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Shark Records from Longline Fishing Programs in Hawai'i with Comments on Pacific Ocean Distributions[1]

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ABSTRACT: This paper summarizes records from longline fishing programs conducted in Hawai'i between 1959 and 1980. Data from 11 species of sharks (173 individual sharks) are reported and compared with worldwide records. Although much of the data is nearly 30 yr old, the information was never fully utilized and represents the following important findings. The relationship between clasper length and total length (TL) for bluntnose sixgill shark, *Hexanchus griseus* (Bonnaterre), indicates that males mature at about 309 cm TL. High fecundity (114 pups) is reported for the prickly shark, *Echinorhinus cookei* Pietschmann. The smallest mature male *E. cookei* (183 cm TL) and the smallest pregnant (205 cm TL) bignose shark, *Carcharhinus altimus* (Springer), are recorded. New maximum depth of capture records for the blacktip shark, *Carcharhinus limbatus* (Valenciennes), at 64 m, and for the smooth hammerhead shark, *Sphyrna zygaena* (L.), at 68 m, are also documented. Distributions of deep-sea sharks in Hawai'i appear to be associated with isothermic submergence, and the sharks remain below the thermocline (100–400 m) and in water temperatures of 9–12°C. Carcharhiniform sharks in Hawai'i range to greater depths than reported elsewhere; this appears to be correlated with the Tropics having warmer water temperatures (20–26°C), which extend down to 100–400 m in depth.

HISTORICALLY, SHARK ATTACKS in Hawai'i have resulted in the establishment of shark control programs (Wetherbee et al. 1994). Recent attacks in Hawai'i have placed renewed emphasis on understanding the biology of sharks. Shark control longline fishing programs have targeted potentially dangerous shark species, but have also resulted in the capture of a number of poorly understood species. Six shark control programs in Hawai'i were conducted between 1959 and 1976 (for additional details see Wetherbee et al. [1994]). In addition to the control programs, sharks were caught by longline during the Resource Investigations in the Northwestern Hawaiian Islands (RINWHI) conducted from 1978 to 1980 (De Crosta et al. 1984). These longline fishing programs captured 15 species of sharks. Despite this extensive fishing effort, accounts have been published for only four of the 15 species of sharks, including the sandbar, *Carcharhinus plumbeus* (Nardo) (Wass 1973); gray reef, *C. amblyrhynchos* (Bleeker) (Wass 1971, De Crosta et al. 1984, Radtke and Cailliet 1984); Galápagos, *C. galapagensis* (Snodgrass & Heller) (De Crosta et al. 1984, Wetherbee et al. 1996); and the tiger, *Galeocerdo cuvier* (Peron & LeSueur) (De Crosta et al. 1984, Lowe et al. 1996).

The purpose of this paper is to summarize records of 11 species of sharks captured by longline fishing in Hawai'i, with an emphasis

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on biological data of poorly investigated species. In addition, this paper updates the geographic distribution of these species in the Pacific Ocean.

MATERIALS AND METHODS

For a review of fishing methods, locations, and catch per unit effort around the main Hawaiian Islands, see Wetherbee et al. (1994) and in the Northwestern Hawaiian Islands see De Crosta et al. (1984). Surface water temperatures around O'ahu during the 1967–1969 program ranged from a winter low of 23°C to a summer high of 28°C (Wass 1971). All shark program data were combined and reported in individual species accounts except for four species, where sample size was limited. The individual species accounts were divided into the following sections: (1) museum collections; (2) distribution of specimens from Hawai'i, with a comparison with Pacific Ocean and worldwide geographic and depth records; (3) reproduction; and (4) diet. The common and scientific names follow Compagno (1984). During the 1959–1960 and 1967–1969 shark control programs, selected voucher specimens were sent to the U.S. National Museum of Natural History (USNM), Washington, D.C., and the Bernice P. Bishop Museum (BPBM), Honolulu, Hawai'i. The collection catalog numbers are provided for the uncommon species.

Sharks captured during fishing programs were brought on board the boat and measured for total length (TL) and precaudal length (PCL) in cm. For male sharks, clasper length and width were recorded. In addition, claspers were examined to determine the degree of calcification. For female sharks, maximum ova diameter and the width of the uterus were measured; the presence or absence of pups, sex of embryos, and TL of pups were also recorded. Recognizable prey items from stomach contents were identified to the lowest possible taxon.

