.0
												OA =	6.9
Oahu													
Billy Weaver	3,312	2,064	2,640	2,988	120	173	238	166	3.6	8.4	9.0	5.5	6.3
Tester 1967–1969	2,141	2,808	2,224	2,088	89	148	175	122	4.1	5.3	7.9	5.8	5.8
1971	0	1,008	1,495	0	0	31	46	0	0	3.1	3.1	0	3.1
1976	0	0	141	0	0	0	3	0	0	0	2.1	0	2.1
												OA =	5.7
Molokai													
Tester 1967–1969	0	153	0	280	0	18	0	57	0	11.8	0	20.3	17.3
1971	0	216	240	0	0	19	13	0	0	8.8	5.4	0	7.0
												OA =	12.0
Maui													
Tester 1967–1969	0	157	72	72	0	25	9	20	0	21.0	12.5	27.8	20.1
1971	0	432	431	0	0	30	26	0	0	6.9	6.0	0	6.5
1976	0	0	988	0	0	0	57	0	0	0	5.7	0	5.7
												OA =	8.1
Lanai													
Tester 1967–1969	0	0	0	144	0	0	0	32	0	0	0	22.2	22.2
												OA =	22.2
Kahoolawe													
Tester 1967–1969	0	81	0	72	0	23	0	10	0	28.4	0	13.9	21.5
												OA =	21.5
Hawaii													
OI 1966–1967	640	96	96	96	64	3	15	10	10.0	3.1	15.6	10.4	9.9
Tester 1967–1969	504	218	408	576	25	6	20	35	5.0	2.7	4.9	6.1	5.0
1971	0	480	573	0	0	27	25	0	0	5.6	4.4	0	4.9
												OA =	6.2
Total	7,005	8,361	11,364	7,317	320	606	869	541	4.6	7.2	7.6	7.4	6.9

Wi, winter; Sp, spring; Su, summer; and Fa, fall. OI, Oceanic Institute; OA, overall average for all programs on each island.

Shark fishing was conducted aboard a tuna fishing boat during four circuits around the island of Oahu in 17 designated areas between 1 April 1959 and 31 March 1960 (Table 1). Sharks were caught using three 800-m sections of longline, with 24 hooks per section. The longlines were set parallel to shore in water about 45 m deep in the afternoon and were retrieved at dawn the next morning. Skipjack tuna, *Katsuwonus pelamis* (L.), was the primary bait used, although other types of bait were used in bait preference studies. Standard longlines of three 24-hook sections were used throughout each of the subsequent control programs (with the exception of the Oceanic Institute program) to allow comparison of catch rates between programs.

Nine species of sharks were caught, most of which were identified as "sand" sharks, *Carcharhinus* sp.; tiger sharks, *Galeocerdo cuvier* (Peron & LeSueur); and blacktip sharks, *Carcharhinus limbatus* (Valenciennes) (Table 2). Two great white sharks, *Carcharodon carcharias* (L.), were also caught. Although great white sharks are rare in Hawaii, they are responsible for attacks on humans and are

TABLE 2

SUMMARY OF THE SIX SHARK CONTROL PROGRAMS CONDUCTED IN THE STATE OF HAWAII

			NO. OF SHARKS KILLED			
PROGRAM DATE	COST	COST PER SHARK	SANDBAR	TIGER	OTHER SPECIES	TOTAL
Billy Weaver 1959–1960	$27,440	$39	"sand sharks" 492	87	Blacktip, 81 Hammerheads, 18 Sixgill, 11 Prickly, 3 White, 2 Blue, 1 Mako, 1 Unidentified, 1	697 [641]
Oceanic Institute 1966–1967	$20,000	$217	52	32	Blacktip, 6 White, 2	92
Tester 1967–1969	$200,000	$116	789	280	Gray reef, 274 Galápagos, 206 Unidentified, 64 Blacktip, 47 Hammerheads, 35 Prickly, 9 Sixgill, 9 Bignose, 9 Mako, 2 False cat, 2 Silky, 1	1,727 [1,095]
1971 March–August	$50,000	$210	88	109	Galápagos, 19 Blacktip, 19 Gray reef, 2 Mako, 1	238 [83]
1976 10–20 June	$8,200	$283	14	15	None	29
1976 August–September	$15,000	$227	20	31	Galápagos, 12 Gray reef, 1 Blacktip, 1 Mako, 1	66
Totals	$320,640	avg. $182	1,455 (963)	554	838	2,849 [1,819]
Grand total						4,668

NOTE: Numbers in brackets represent the numbers of pups removed from pregnant females; numbers in parentheses represent the confirmed number of sandbar sharks killed in total.

considered one of the most dangerous species of shark (Taylor 1985). To determine whether or not sharks range over a limited area, 14 sharks were tagged and released. None was recaptured. A progressive decrease in sharks caught per 100 hooks was observed during successive circuits around Oahu (Ikehara 1961).

Oceanic Institute Shark Control Program, 1966–1967

Oceanic Institute, a privately funded scientific research organization, conducted a small-scale shark fishing program restricted to Kawaihae Bay on the island of Hawaii from January 1966 through March 1967 (Table 1). Longlines consisting of a total of 32 hooks were used through March 1967, at which time the program was merged with the Hawaii Cooperative Shark Research and Control Program and 72 hook lines were used to fish this area (Norris and Harvey 1969). A total of 92 sharks was caught in the bay, predominately sandbar, *Carcharhinus plumbeus* (Nardo), and tiger sharks (Table 2). Norris and Harvey (1969) estimated that the combined fishing programs had resulted in an 80–90% reduction in the shark population of Kawaihae Bay.

Hawaii Cooperative Shark Research and Control Program, 1967–1969

The Hawaii Cooperative Shark Research and Control Program was initiated based on advice from local fisheries scientists to respond to an increase in shark sightings around the main Hawaiian Islands. The primary objectives of this program were to determine the species composition of coastal sharks and to gather information on abundance, life history, movement, growth rate, diet, and fecundity. Additional objectives were to determine the effects of fishing on coastal shark populations and to recommend effective measures for future shark control. The program was headed by Dr. Albert L. Tester, professor of zoology, and run under the auspices of the Institute of Marine Biology, University of Hawaii, with support from federal, state, and private agencies (Tester 1969).

Shark fishing was conducted between 1 June 1967 and 30 June 1969, again aboard a single tuna fishing boat. Fishing was conducted within 77 stations designated around all eight of the main Hawaiian Islands, but was concentrated around Oahu (eight successive circuits, during each of which all the designated areas were fished once) (Table 1). In addition to standard longlines, light longlines (12 hooks, set between 18 and 118 m) and "timed" handlines (fished at 18–109 m) were used to target smaller sharks. Experimental fishing trials, which consisted of bait preference tests, sets perpendicular to shore, and deep-water sets, were conducted off the south shore of Oahu.

The majority of sharks captured were sandbar sharks, followed by tiger; gray reef, *Carcharhinus amblyrhynchos* (Bleeker); and Galápagos sharks, *C. galapagensis* (Snodgrass & Heller) (Table 2). Of 16 tiger sharks tagged, four were recaptured, one of which had traveled 73 km after 207 days at liberty.

Again, a progressive decrease in the number of sharks caught per 100 hooks in successive fishing circuits was observed. However, the extended period of sampling for this program revealed considerable seasonal fluctuation in catch rates (Wass 1971). Tester (1969) concluded that coastal shark populations were very susceptible to fishing pressure and suggested that "the state undertake a continuing shark research and control program, at least until a commercial fishery is developed." Tester further recommended a continuous control program that would reduce shark abundance by at least 50% along all populated coastlines utilized for recreation and coastal fisheries.

1971 Shark Control and Research Program

The 1970 Hawaii state legislature mandated the Hawaii State Department of Land and Natural Resources to oversee a fourth shark control and research program in Hawaii (Fujimoto and Sakuda 1971). The program was initiated to reduce "fear and apprehension against sharks felt by locals and tourists" that restricted the optimum potential of recreational usage of the state's coastal waters. The major goal of this program was to remove sharks from coastal waters "using the knowledge of shark behavior gained from the two previous programs." Additional objectives were to gather biological data on species composition, catch rates, sex ratios, length measurements, and diet of sharks. The potential hazards for commercial utilization of shark meat were investigated by measuring mercury and pesticide levels in shark tissue as well as the suitability of shark as food for cultured prawns.

Shark fishing using standard longlines began on 3 March 1971 and continued until 27 August 1971 (Table 1). Tiger sharks were caught in the greatest numbers followed by sandbar, blacktip, Galápagos, and gray reef sharks (Table 2).

It was concluded that the coastal shark population could be considerably reduced by control program fishing, based on decreases in catch rates observed in consecutive fishing rounds in the 1971 program and in the previous two programs. Fujimoto and Sakuda (1971) noted that the Billy Weaver program (1959–1960) and the 1967–1969 program (7 yr later) both had initial catch rates of about 11 sharks per 100 hooks, whereas the 1971 program had an initial catch rate of only 4.4 sharks per 100 hooks (2 yr after the previous program). Based on these comparisons Fujimoto and Sakuda concluded that between 2 and 7 yr were required for the coastal shark population to recover to maximum density. No specific recommendations for future shark control were offered except that "the best method of controlling the near shore shark population appears to be the institution of a systematic and continuous shark control program conducted by the state" (Fujimoto and Sakuda 1971).