RESULTS AND DISCUSSION

Eleven shark species (173 sharks) in this report were captured during longline fishing programs (Table 1). Because the University of Hawai'i program in 1967–1969 composed the major data set, these data were used to evaluate depth distributions and provide catch per unit effort (standardized per 100 hooks) at different depth intervals (converted from 20-fathom intervals) (Table 2).

TABLE 1

NUMBERS OF SHARKS IDENTIFIED TO SPECIES (EXCLUDING PUPS) REPORTED IN THIS PAPER CAUGHT DURING SHARK FISHING PROGRAMS IN HAWAI'I BETWEEN 1959 AND 1980 (DATA FROM DE CROSTA ET AL. 1984 AND WETHERBEE ET AL. 1994)

	SPECIES[b]										
PROGRAM[a]	H. g.	E. c.	C. c.	I. o.	P. m.	C. al.	C. f.	C. l.	P. g.	S. l.	S. z.
BW (1959–1960)	11	3	2	1	—	—	—	—	1	12	4
OI (1966–1968)	—	—	2	—	—	—	—	—	—	—	—
UH (1967–1969)	9	10	—	2	2	9	1	44	—	23	10
SH (1971)	—	—	—	1	—	—	—	19	—	—	—
N (1976)	—	—	—	1	—	—	—	1	—	—	—
RINWHI (1978–1980)	—	—	—	—	—	—	—	4	—	1	—
Total	20	13	4	5	2	9	1	68	1	36	14

[a] BW, Billy Weaver program; OI, Oceanic Institute program; UH, University of Hawai'i program; SH, State of Hawai'i program; N, Naftel et al. unpubl.; RINWHI, De Crosta et al. (1984).

[b] H. g., *Hexanchus griseus*; E. c., *Echinorhinus cookei*; C. c., *Carcharodon carcharias*; I. o., *Isurus oxyrinchus*; P. m., *Pseudotriakis microdon*; C. al., *Carcharhinus altimus*; C. f., *Carcharhinus falciformis*; C. l., *Carcharhinus limbatus*; P. g., *Prionace glauca*; S. l., *Sphyrna lewini*; S. z., *Sphyrna zygaena*.

TABLE 2

NUMBERS OF SHARKS CAPTURED AT DEPTH INTERVALS DURING THE 1967–1969 SHARK CONTROL PROGRAM OF THE UNIVERSITY OF HAWAI'I

HOOK DEPTHS (m)	HOOKS RECOVERED	SPECIES[a]									SHARKS/100 HOOKS (CPUE)
		H. g.	E. c.	I. o.	P. m.	C. al.	C. f.	C. l.	S. l.	S. z.	
0–37	4,114	—	—	—	—	1	1	24	15	3	1.1
38–73	5,295	—	—	1	—	2	—	20	7	6	0.7
74–110	481	1	—	—	—	—	—	—	—	—	0.2
111–146	137	—	—	—	—	1	—	—	1	—	1.5
147–183	103	—	1	—	—	1	—	—	—	—	1.9
184–220	171	—	—	—	—	2	—	—	—	—	1.2
221–256	15	—	—	—	—	—	—	—	—	—	0.0
257–293	63	—	—	—	—	—	—	—	—	—	0.0
294–329	32	—	3	—	—	—	—	—	—	—	9.4
330–366	105	8	3	—	1	2	—	—	—	—	13.3
367–402	66	—	2	—	1	—	—	—	—	—	4.5

NOTE: Depth intervals were standardized to catch per unit effort (CPUE) for 100 hooks.
[a] Abbreviations of shark scientific names as in Table 1.

Four species of sharks were caught in very low numbers. Four great white sharks, *Carcharodon carcharias* (L.), were caught in the control programs; three were captured between December and March, at depths of 33 to 47.5 m. Two were captured on the west coast of the island of Hawai'i (no size reported), one on the north shore of the island of O'ahu (348 cm TL), and one on the east coast of O'ahu (279 cm TL). Taylor (1985) provided additional records of great white sharks in Hawai'i. Five shortfin mako sharks, *Isurus oxyrinchus* Rafinesque, were captured in control programs off the north and south shores of O'ahu and the west coast of the island of Maui at depths that ranged from 34.7 to 54.9 m. Males measured 152 to 237 cm TL ($n = 3$) and females were 338 and 355.6 cm TL. A 229-cm TL female silky shark, *Carcharhinus falciformis* (Bibron), was captured off the east coast of O'ahu in 37 m. A blue shark, *Prionace glauca* (L.), 228.6 cm TL, was hooked off the south coast of O'ahu at an estimated depth of 47.5 to 51.2 m.

Species Accounts

Bluntnose sixgill shark, *Hexanchus griseus* (Bonnaterre)

MUSEUM COLLECTIONS. BPBM 9649, captured 9 March 1968, 276 cm TL; USNM 179770, captured 11 November 1959, 243.8 cm TL, 159 kg; USNM 220178, captured 9 March 1968, 308 cm TL, male in pieces; USNM 206071, captured 9 March 1968, no further information; USNM 232588, captured 9 March 1968, skull only.

DISTRIBUTION. Twenty bluntnose sixgill sharks were caught during the control programs on deep longline sets off the southern and western coasts of O'ahu. Specimens were captured on bottom longline sets between 110 and 366 m, and all but one were caught deeper than 330 m (Table 2). An additional male specimen was captured off the south coast of O'ahu at a depth of 347 m on 21 March 1995. This species has also been observed by submersible on the east coasts of the islands of Hawai'i and O'ahu at depths between 500 and 1400 m (Chave and Mundy 1994). In the Hawaiian Island chain, bluntnose sixgill sharks range from the island of Hawai'i, throughout the Northwestern Hawaiian Islands, to Kimmei Seamount (34°54′–35°36′ N, 170°43′–172°00′ E) of the southern Emperor Seamounts (Humphreys et al. 1984, Borets 1986, Chave and Mundy 1994).

Worldwide, this species has been reported from the surface to at least 1875 m (Compagno 1984). Yano and Kugai (1993) reported the capture of seven bluntnose sixgill

TABLE 3

RELATIONSHIP OF CLASPER LENGTH TO BODY LENGTH OF THE BLUNTNOSE SIXGILL SHARK, *Hexanchus griseus*, FROM O'AHU, HAWAI'I

DATE OF CAPTURE	TL (cm)	PCL (cm)	CLASPER LENGTH (cm)	CALCIFIED
21 March 1995	273	196	14.0	No
9 March 1968	276	199	17.0	No
9 March 1968	308	224	18.5	No
9 March 1968	309	225	26.2	Yes
9 March 1968	326	238	21.4	Yes
24 March 1968	326	239	23.0	Yes
28 May 1968	331	241	24.0	Yes

sharks on bottom longlines in Okinawa at a narrow depth range of 400 to 550 m while fishing at depths that ranged from 210 to 1250 m. In Bermuda, two bluntnose sixgill sharks tracked using acoustic transmitters showed an orientation to the Bermuda escarpment, typically remaining within a 600- to 1100-m depth range in 9.5°C water (Carey and Clark 1995). Hubbs (1952) suggested isothermic submergence to explain the presence of the bluntnose sixgill shark in the Tropics.

In the Pacific, this species has been reported from Hawai'i, Okinawa, Japan, Taiwan, Malaysia, Sumatra, Australia, New Zealand, Palau, Guam, Enewetak, Aleutian Islands to Baja California, Mexico, and Chile (Kami 1971, Compagno 1984, Randall 1986, Yano and Kugai 1993). In addition, this species has been reported to be almost cosmopolitan, inhabiting tropical to temperate waters of all oceans and the Mediterranean Sea (Compagno 1984, Borets 1986).

REPRODUCTION. In this study, eight males measured 273 to 331 cm TL, and two females were 311 cm and 378 cm TL. For 11 additional specimens, no size was reported. Males 273–308 cm TL had uncalcified claspers, whereas males 309–331 cm TL had calcified claspers and appeared to be mature. Information on size at maturity for male bluntnose sixgill sharks from Hawai'i represents the largest data set reported for this species and is summarized in Table 3. Clark and Kristof (1990) reported the capture of a mature 287-cm TL male from Bermuda. A 325-cm TL male caught in the Gulf of Mexico had calcified claspers (Branstetter and McEachran 1986).