1976 Control Programs

Two brief shark control programs that were carried out during the summer of 1976 were the Shark Abatement/Student Training Program, and the Shark Utilization/Student Training Program, funded by the State of Hawaii Department of Planning and Economic Development and the State Marine Affairs Coordinator's Office (Naftel 1976, Naftel et al. 1976). The intent of the programs was to control a suspected increase in the population of coastal sharks in selected areas, to provide training opportunities for community college marine technology students, and to supply biological data for graduate students at the University of Hawaii. Other objectives included the investigation of marketing shark meat for human consumption and the evaluation of the potential for establishing a shark fishery in Hawaii. The first program operated from 10 to 20 June 1976 and the second from 21 August through 18 September 1976. Fishing effort and number of sharks caught were both limited compared with the previous four control programs (Table 1). The majority of sharks caught were sandbar, tiger, and Galápagos sharks (Table 2).

Naftel et al. (1976) concluded that the first 1976 program had demonstrated the existence of "a serious shark danger in Hawaiian waters" and that "some form of control should begin soon." They further concluded that unless shark populations were reduced, sharks would "compete with local fishermen for commercial food fish" and that "it would only be a matter of time before the food fish would be decreased to a point where sharks would then begin to sample other available forms of food, such as man."

Recommendations of the second 1976 program included continued funding by the state for a shark fishing/student training program and the establishment of a well-managed shark fishery, which would provide an economical fish product and serve to maintain shark populations at "acceptable levels" (Naftel 1976).

INFORMATION GAINED FROM SHARK CONTROL PROGRAMS IN HAWAII

Species Composition

Fifteen species of sharks were caught during the control programs: sandbar; tiger;

gray reef; Galápagos; blacktip; mako, *Isurus oxyrinchus* Rafinesque; great white; bignose, *Carcharhinus altimus* (Springer); silky, *Carcharhinus falciformis* (Bibron); blue, *Prionace glauca* (L.); scalloped hammerhead, *Sphyrna lewini* (Griffith & Smith); smooth hammerhead, *S. zygaena* (L.); bluntnose sixgill, *Hexanchus griseus* (Bonnaterre); false catshark, *Pseudotriakis microdon* Capello; and prickly, *Echinorhinus cookei* Pietschmann (common and scientific names follow Compagno [1984]). The Galápagos, bignose, smooth hammerhead, bluntnose sixgill, and false catshark were new records for Hawaiian waters. The following sharks were typically caught in water deeper than 180 m off Oahu, with maximum depth recorded in parentheses: bignose (361 m), bluntnose sixgill (366 m), prickly (379 m), and false catsharks (375 m) (A. L. Tester, unpublished data).

Relative Abundance

A total of 36,122 hooks was set, with a catch of 2849 sharks, or eight sharks per 100 hooks. In addition, 1819 pups were removed from pregnant sharks, for a grand total of 4668 sharks killed (Table 2). The combined catch for all control programs (excluding unidentified sharks, unborn pups, and all sharks from the Billy Weaver program, because of lack of positive identification: a total of 2088 sharks) consisted of 46% sandbar, 22% tiger, 13% gray reef, and 11% Galápagos sharks. Catch rate of sharks (sharks per 100 hooks) was highest in waters off Lanai (22.2) and Kahoolawe (21.5), followed by Niihau (14.8), Molokai (12.0), Maui (8.1), Kauai (6.9), Hawaii (6.2), and Oahu (5.7) (Table 1).

However, comparison between islands is difficult because fishing techniques varied between islands and fishing outside of Oahu was limited. Fishing was conducted along the entire coastline of only two islands (Oahu and Niihau), and only two longline sets were made at Lanai and Kahoolawe during any of the control programs. Fishing at islands other than Oahu occurred mostly during the spring and summer, which may partially explain elevated catch rates at those locations. On Oahu, where fishing was conducted year-round, catch rates were higher during the summer (7.1 sharks per 100 hooks) than in winter months (3.8) (Wass 1971). Also, a majority of fishing at islands other than Oahu consisted of bait preference tests and sets perpendicular to the depth contour rather than standard sets (Tester 1969). Wass (1971) found that average catch rate of sandbar sharks per 100 hooks was 12.6 for all perpendicular sets compared with 5.7 for all sets made parallel to the depth contour when an area was fished for the first time.

Distribution

Comparison of catch rates from various locations during the 1967–1969 program revealed information on spatial distribution of shark species in Hawaiian waters. Catch rates of sandbar sharks were highest around Molokai and Lanai and lowest around Kauai (Wass 1971) and revealed evidence of segregation on the basis of sex and age class. Depth of capture for adult male sandbar sharks ranged from 27 to 278 m, with an average depth of 112 m. Capture depth of adult females ranged from 9 to 187 m, with an average depth of 68 m. Nearly three times more female (182) than male (63) sandbar sharks were caught off Oahu, although there were seasonal fluctuations in the ratio of females to males (Table 3). Wass (1971) reported a peak in catch of male sandbar sharks with sperm-laden claspers during the summer (May–September) and noted that mature males were caught more frequently at shallower depths during late spring and summer months, based on catch data from lines set perpendicular to the depth contour and from light longlines set at various depths. He theorized that males moved inshore to join females for mating in the late spring and returned to deeper water during the late summer. He offered as further evidence of offshore movement of males the observation that not a single mature male sandbar shark was caught off Oahu during the two fall quarters of fishing in the 1967–1969 program.

TABLE 3

FISHING EFFORT, CATCH PER UNIT EFFORT, AND SEX RATIO FOR SANDBAR SHARKS (*Carcharhinus plumbeus*) CAUGHT ON OAHU DURING THE TESTER 1967–1969 CONTROL PROGRAM

SEASON	NO. HOOKS	NO. FEMALES	NO. MALES	CPUE FEMALE	CPUE MALE	RATIO F : M
Summer	2,224	69	17	3.1	0.76	4.0 : 1
Fall	2,088	43	10	1.9	0.45	4.3 : 1
Spring	2,808	26	11	1.1	0.48	2.4 : 1
Winter	2,141	44	25	1.9	1.10	1.8 : 1

CPUE, number of sharks per 100 hooks. F : M represents the female to male ratio (data from Tester [1969]).

Catch rate of adult sandbar sharks was higher in fishing areas on the leeward coast of Oahu (4.6 sharks per 100 hooks) than in other fishing areas off Oahu (2.6) (Wass 1971). Catch rate of pregnant female sandbar sharks in Oahu waters was higher on the windward coast (Wass 1971). Juvenile sandbar sharks were abundant on the north and east coasts of Oahu in comparison with the south and west coasts, whereas subadults were found to be more uniformly distributed (Figure 1*a*). Mature male sandbar sharks also showed a fairly uniform distribution around Oahu, although samples sizes were low. Catch rate of mature females was highest on the west coast of Oahu and lowest along the east coast.

Catch rate of tiger sharks was highest on the south coast of Oahu and lowest on the west coast, with higher catch rates generally occurring during fall and winter months (Figure 2). Immature and adult tiger sharks appear to have similar distributions, most abundant on the south coast of Oahu and least abundant on the west coast (Figure 1*b*). Tiger sharks ranged from 11 to 371 m in depth, and Galápagos sharks were caught between 18 and 286 m (Tester, unpublished data).

Gray reef sharks showed a restricted distribution: they were common off Niihau and Molokini Crater, but were rarely taken elsewhere (Tester 1969). Juveniles were caught in shallower water than adults (Table 4). Gray reef sharks were usually caught in areas where water visibility was higher (32 m) than visibility where sandbar sharks were common (22 m) (Wass 1971). Eleven gray reef sharks that were tagged and recaptured moved short distances (3–6 km) along the coastline over periods of 65–138 days (Tester 1969).

Biology

Total and precaudal lengths were measured for sharks caught in the control programs and were used to estimate size range for each species. Reproductive tracts of sharks were examined to quantify life history characteristics such as size at birth, size at maturity, mating and pupping seasons, and fecundity. Information gained on life history aspects of sandbar and gray reef sharks caught during the 1967–1969 control program is shown in Table 4. Diet of Hawaiian sharks was quantified by examination of stomach contents. Stomach contents of the most common species of sharks captured during the 1967–1969 program are summarized in Table 5.