A 378-cm TL female, with small ova, 1 mm maximum diameter, was captured in March, in Hawai'i. No pregnant females were captured in this study. Female sharks have been reported to mature at about 421–482 cm TL (Compagno 1984, Ebert 1986). This species has been reported to exhibit aplacental viviparity, with litters that ranged from 22 to 108 and a 65- to 70-cm TL size at birth (Compagno 1984). Ebert (1986) reported that a 421-cm TL shark was pregnant with 51 pups that measured 68–73.6 cm TL.

DIET. Of nine stomachs examined from Hawaiian sharks, two contained unidentified teleost remains and another had a cephalopod beak. In South Africa, ontogenetic dietary shifts have been reported for the bluntnose sixgill shark (Ebert 1994). The diet of juvenile bluntnose sixgill sharks <120 cm TL consisted of 54% cephalopods, 5% sharks, and 40% teleosts, whereas the diet of sharks >200 cm TL included 11% cephalopods, 11% chimaerids, 29% teleosts, 18% pinnipeds, and 18% cetaceans (numbers expressed as percentage frequency of occurrence) (Ebert 1994).

Prickly shark, *Echinorhinus cookei* Pietschmann

MUSEUM COLLECTIONS. USNM 179768, captured 6 November 1959, pregnant female 304.8 cm TL, mold made of specimen 267 kg; USNM 179805, 90 pups from the above specimen in two jars; USNM 179769, captured 9 November 1959, 238.8 cm TL, 136 kg.

DISTRIBUTION. Thirteen prickly sharks were captured during Hawaiian control programs on deep longline sets off the southern coast of O'ahu. Depth of capture ranged from 177 to 370 m, and all but one were caught deeper than 294 m (Table 2). The prickly shark was originally described from Hawai'i off the south coast of the island of Kaua'i (Pietschmann 1930). Submersible observations have been made from the southern coast of the island of Hawai'i and Cross Seamount (18°44′N, 158°15′W) over sandy bottoms at depths of 360–420 m (Chave and Mundy 1994). The prickly shark occurs throughout the Hawaiian Island chain to Kimmei Seamount (Borets 1986, Chave and Mundy 1994).

Depths of capture records worldwide range from 11 to 650 m (Compagno 1984, Kobayashi 1986). Prickly sharks have been captured at depths between 550 and 650 m off Japan (Kobayashi 1986). This shark was observed on the Nazca Submarine Ridge (off the coast of Chile), swimming 0.3 to 1.3 m over the top of seamounts at 300 to 340 m (Golovan and Pakhorukov 1987). Prickly sharks have also been observed by scuba divers in the Monterey Submarine Canyon, Monterey, California, at depths of 15–35 m, either singly or in groups of up to 30 sharks (Crane and Heine 1992). This species was captured in 5.5–6.0°C water on bottom gill net sets off Japan (Kobayashi 1986), and Chavez-Ramos and Castro-Aguirre (1975) suggested a preferred temperature range of 9–11°C, which may dictate geographic depth distribution. Hubbs (1952) suggested isothermic submergence to explain the presence of the prickly shark in the Tropics.

Prickly sharks have been reported only from the Pacific Ocean at the following locations: Hawai'i, Japan, Taiwan, Palau, central California to the Gulf of California, Isla Guadalupe, Mexico, Peru, Chile, and New Zealand (Kato et al. 1967, Chavez-Ramos and Castro-Aguirre 1975, Flores and Rojas 1979, Taniuchi and Yanagisawa 1983, Compagno 1984). Prickly sharks were misidentified as the bramble shark, *Echinorhinus brucus* (Bonnaterre), in capture records from Japan, California, Taiwan, and Peru (Taniuchi and Yanagisawa 1983).