EVALUATION OF SHARK CONTROL PROGRAMS

Each shark control program that has operated in Hawaii has been described as having been successful in controlling sharks. In these instances "success" refers to steady declines in catch rates of sharks and a reduction in the number of large sharks in the population. The following is an evaluation of the success of shark control efforts in Hawaii in terms of their success in increasing the body of knowledge useful for improving future control measures, decreasing shark populations, decreasing the number of large sharks, and, ultimately, success in reducing the risk of shark

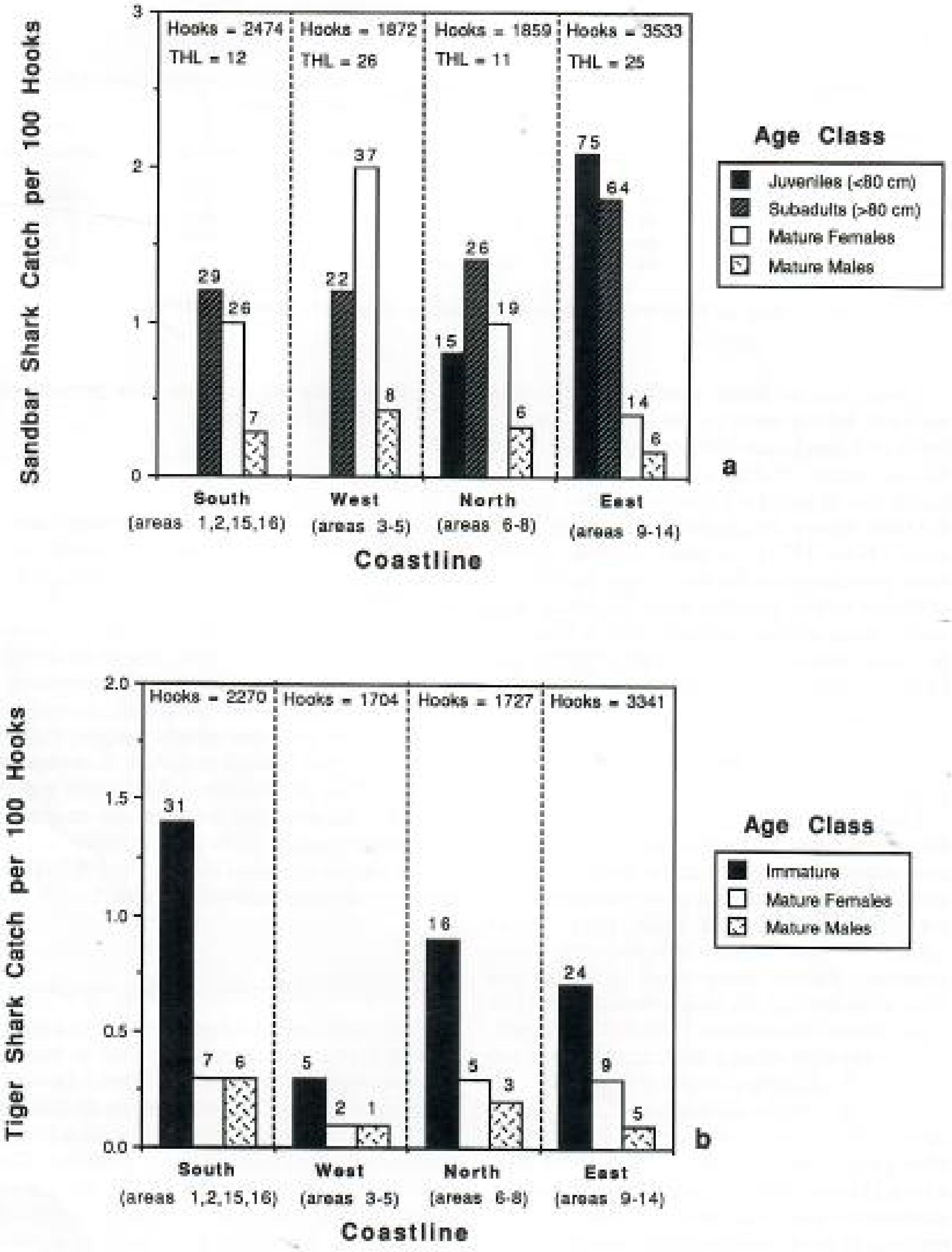

FIGURE 1. Catch rate per 100 hooks in coastal areas of Oahu with standard longlines during the 1967–1969 control program: *a*, for sandbar sharks (*Carcharhinus plumbeus*) of different age classes (based on precaudal length) (THL, timed handline fishing in each area—not included in fishing effort, data from Wass [1971]); *b*, for tiger sharks (*Galeocerdo cuvier*) (sharks > 305 cm total length considered mature) (data from Tester [1969] and Tester, unpublished data). Numbers above each bar represent number of sharks caught.

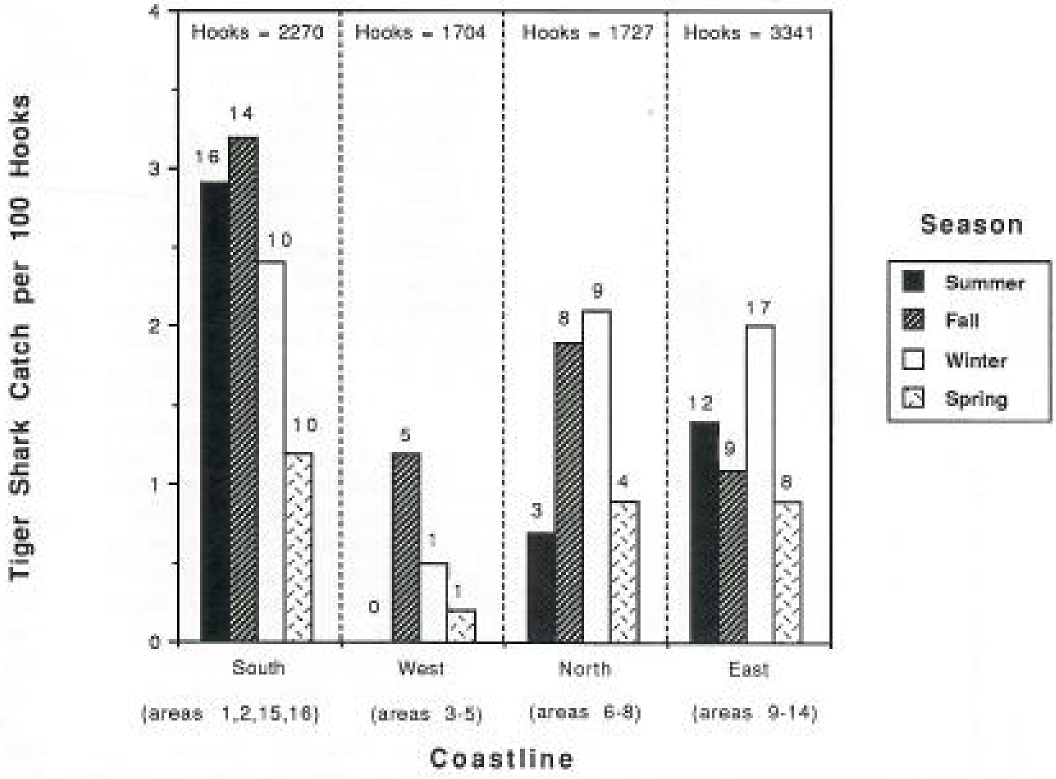

FIGURE 2. Catch rate per 100 hooks for tiger sharks (*Galeocerdo cuvier*) using standard longlines in different coastal areas of Oahu for each season during the 1967–1969 control program (data from Tester [1969]). Numbers above each bar represent number of sharks caught.

attack in Hawaiian waters. Our evaluation concentrates on sandbar and tiger sharks caught around Oahu during the 1967–1969 program, because these were by far the most abundant sharks caught and that was the first program where sharks were identified to species and the only program where fishing was conducted in all areas around Oahu for two consecutive years.

An objective of each of the control programs was to compile data that would add to the body of knowledge on sharks, and yet little of the information gathered during the control programs is available to the general scientific community. Wass (1973) reported a portion of his findings in the only peer-reviewed journal publication from any of the shark control programs. The validity of the control program reports has remained largely unquestioned although the reports did not receive the benefit of formal scientific peer review. Had the data been fully analyzed and the reports reviewed, it is unlikely that the influence of factors such as seasonality, annual fluctuations in abundance, weather, and variable fishing techniques on catch rate would have been ignored. Consequently, conclusions made about the effectiveness of the programs in reducing shark populations might well have been stated with less confidence.

Success in Reducing Shark Populations

Shark control programs in Hawaii have operated on the premise that by fishing for sharks, the population could be reduced to a level where the risk of shark attack was decreased. Each of the major control pro-

TABLE 4

Life History and Distribution Data of Hawaiian Sandbar Sharks (*Carcharhinus plumbeus*) and Gray Reef Sharks (*C. amblyrhynchos*) from Wass (1971)

SHARKS	SIZE AT MATURITY: PRECAUDAL LENGTH (cm)	AGE (yr)	SIZE AT BIRTH: PRECAUDAL LENGTH (cm)	MATING SEASON MONTHS (GESTATION)	PUPPING SEASON MONTHS	AVG. NO. OF PUPS	AVG. DEPTH CAUGHT (m)
Sandbar Shark							
Male	110	10.2		July–September (12 months)	July–September		112
Female	115	13.1				5.5	68
Juvenile	—	—	45–51				79
Gray reef shark							
Male	100	7.4		February–April (unknown)	September–October		71
Female	105	7.2				5.0	56
Juvenile	—	—	45–50				38

Note: Juvenile sharks (<80 cm total length) were caught on light longlines or timed handlines.

grams referred to continual decreases in catch rates for consecutive fishing circuits as evidence that shark populations had been reduced and that control efforts had been successful (Ikehara 1961, Tester 1969, Fujimoto and Sakuda 1971). It was estimated that shark populations were reduced by as much as 50–90% after the moderate fishing effort of the control programs (Norris and Harvey 1969, Tester 1969). The removal of nearly 4700 sharks from Hawaiian waters over an 18-yr period undoubtedly resulted in a substantial decrease in the population, and declines in shark abundance are evident in reduced catch rates in long-running programs (Figure 3). However, factors such as seasonality, weather, and fishing effort also appear to have contributed to declines in catch rates observed during control programs. The following is an attempt to examine the influence that some of these factors might have had on catch rate and to obtain a more accurate estimate of the degree to which local populations of sharks were reduced by the control programs.

Results of the Billy Weaver program first appeared to indicate that a sudden decline in the shark population could be effected by continuous fishing circuits around Oahu (Ikehara 1961). Fishing in this program began in April and ended the following March. Inshore movement of sharks for mating and parturition during late spring and early summer has been documented for many species of sharks (Pratt and Casey 1990, Reid and Krogh 1992, Simpfendorfer 1992). Seasonal inshore and offshore movements have also been reported for sandbar sharks (Springer 1960, Medved and Marshall 1983, Stillwell and Kohler 1993). Although standard fishing in the control programs was conducted at an average of 45 m, male sandbar sharks range into much deeper water and were caught at depths of up to 278 m (Tester 1969, Wass 1971). Movement of large numbers of male sandbar sharks into water deeper than 45 m during fall and winter as noted by Wass (1971) would have contributed to decreased catch rates observed in later fishing rounds (fall and winter quarters) during the Billy Weaver program. Seasonal movements of sharks into

TABLE 5

SUMMARY OF STOMACH CONTENTS FOR HAWAIIAN SHARKS AS PERCENTAGE OCCURENCE FOR TIGER (*Galeocerdo cuvier*), SANDBAR (*Carcharhinus plumbeus*), GALÁPAGOS (*C. galapagensis*), AND GRAY REEF (*C. amblyrhynchos*) SHARKS FROM WASS (1971)

		TIGER		SANDBAR		GALÁPAGOS		GRAY REEF	
		n	%	*n*	%	*n*	%	*n*	%
STOMACH	NO. OF EMPTY STOMACHS	29	14	298	55	90	58	65	71
CONTENTS	FOOD PRESENT	181	86	243	45	65	42	27	29
Cephalopods		20	11	66	27	18	28	5	19
Crustaceans		47	26	44	18	6	9	1	4
Elasmobranchs		26	14	8	3	5	8	—	—
Teleosts		90	50	170	70	46	71	25	93
Sea turtles		20	11	—	—	—	—	—	—
Birds		42	23	—	—	—	—	—	—
Cetaceans		13	7	—	—	1	2	—	—
Indigestible items		32	18	2	1	2	3	—	—
Total no. examined		210		541		155		92	

deeper water during fall and winter would have biased catch rates reported for the 1971 control program in a similar manner. Cliff et al. (1988) found a predominance of female sandbar sharks caught in protective nets in South Africa and postulated that males inhabit deeper water, farther from netted areas. Cliff et al. (1988) also reported that the highest catches of both sexes in protective netting occurred during summer months and lowest catches were in autumn and winter. They theorized that male sandbar sharks move onshore and offshore seasonally.

Of the three major control programs, only the 1967–1969 program spanned more than 12 months and provided information permitting examination of the effects of season on catch rate. Seasonal fluctuations are evident in catch rate of the two species of sharks (sandbar and tiger) caught in the highest numbers during this program (Figure 3). Catch rate of sandbar sharks peaked during summer and was lowest in winter, coinciding with seasonal changes in the depth distribution of adult sandbar sharks (Wass 1971). In fact, the second highest catch rate of sandbar sharks was observed during the very last round of fishing. Considering that 46% of sharks caught in the 1967–1969 program were sandbar sharks, seasonal movements of sandbar sharks out of fishing areas may have contributed greatly to decreased catch rates in control programs over time. Seasonal fluctuations in catch rate and differential catch rates for male and female tiger sharks were observed by Paterson (1990) and Simpfendorfer (1992) in Australia and may also occur in Hawaii.

Season and weather may have influenced the actual fishing power of the gear and therefore the effective fishing effort and ensuing catch rate. Strong currents and rough seas during the fall and winter months resulted in fouled and tangled sections of longline more frequently than during the spring and summer, and these sections were not subtracted from the total effort in quantifying catch per unit effort. Of 20 references to fouled or tangled lines in the final report of the 1967–1969 program, only six occurred during the spring or summer (Tester 1969). The effectiveness of fishing in winter months also may have been reduced as a result of rapid dispersion of bait odor along strong, turbulent currents and more frequent stripping of bait from hooks. Reduced effective fishing in winter months resulting from rough weather would also have contributed to lower catch rates recorded during later fishing rounds in fall and winter.

Targeting larger sharks during later cir-

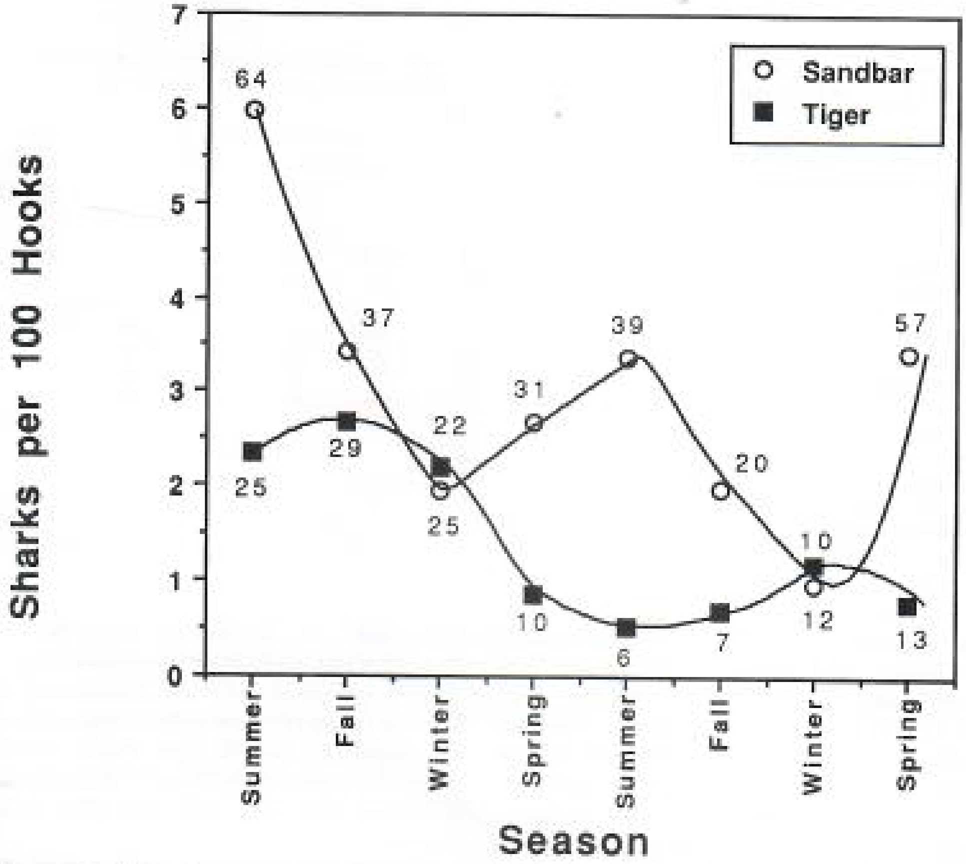

FIGURE 3. Catch rate for sandbar sharks (*Carcharhinus plumbeus*) and tiger sharks (*Galeocerdo cuvier*) captured off Oahu during each season in the 1967–1969 shark control program (data from Tester [1969]). Numbers adjacent to data points represent number of sharks caught.

cuits within a program by modification of fishing techniques could have resulted in the capture of fewer sharks because smaller individuals were excluded. This would have resulted in an underestimation of the number of sharks in fishing areas during later rounds and further complicates comparison of catch rates between fishing rounds.

In each of the major control programs, catch rate was used as an indicator of shark abundance, and catch rates of programs were compared to evaluate changes in the shark population (Ikehara 1961, Tester 1969, Fujimoto and Sakuda 1971). The assumption that catch rate was indicative of the shark population, without considering factors such as fishing technique, may lead to erroneous conclusions about changes in shark abundance. For example, if one assumes that catch rate of tiger sharks was directly proportional to the tiger shark population, one may conclude that continued shark fishing during control programs actually led to an increase in the tiger shark population. The catch rate of tiger sharks increased from 0.9 per 100 hooks during the Billy Weaver program to 1.4 in the

1967–1969 program and to 2.0 for the 1971 program. Tiger sharks made up only 12.5% of the catch in the Billy Weaver program, but increased to 16% in the 1967–1969 program and to 46% in the 1971 program. These changes in catch rate of tiger sharks were more likely the result of selectively catching larger sharks rather than an actual increase in tiger shark abundance.