REPRODUCTION. Seven males ranging between 183 and 233 cm TL and two females 184 cm and 304.8 cm TL were captured in Hawai'i. No size was reported for four additional specimens. All male sharks caught in Hawai'i had calcified claspers and appeared to be mature. Apparently this species matures at a smaller size than the 220 cm TL reported by Compagno (1984). A 184-cm TL female captured in August had a maximum ova diameter of 6 mm, and a 304.8-cm TL female captured in November was pregnant with 114 pups, which were reported to average 61 cm TL (Ikehara 1961). However, recent measurements of pups showed an average of 21.6 cm TL (range 16.5–24.1 cm, $n = 20$) in the USNM collection (Jerry Finan, pers. comm.). Females are reported to be adult at 299 cm TL (Compagno 1984). Size at birth has been reported to be about 45 cm TL (Compagno 1984).

DIET. Of nine stomachs examined from Hawaiian prickly sharks, four had unidentified teleost remains and one contained shark remains. This species has been reported to feed on a wide variety of organisms including octopus, squid, spiny dogfish shark, bluntnose sixgill shark, chimaeras, hake, flounder, rockfish, lingcod, topsmelt, and herring (Compagno 1984).

False cat shark, *Pseudotriakis microdon* Capello

MUSEUM COLLECTIONS. BPBM 9653, captured 24 March 1968, 274 cm TL; BPBM 9654, captured 4 September 1968, 264 cm TL, head only.

DISTRIBUTION. Two false cat sharks were caught in the Hawai'i control programs during deep longline sets: one each off the southern and western coasts of O'ahu. Specimens were captured at depths of 366 and 371 m (Table 2). A false cat shark was observed during a submersible dive off southern O'ahu at 500 m (Chave and Mundy 1994).

Yano and Kugai (1993) reported the capture of 22 false cat sharks from Okinawa on

deep bottom longlines at depths that ranged from 470 to 899 m while fishing between 210 and 1250 m. False cat sharks were also captured on bottom gill nets in Japan at depths of 300–500 m (Kobayashi 1986). Worldwide, this species has been reported to be associated with the bottom and has never been caught shallower than 200 m, with a maximum depth of capture at 1500 m (Compagno 1984).

This species has been reported in the Pacific from Hawai'i, Okinawa, Japan, Taiwan, and New Zealand (Compagno 1984, Yano 1992, Yano and Kugai 1993). The false cat shark has also been reported from the Indian and Atlantic oceans (Compagno 1984).

REPRODUCTION. Both sharks captured in Hawaiian waters were females, 264 and 274 cm in TL. The 264-cm TL shark was captured in August and had a maximum ova diameter of 14 mm. A 275-cm TL female captured in October off New Zealand had mature, ovulated eggs 30–50 mm in diameter (Yano 1992). Compagno (1984) estimated size at maturity for males to range from 200 to 269 cm TL, and for females from 212 to 295 cm TL. Yano (1992) reported embryonic nutrition to be matrotrophic oophagy, with one embryo per uterus and a near-term size of 116–120 cm TL.

DIET. Of the two false cat sharks captured in Hawai'i, one contained unidentified teleost remains. Yano and Musick (1992) reported cephalopods, shark remains (including Squalidae), and teleosts from sharks captured in the Pacific. Stomach contents from specimens captured off Japan consisted of octopus and *Heterocarpus* shrimp (Kobayashi 1986).

Bignose shark, *Carcharhinus altimus* (Springer)

MUSEUM COLLECTIONS. BPBM 9651, captured 14 November 1967, 147 cm TL.

DISTRIBUTION. Nine bignose sharks were captured off the southern and eastern coasts of O'ahu, and the southwestern coast of Kaua'i. Sharks were captured at depths that ranged from 27 to 360 m (Table 2). Worldwide, they are reported from warm-temperate and tropical waters, with a highly variable depth range of 25–810 m (Compagno 1984, Stevens and McLoughlin 1991).

In the Pacific, the bignose shark has been reported from Hawai'i, Taiwan, China, Gulf of California, southern Mexico, Columbia, Ecuador, Revillagigedo Islands, and Australia (Compagno 1984, Chen et al. 1985, Stevens and McLoughlin 1991). This species has also been reported from the Indian and Atlantic oceans and the Mediterranean and Red seas (Compagno 1984).

REPRODUCTION. Four males caught in Hawai'i ranged from 115 to 152 cm TL, and five females ranged from 147 to 244 cm TL, with no size reported for two additional females. All males were immature, with clasper lengths of 3.5–5.4 cm. Male bignose sharks, worldwide, have been reported to mature at between 204 and 267 cm TL (Compagno 1984, Stevens and McLoughlin 1991).