Although each major control program reported drastic declines in shark abundance at the completion of fishing, the only attempt to estimate shark populations in Hawaii was made by Lawrie (1978), based on catch rate data from the 1967–1969 program. Using the Leslie and DeLury models, Lawrie estimated the tiger shark population in waters around Oahu to be between 80 and 130 individuals at the start of that program. Because 127 tiger sharks were caught around Oahu during that program, Lawrie's analysis appears to grossly underestimate the abundance of tiger sharks. Much of the catch data from the program was not included in Lawrie's analysis because it was inconsistent with the models. Bias was also created in each program by use of gear and bait that favored large sharks and by fishing within a limited portion of the full depth range inhabited by the sharks, thereby sampling a limited portion of the population. Removal of over 100 sharks from the south coast of Oahu during experimental fishing episodes further complicates attempts to determine declines in shark abundance using catch rates. These limitations make it virtually impossible to accurately estimate entire shark populations in Hawaii from the control program data.

Because of the short duration of each of the control programs, annual and long-term changes in the population could not be monitored. Annual variation in shark abundance in a given area may go undetected in the absence of long-term fishing. Cliff et al. (1988) recorded considerable annual variation in catch rate of sandbar sharks captured in South African shark nets. Although catches fluctuated, catch rates were highest during 3 of the last 4 yr of sampling and showed an increasing trend.

Success in Eliminating Large Sharks

Tester (1969) described a decrease in the average size of sharks caught in successive fishing rounds during the 1967–1969 program and suggested that the water was safer for humans because the larger, presumably more dangerous, sharks had been removed. However, decreased average size for sharks overall during the final fishing rounds referred to by Tester is largely due to a decrease in the average size of sandbar sharks during those rounds (Figure 4). The decrease in average size of sandbar sharks during the final circuits in 1969 was primarily due to an increased number of small sharks captured, which Tester attributed to reduced predation resulting from the elimination of large tiger sharks. However, other explanations may include immigration and/or the change of bait from large pieces of tuna in the first seven circuits to smaller akule, *Selar crumenophthalmus* (Bloch) during the final circuit. This change in bait may have affected the size distribution of all shark species in the catch. The highest catch rate of sharks other than sandbar and tiger sharks was recorded during the final fishing circuit. Bait tests conducted during the 1967–1969 program showed that composition of shark catch was influenced by the type of bait used. In bait tests using porpoise, 44% of sharks caught were Galápagos sharks, leading Tester (1969) to conclude that use of tuna for bait during most of the standard fishing was not providing an adequate estimate of Galápagos abundance.

Although changes in the number of large sandbar sharks may have occurred, the change in the size distribution of tiger sharks is of primary interest because these sharks present a much greater danger to humans than sandbar sharks (Compagno 1984). Tiger sharks showed substantial variation in average size over the eight circuits during the 1967–1969 program, with the largest average size recorded during the third to last round (Figure 4). The poor fit of the data to a linear regression model ($r^2 = 0.113$) and low sample sizes in later fishing rounds (Figure 4) do not support Tester's conclusion that the number

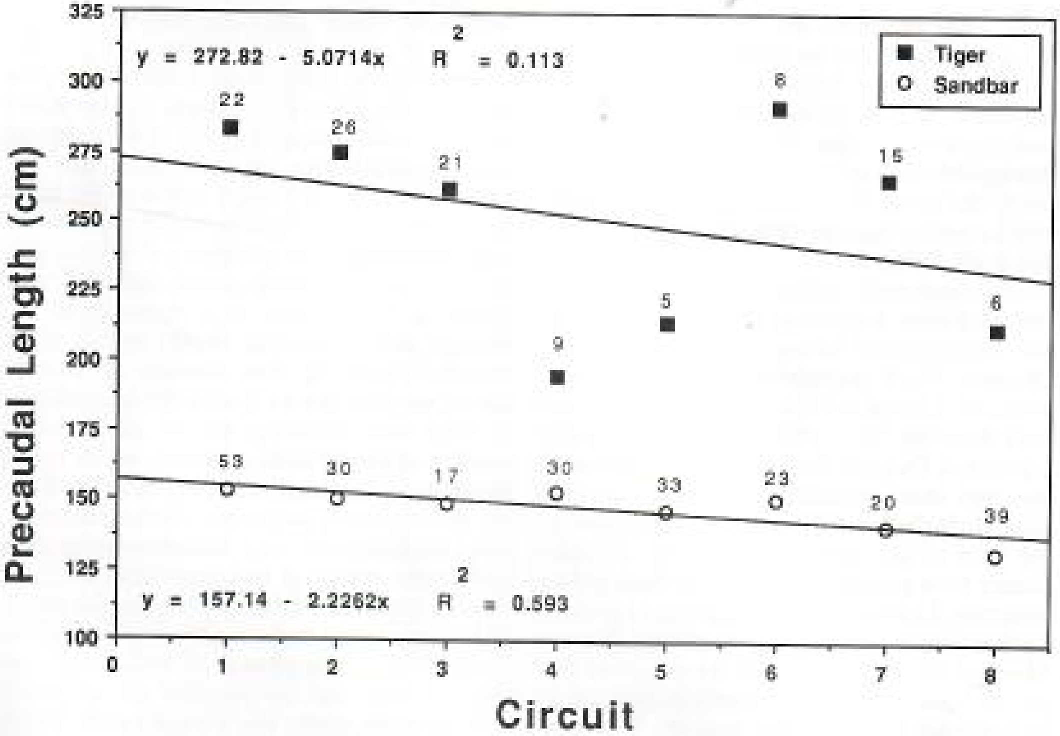

FIGURE 4. Average size of sandbar sharks (*Carcharhinus plumbeus*) and tiger sharks (*Galeocerdo cuvier*) caught in consecutive fishing circuits around Oahu during the 1967–1969 shark control program (data from Tester [1969]). Numbers above data points represent sample sizes.

of large tiger sharks was actually decreased as a result of fishing pressure.

Evidence from shark control programs in Australia indicates that tiger shark populations may be less affected by antishark measures than populations of other species of sharks. Simpfendorfer (1992) concluded that there was no significant reduction in the abundance or mean size of tiger sharks caught during an extensive meshing program in Australia between 1964 and 1986. He suggested that the lack of decline in the local tiger shark population examined was a result of light fishing pressure in relation to population size and movement of tiger sharks over a wide geographical range. Paterson (1990) and Reid and Krogh (1992) found that the number of tiger sharks caught in antishark nets in Australia actually increased between 1962 and 1990.

Based on the results of research conducted during the control programs in Hawaii, it is difficult to quantify the effect the programs actually had on shark abundance and size composition of the populations. However, the real test of success of these control programs is their effectiveness in reducing shark attacks.

Success in Reducing Attacks

Shark attacks dating back to the 1700s have been documented in Hawaii (Balazs and Kam 1981; G. Balazs, 1992, unpublished data), but abatement programs were not initiated until after the fatal attack on Billy Weaver in 1958. According to the International Shark Attack File (ISAF) (kept at Florida Museum of Natural History, University of Florida, Gainesville, by G. Burgess), an incident is considered a shark attack if confirmed as either a provoked or unprovoked attack on a live human in the shark's natural environment; therefore, attacks on dead humans are not considered (G. Burgess, pers. comm.).

Based on records of shark attacks in Hawaii that meet the criteria of the ISAF (drawn from a larger pool of incidents reported by G. Balazs [1992, unpublished data]), there was no difference between the average number of shark attacks per year for the 18 yr before control efforts (0.6) and during the 18 yr that control programs intermittently operated (0.6). A shark attack occurred 3 months before the completion of the 1967–1969 control program, and another attack occurred 5 months after the program had ended (G. Balazs, 1992, unpublished data). In the years following control programs, the rate of attack has increased to an average of 1.4 per year. Although there have been two confirmed fatal shark attacks in Hawaii since 1991, there were no fatal attacks during the 31-yr period between 1959 and 1990. Although the mean number of attacks after control programs seems large compared with numbers from the other periods, the data consist of highly variable, small, discrete numbers. One factor that has undoubtedly increased the number of documented attacks after control programs ended is a greater effort and interest in documenting shark attacks by Balazs since the implementation of an "official list" of Hawaiian shark incidents in 1979.

Rate of shark attacks appears to be better correlated with human population than with shark population. For example, in Florida the rate of shark attacks and the human population have increased in a similar fashion over the past century (Figure 5A). Recently, shark populations in Florida have been severely reduced as a result of overfishing (Manire and Gruber 1990), yet the rate of shark attacks has continued to increase. The resident population of Hawaii has increased from 520,000 in 1946 to 1.1 million in 1990 (Figure 5B). Over the same period of time the number of people visiting Hawaii annually has increased exponentially from 15,000 to 7 million (Hawaii Visitors Bureau, pers. comm.). Because many of the tourists that come to Hawaii engage in water-related activities, using population figures of the resident population grossly underestimates the number of people entering the water. The increasing popularity of water-related activities such as scuba diving and surfing has undoubtedly resulted in an enormous increase in the proportion of people that enter the water. Given this great increase in the number of humans entering the ocean, a concomitant increase in the number of shark attacks per year might be expected. Although there have been more shark attacks during the past few years, the rate of shark attacks in Hawaiian waters has remained fairly constant at less than one attack per year over the past 48 yr. Therefore, based on the available data, shark control programs and the associated reduction in coastal shark populations do not appear to have had a dramatic effect on the rate of shark attacks in Hawaii.

Shark Control Outside Hawaii

Shark control programs have been in operation in Australia since the 1930s and in South Africa since the early 1950s (Wallett 1983, Cliff and Dudley 1992, Reid and Krogh 1992). Longlining has not been used extensively as a method of shark control in other parts of the world. Longlining was abandoned after use for a few years in South Africa (Cliff and Dudley 1992) and has raised concerns about baited lines attracting sharks to regions that they would otherwise not frequent (Paterson 1990). A series of gill nets used to "mesh" beaches has been successful in reducing the number of shark attacks in Australia and South Africa (Cliff and Dudley 1992, Reid and Krogh 1992). However, these successful antishark measures are not without drawbacks. Dolphins, dugongs, turtles, birds, rays, tuna and other teleosts, nondangerous sharks, and even humpback whales are killed in the gill nets (Paterson 1979, Cliff and Dudley 1992, Reid and Krogh 1992). Reid and Krogh (1992) estimated that one dolphin was killed for every 30–40 sharks caught and that one ray was killed for every two or three sharks caught in gill nets off New South Wales.

Removing large numbers of apex predators from a marine area may have large-scale effects on the ecological balance of that region. Large-scale changes observed in the

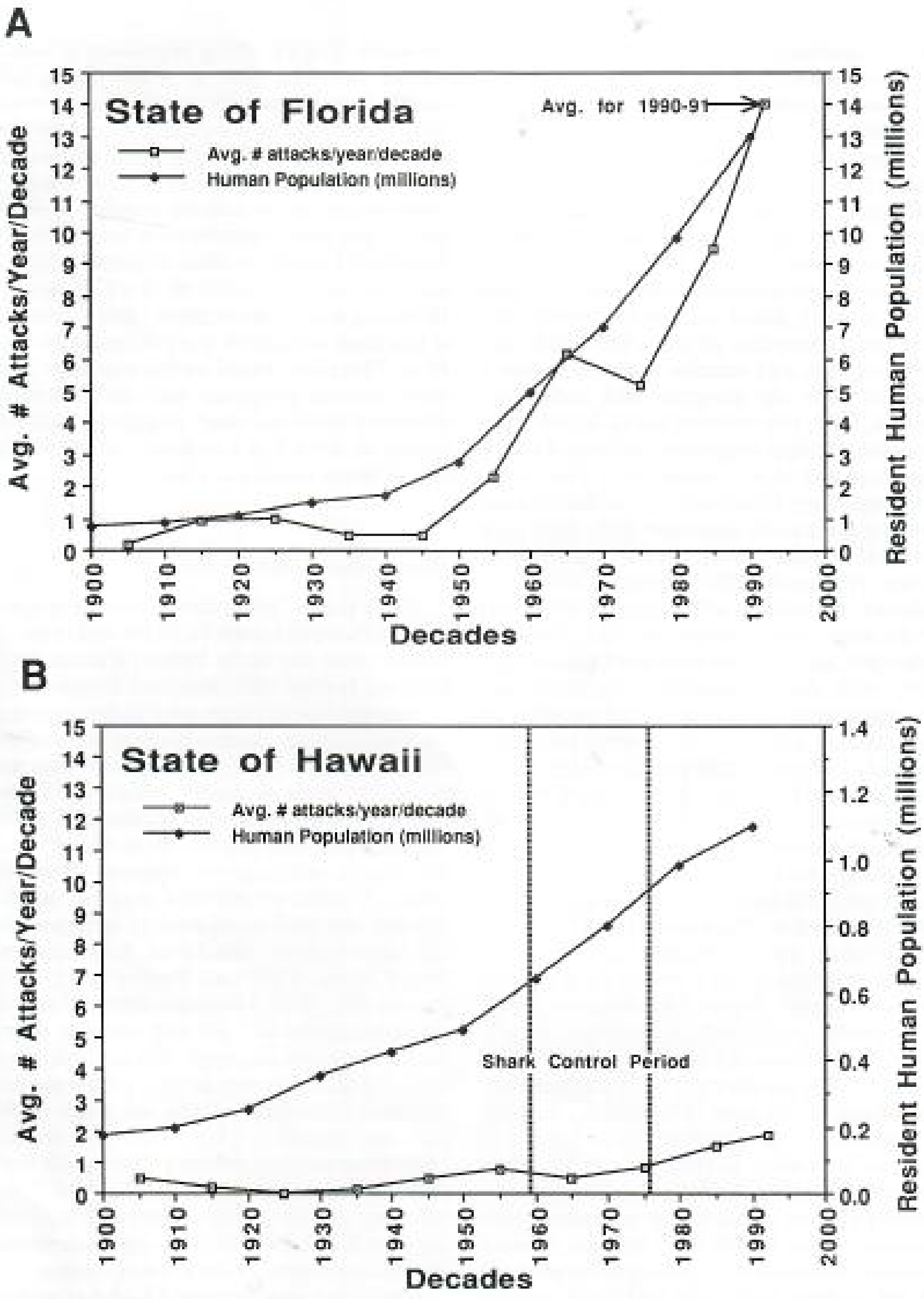

FIGURE 5. Average number of shark attacks per year per decade and resident human population between 1900 and 1992: A, in Florida; B, in Hawaii (Florida attack data from G. Burgess, pers. comm.; Hawaii attack data from G. Balazs, 1992, unpublished data per criteria of the International Shark Attack File).

composition of species of sharks captured in nets in Queensland and New South Wales have been attributed to antishark measures (Reid and Krogh 1992). In South Africa, competition between fishermen and sharks for important fish stocks may have increased because of a proliferation of small sharks as a result of the removal of larger predatory sharks by meshing (van der Elst 1979). Paterson (1990) noted that once introduced, control measures are likely to be permanent, and any deleterious ecological effects that they cause will generally be regarded as unfortunate consequences secondary to consideration of human safety. He recommends a coordinated biological program to monitor the effects of antishark measures both on target and nontarget species.

Shark meshing programs are expensive to initiate and maintain. Installation of gill nets necessary for protective meshing of a beach in South Africa costs roughly $100,000 (U.S.) in its first year, and annual government funding to the Natal Sharks Board for maintaining all antishark measures in South Africa is now over $2 million (U.S.) (Cliff and Dudley 1992). Despite substantial investment in widespread meshing of beaches, shark attacks still occur. With 44 km of nets in place at over 40 beaches in South Africa (and nearly 1500 sharks caught annually), the rate of shark attack was reduced to an average of one per year during the 1980s, but one-third of all attacks occurred at or near protected beaches (Cliff 1991, Cliff and Dudley 1992).

CONCLUSIONS

Control programs have contributed information on sharks, including data on diet, reproduction, species composition, and seasonal distribution. Diet of Hawaiian sharks has also been examined extensively during subsequent studies (Taylor and Naftel 1978, Okamoto and Kawamoto 1980, DeCrosta et al. 1984). Although information on diet and feeding habits can contribute to a greater understanding of the role that sharks play in marine ecosystems (Wetherbee et al. 1990), continued emphasis on examination of stomach contents of large numbers of dead sharks is unlikely to reveal further information useful for control measures.

Because only a small portion of the results of research conducted during control programs was published in reviewed journals, information gained is not available to the scientific community at large. Thus, the programs have made only limited contributions to the understanding of shark biology. Publication in reviewed journals would have resulted in a greater dissemination of information to a much wider audience, a more rigorous analysis of the data, and possibly more restricted endorsement of continued large-scale control efforts.

Because the primary purpose of the control programs was to remove as many sharks as possible, research conducted during the programs was limited largely to information that could be acquired from dead sharks. Although considerable information was obtained for sandbar and gray reef sharks, virtually no information was reported for the tiger shark in regard to depth distribution, population biology, seasonal movements, and sexual segregation. This type of information has particular importance because tiger sharks are responsible for most of the shark attacks in Hawaii (Randall 1992). Future studies involving shark-human interactions in Hawaii should be concentrated on the tiger shark and aspects of their biology that relate to control measures. Whether tiger sharks are far-ranging or site-attached has yet to be determined. Diurnal and seasonal movements of tiger sharks on- and offshore are also poorly understood. The possibility that tiger shark populations are less susceptible to control by antishark measures because of characteristics such as their high fecundity and widespread populations compared with other species remains to be investigated.