A 147-cm TL female caught in Hawai'i, with a 0.5-cm uterus width and 8 mm maximum ova diameter, appeared to be immature. Two Hawaiian bignose sharks were pregnant. A 244-cm TL shark captured in August had 11 embryos that averaged 5.8 cm TL, and a 205-cm TL female captured in November had three embryos that averaged 29 cm TL. The 205-cm TL female was the smallest pregnant bignose shark recorded, indicating that female bignose sharks mature at a smaller size than the 226–282 cm TL reported by Compagno (1984). This species is viviparous, with a yolk-sac placenta, and reported litter sizes of 3–15, and a birth size of 70–80 cm TL (Compagno 1984). A 60-cm TL free-swimming bignose shark with a fresh umbilical scar was caught off Australia (Stevens and McLoughlin 1991).

DIET. Of the seven sharks examined in Hawai'i, two stomachs contained elasmobranchs (including one whole 75-cm TL *Squalus mitsukurii* Jordan & Synder), and two had teleost remains (including Scorpaenidae). Worldwide, this species has been reported to feed on crustaceans, cephalopods, elasmobranchs, and a wide variety of teleosts (Compagno 1984, Stevens and McLoughlin 1991).

Blacktip shark, *Carcharhinus limbatus* (Valenciennes)

DISTRIBUTION. Sixty-eight blacktip sharks were caught during fishing programs (64 from the main Hawaiian Islands and four from the Northwestern Hawaiian Islands), between 13 and 64 m (Table 2). The capture at 64 m represents a new depth record for this species. Previously, this species was documented from shallow coastal waters rarely deeper than 30 m (Compagno 1984).

In the Pacific, this species has been recorded from Hawai'i, Australia, New Guinea, Java, Borneo, New Caledonia, Tahiti, Marquesas, Philippines, Thailand, China, Taiwan, southern California to Peru, and the Revillagigedo and Galápagos Islands (Compagno 1984). Worldwide, they are reported to be common in tropical and warm-temperate inshore and offshore waters of the Atlantic and Indian oceans and the Mediterranean and Red seas (Compagno 1984).

REPRODUCTION. Ninteen male blacktip sharks captured in Hawai'i measured 108–201 cm TL, and 15 females were 116–215 cm TL. No data were reported for 14 additional sharks. Male blacktip sharks 108–163 cm TL had uncalcified claspers, whereas males 182–201 cm TL had calcified claspers and appeared to be mature. Size at maturity of the blacktip shark is variable depending on geographic location. Killam and Parsons (1989) reported male maturity at 133–136 cm TL for sharks from Tampa Bay, Florida. In India, the smallest mature male was 155 cm TL (Devadoss 1988), and Dudley and Cliff (1993) reported 50% of the males were mature at 199–204 cm TL in South Africa.

In Hawai'i, female blacktip sharks began to mature at about 176 cm TL and the smallest pregnant shark was 184 cm TL. Litters ranged from two to seven pups ($n = 5$), and ovulation occurred in June and July with maximum ova diameters of 40–47 mm.

Killam and Parsons (1989) reported female maturity at 158–162 cm TL in Tampa Bay, Florida, and the smallest mature female from India was 165 cm TL (Devadoss 1988). Dudley and Cliff (1993) reported 50% of the females were mature at 206–211 cm TL from South Africa, although Compagno (1984) reported mature females as small as 120 cm TL. In South Africa, maximum ova diameter measured during the mating season was 34 mm (Dudley and Cliff 1993). This species was reported to exhibit viviparity with a yolk-sac placenta, a 12-month gestation with litters ranging from 1 to 11, and a size at birth of 38–72 cm TL (Compagno 1984, Dudley and Cliff 1993).

DIET. Of the 20 blacktip sharks examined in Hawai'i, seven had food in their stomachs. Six contained teleost remains (including Anguilliformes, Muraenidae, and Sphraenidae), one an ophiuroid, and one a cephalopod. The diet of 655 South African blacktip sharks, expressed as percentage frequency of occurrence, consisted of 83% teleosts, 16% elasmobranchs, 10% cephalopods, 4% crustaceans, and <1% cetaceans (Dudley and Cliff 1993).