Past control programs have not adequately addressed a number of important questions concerning shark behavior that are relevant to shark-human interactions. An understanding of home range, diel activity patterns, social interactions, feeding periodicity, and depth distribution may provide a basis for effectively reducing the probability of shark attack. The above-mentioned aspects of shark behavior can be investigated using modern techniques such as acoustic telemetry and remote sensing (Myrberg 1987). Telemetered sharks can be tracked to determine activity patterns, space utilization, and short-term movements (Tricas et al. 1981, Nelson 1990, Holland et al. 1993). Until short-term behavior of sharks is better understood, the merits of control measures such as selective fishing in an area immediately after an attack remain uncertain. Given that the shark responsible for an attack may have already left an area when baited lines are set to catch the shark, the only value of such a response may be the psychological reassurance to those entering the area that the chances of a second attack are small (Cliff and Dudley 1992).

More extensive tag-and-release studies may be used to examine patterns of migration, distribution, and factors that influence the distribution observed (Casey and Kohler 1992). Tagging studies may also provide information on growth, population size, and segregation based on size or sex (Casey and Taniuchi 1990). Parameters useful for understanding population dynamics (fecundity, recruitment, mortality, age at maturity, DNA fingerprinting) are particularly relevant for managing a population and assessing the effects of human interactions on that population.

Because sharks play an important role as apex predators in marine ecosystems in Hawaii (DeCrosta 1984), removal of large numbers of sharks from an area could drastically affect the natural ecological balance, on a scale similar to what has occurred in Australia and South Africa (van der Elst 1979, Reid and Krough 1992). Dramatic declines in shark populations have occurred over short periods of time elsewhere in the world and are evidence of the susceptibility of sharks to overfishing (Manire and Gruber 1990). Carefully planned and focused trophic research would increase understanding of the importance of sharks in the marine environment and enable assessment of the ecological effects of large-scale shark control in Hawaii. All of these results would contribute to a better understanding of the ecology of sharks and their effects on the ecosystem.

Meshing beaches with gill nets has been effective in reducing the rate of shark attacks in Australia and South Africa and is an option for shark control in Hawaii. However, the high cost of meshing programs, unknown ecological impacts brought on by removing large numbers of sharks, and incidental catch of marine mammals, sea turtles, and other nontarget animals are undesirable aspects of such control measures. The rate of shark attacks in Hawaii is low in comparison with areas where meshing has been initiated, and attacks are rare at Hawaiian beaches most often frequented by tourists. Rough surf conditions at beaches frequented by oceangoers in Hawaii could also present a potential obstacle for maintenance of gill nets.

Public desire for protection against shark attacks is often an emotional issue and may also be a result of economic considerations in areas heavily dependent on tourism. Cliff (1991) attempted to put the threat of shark attack in perspective compared with other ocean-related fatalities by noting that there were only seven shark attacks (none fatal) in South Africa in 1989, while 139 people drowned. A similar situation exists in Hawaii, where there has been an average of less than one shark attack per year compared with an average of 40 drownings per year (State of Hawaii Health Department, pers. comm.).

Success of the past control programs in decreasing shark populations and removing large sharks from Hawaiian coastal waters seems uncertain and appears to have been overestimated in previous reports. The tentative conclusion that these sharks are territorial (based on limited tag-and-recapture data) contributed to the belief that sharks can effectively be eliminated from specific areas. However, long-term site fidelity has not been documented for any species of shark (McKibben and Nelson 1986, Myrberg 1987). Because there is little evidence that increasingly expensive shark control programs have been effective in reducing the already relatively low rate of shark attacks in Hawaii, such large-scale longlining programs may no longer be cost-effective.

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We appreciate the help of J. D. Parrish, K. N. Holland, G. D. Lowe, B. Carlson, and K. Yates in reviewing the manuscript. Special thanks to L. Taylor for information on control programs, to J. Sakazaki for Hawaii visitor data, to G. Burgess for shark attack data, and to R. Goto for information on water safety.

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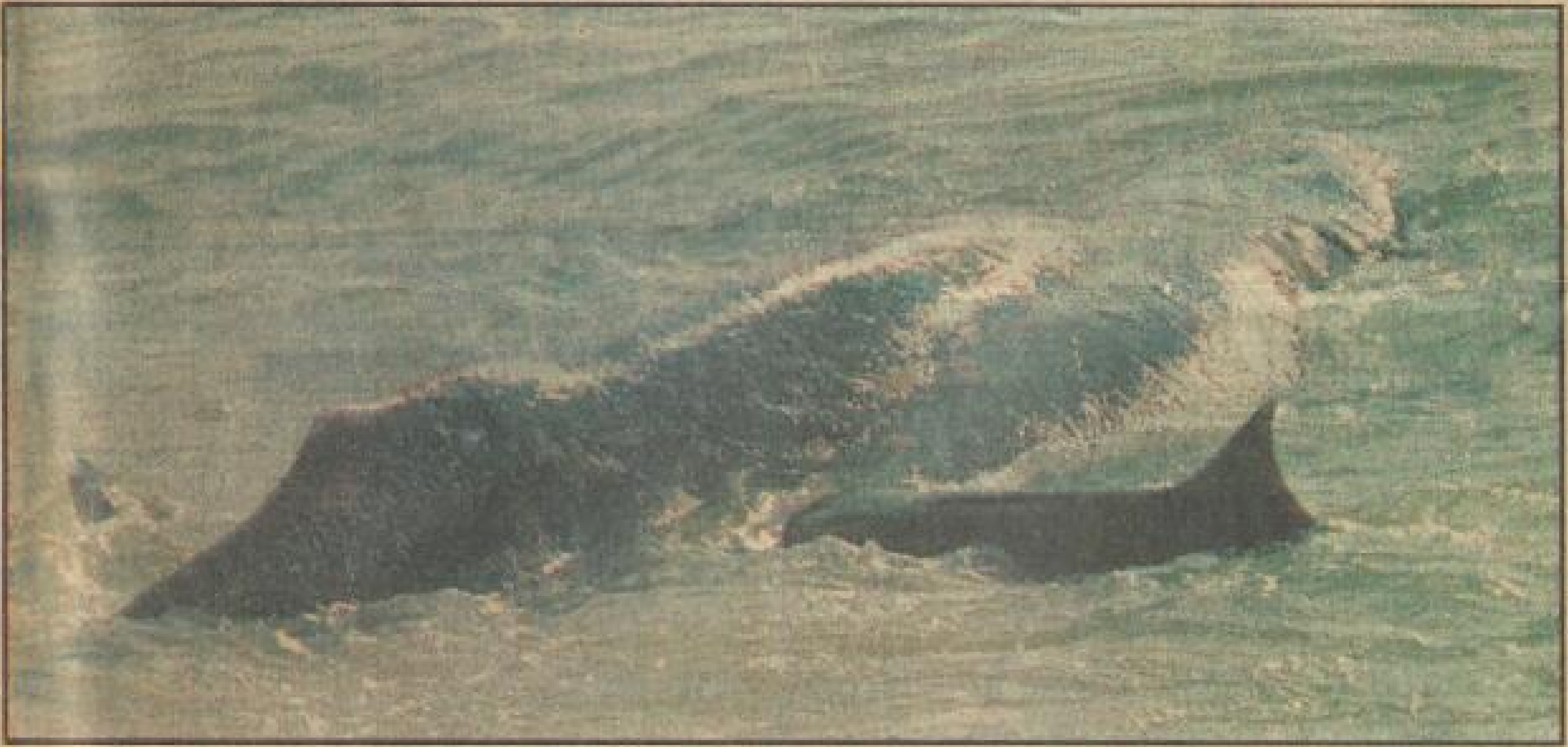
3/2/95 A1
The Honolulu Advertiser

"We swim a lot, snorkel out there. I guess we won't be doing that for a while."

— Crystal McCandless, witness to shark attack

Sharks kill crippled whale near Maui shore



Advertiser photo by Edwin Tanji

A 10-foot tiger shark attacks a humpback whale near shore at Kihei, Maui, yesterday.

Young humpback attacked after being tangled in lines

Tiger sharks in shallows

By Edwin Tanji
Advertiser Maui County Bureau

KIHEI, Maui — A young humpback whale, tangled in mooring lines and apparently weakened by illness, was killed by sharks as it struggled in murky storm waters off Kihei yesterday.

The wounded whale was washed toward shore off homes along Halama Street yesterday afternoon.

"He was still spouting. He was still alive," said Monique Jutila, whose back yard was packed with spectators.

But tiger sharks, reportedly up to 12 feet long, continued to tear chunks of flesh out of the whale. It died about 4 p.m., Greg Kaufman said.

Kaufman, executive director of the Pacific Whale Foundation, said the humpback was 30 to 35 feet long and appeared to be 3 to 5 years old.

Earlier yesterday, it ran into mooring lines set up for boats off the Sugar Beach area of North Kihei. A Coast Guard official said a crew freed the whale from the lines, but was unable to cut all of them off.

"When we tried to get up to him, he would dive down," the Coast Guardsman said.

Several pieces of thick yellow nylon line still were tangled around the whale's tail when it washed up. Even in shallow water, several sharks, including two 10-footers, continued to tear at the carcass.

Kaufman said the whale apparently had been ill for a while. He said it was emaciated and coated with parasites.

"We swim a lot, snorkel out there," said Crystal McCandless, another Halama Street resident.

"I guess we won't be doing that for a while."

Humpback dies off Maui

Advertiser graphic

Dear George — 1993

Many thanks for sending me the Jim Borg book. It's great to see your data in print.

I haven't had an opportunity to read the whole book, but at first glance it appears to be objective.

Thanks again — George

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8 April 1992

Dr. George Balazs
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Dear George:

Please pardon the delay in my response to your earlier letter with included shark list and literature citations. Major reconstructive knee surgery and associated rehab sessions have severely limited time at my desk.

The revised list plus literature is extremely valuable, and I greatly appreciate your sharing it with the ISAF. As you correctly pointed out, such endeavors are indeed extremely time consuming and truly represent a labor of love, since God knows we don't get any fiscal support for our activities! As I indicated earlier, our interest in the data centers on bringing the ISAF up to date worldwide, leading eventually to a revised worldwide synthesis, rather than on regional analyses. As for the latter, we eagerly anticipate your publication of the Hawaiian data base.

The Hawaii attack problem certainly is a complex one. I have seen your statistics quoted by both sides of the 'fish/don't fish" issue, and must confess that I don't see much in the way a disturbing trend. As a resident of a state with a markedly similar socio-economic base (tourism is king, aquatic activities the focus, etc.) I find Hawaii's level of "attack paranoia" a bit high, especially when one considers that Florida, with 10-15 documented attacks per year (and about one death about every other year), has never felt the need to address the situation in an organized fashion. When I say *documented*, I mean confirmed cases where a shark attack resulted in injury/death to a victim, or where a shark clearly represented a threat to a human through aggressive actions. Shark damage to drowning victims, "dumped" bodies (*Miami Vice*-style activities do occur in south FL!), unrecovered missing persons thought to have encountered a shark, etc. are investigated, but not "tallied", in the above statistics. In reviewing your cases I see a number situations that might fall in these categories. In addition, I have very good data that indicates that the number of reported shark attacks is directly related to the amount of effort being expended to find them! No surprises here -- if I look harder I find more, if I make more of an effort to pass the word along the beaches that I'm seeking reports, I get them. I suspect that the recent rise in Hawaiian attacks may in part reflect your own diligence in data retrieval, but also may reflect an increase in man-hours in the water. In Florida, the increase in tourism over the last three decades [which translates into increased man-hours in the water] has been significant; more people mean more interactions with sharks, even if the shark populations are stable (or decreasing, as in FL). See if you can get some tourism figures and divide your total attacks by this number to get a per capita figure; I wouldn't be surprised to see that the rate between decades is similar.

Reduction of shark populations through fishing pressure certainly will reduce the chances of shark-human interactions, but to get shark populations to the point that these interactions will be *significantly* different would require *major* (=over) fishing pressure. In an era when we are making some progress in regulating fisheries, and have been fighting strongly for protection of shark populations world-wide, I think it would be unwise to embark on such a wholesale reduction program. The Florida story again helps demonstrate this: despite intense commercial and sport fishing pressure (so intense that the proposed emergency NMFS regulation will probably not return stocks to their former levels for decades) our total number of shark attacks is basically staying the same. Thus it seems likely that an eradication program will serve only to damage one of the few remaining "virgin" shark populations while offering little in the way of human protection.

I would recommend initiation of a public awareness program aimed at the those groups most at risk. Such a program should identify high risk groups and geographic areas, suggest ways to minimize these risks, and work to educated the public about the relative infrequency of shark attack injuries/death when compared to other aquatic risks. My perception of the Hawaiian shark attack problem (based in part on *Surfer* magazine, which has little "near-miss" stories in it nearly every month) is that one user group, surfers, is at highest risk and is most vocal about the subject. Perhaps some enlightened discussion with this group might be profitable. Considering the mind-set of most surfers, the problem might be turned around on itself: in Florida, most surfers bearing attack scars wear them like badges of honor!

I appreciate having the opportunity to discuss this with you, and look forward to return comments.

Best wishes,

George

George H. Burgess
Director
International Shark Attack File

PS. Enclosed is an AES application (if you haven't gotten one back yet from Linda Martin)

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904/392-1721

6 May 93

Dear George -

Many thanks for the poster and other items. I really appreciate you keeping me up with what's happening in Hawaii.

I'm happy to see that your Hawaii data will be published in Leighton Taylor's shark book. Let me know when/if there is a prepublication price.

Sorry to hear you were through Gainesville and couldn't stop in, but hope we can get together in July. I'd love to show you our operation & get your input & insights on the Hawaiian shark attack situation. July looks pretty good for me - no planned field work.

- Thanks again for remembering me.

Best - George

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3 September 1993

Dr. George Balazs
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Dear George:

Thanks for continuing to send Hawaiian clippings and your observations on attacks in Hawaii.

My guess about the C/L/W letter is that they feel some of the same concerns I do about how your data is *perceived* by the press, as discussed in my last letter to you. They sure do seem to be on your case and could certainly learn some tact!

I recently received a copy of the 14 July 1993 Kauai Times (not from C/L/W!) that included your December 1992 revision table as a major portion of the story. That table does not differentiate confirmed attacks from unconfirmed ones. You note "See annotated list", but that list of course didn't appear. As scientists, we look carefully at data, reading the footnotes, but the average newspaper reader (or reporter) viewing your table probably never even sees this note, nor cares. The bottom line is that people think all your numbers are confirmed shark attacks. You can't be blamed for others' ineptitude, but it seems to me that you might present your data in a manner that the average Joe will not misinterpret it. When I present ISAF data to the media or general public, I use only figures from *confirmed unprovoked attacks on live human beings in the shark's natural environment* [the words used in the C/L/W letter probably came from my mouth to Lowe during some conversation]. I do not confuse the situation by presenting pooled statistics that includes provoked attacks, boat attacks, air/sea disasters, and doubtful (unconfirmed) attacks. All possible attacks, including tabloid stories, *are* investigated, assigned case numbers, and curated in the File, and are made available for future reconsideration by researchers, but it is my opinion that lumping them with confirmed unprovoked attack statistics leads to a distorted conception of the attack problem.

See Gilbert ←

The hard part, of course, is determining what is "confirmed". It's not easy. I don't need a witness. Circumstantial evidence may be enough to accept one case but not another. If it's close I tend to call it an attack. Maybe we could look over your Hawaiian attacks together and come to a mutual understanding of what we would call confirmed unprovoked attacks or "doubtful" attacks. Your note that you have but one "doubtful" case suggests to me that we may differ on our interpretations of confirmed and doubtful. In the absence of witnesses or other strong evidence, pro or con, I need to see some evidence why an incident was not a drowning before I assign it to an attack since there are a lot more drownings than shark attacks worldwide.

Hope this helps some. Don't get too down on Lowe and Wetherby -- they're young, zealous and well-meaning. They just need to acquire some social skills. Maybe a good way to deal with them is to get together over a beer and hash things out.

Looking forward to hearing from you.

Best wishes,

George

George H(owell) Burgess
Director
International Shark Attack File

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February 23, 1998

Dr. George Balazs
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96825

Dear George:

It is my distinct pleasure to re-appoint you to the 1998-1999 Shark Attack File Committee of the American Elasmobranch Society. I apologize for the delay but there was a transitional period during which all the records were being transferred. Dr. George Burgess has graciously agreed to remain as the chair of this committee. Dedicated efforts such as yours allow us all to continue research and conservation efforts on elasmobranchs. On behalf of the chair and other members of the committee, the American Elasmobranch Society and its officers, thank you for your time and efforts.

Sincerely

Philip J. Motta
Associate Professor of Biology
President, American Elasmobranch Society

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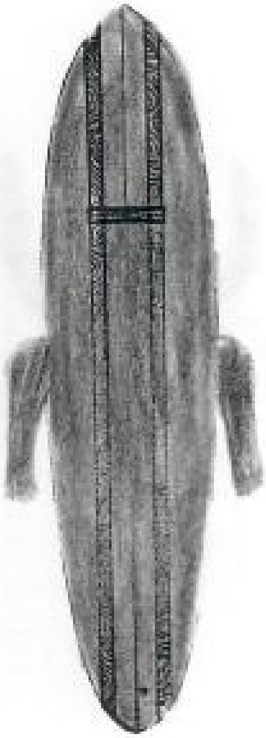

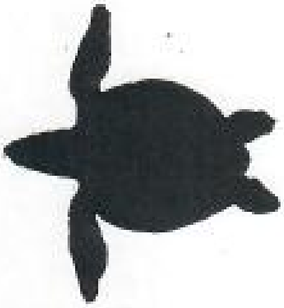

SILHOUETTES