Scalloped hammerhead shark, *Sphyrna lewini* (Griffith & Smith)

DISTRIBUTION. Thirty-five scalloped hammerhead sharks were caught in the main Hawaiian Islands and one from the Northwestern Hawaiian Islands. These sharks were captured at depths that ranged from 6 to 139 m (Table 2). The maximum depth of capture record for Hawai'i was from a gill net at 275 m (Clarke 1971). In Hawai'i, Clarke (1971) studied the ecology of juveniles, and Holland et al. (1993) studied activity patterns of juveniles in Kāne'ohe Bay, O'ahu. Adult scalloped hammerhead sharks in Hawai'i appear to be offshore in deeper water and enter coastal waters for mating and pupping (Clarke 1971). Worldwide, this species has been recorded as circumglobal, from coastal and pelagic, semioceanic, warm-temperate, tropical waters from the surface to 275 m (Compagno 1984).

In the Pacific this species has been reported from Hawai'i, Guam, Indonesia, China, Taiwan, Japan, Philippines, Australia, New Caledonia, Tahiti, southern California to the Gulf of California, Panama, Ecuador, and Peru (Kami 1971, Compagno 1984). The scalloped hammerhead shark has also been reported from the

Atlantic and Indian oceans and the Mediterranean and Red seas (Compagno 1984).

REPRODUCTION. Eleven male sharks captured in Hawai'i measured 54–260 cm TL, and eight females were 52–309 cm TL. Male scalloped hammerhead sharks 54–138 cm TL had uncalcified claspers, whereas males 213–260 cm TL had calcified claspers and appeared to be mature. Compagno (1984) and Devadoss (1988) reported that males mature at 140–165 cm TL. Stevens (1984) reported that males mature at 235–281 cm TL in Australia, and Chen et al. (1988) reported maturity between 198 and 210 cm TL in Taiwan.

In Hawai'i, an immature female 214 cm TL had a uterus diameter of 1.5 mm. A 309-cm TL scalloped hammerhead shark captured in May was pregnant with 31 pups that averaged 44.7 cm TL. Worldwide, size of maturity for females ranged from 180 to 230 cm TL (Compagno 1984, Chen et al. 1988, Devadoss 1988). This species has been reported to be viviparous, with a compartmentalized uterus and a yolk-sac placenta with litters that ranged from 12 to 38 (Chen et al. 1988). Worldwide, the size at birth ranged from 42 to 55 cm TL (Compagno 1984).

DIET. Of 17 stomachs examined in Hawai'i, seven contained teleosts (including Aulostomidae), two had cephalopod beaks, two had crustaceans, one had indigestible material (mud). The percentage frequency of occurrence of prey in the diet of 108 juveniles from Kāne'ohe Bay, O'ahu, consisted of 68% teleosts and 54% crustacea (Clarke 1971). In the Gulf of California, stomach contents as an index of relative importance from 108 adult sharks included 65% teleosts, 30% pelagic cephalopods, and 5% crustaceans (Galvan-Magana et al. 1989). Worldwide, this species has also been reported to feed on gastropods and elasmobranchs (Compagno 1984).

Smooth hammerhead shark, *Sphyrna zygaena* (L.)

DISTRIBUTION. Fourteen smooth hammerhead sharks were caught during the Hawai'i control programs on shallow longline sets, along the shorelines of O'ahu, both coasts of Ni'ihau, and Penguin Banks. In Hawai'i, specimens were captured at depths that ranged from 33 to 68 m (Table 2). All captures from Hawai'i represent new maximum depth records for this species, because it previously was recorded from the surface to 20 m (Compagno 1984). Juveniles have been reported from coastal waters, whereas adults are believed to occur offshore over deep water (Smale 1991), which may explain the absence of adults from the coastal longline fishing programs in Hawai'i.

This species has been reported in the Pacific from Hawai'i, Thailand, Indonesia, China, Taiwan, Vietnam, Japan, Philippines, Australia, New Caledonia, Norfolk Island, Kermadec Islands, New Zealand, Tahiti, southern California, Gulf of California to Panama, Ecuador to Chile, and the Galápagos Islands (Compagno 1984, Francis 1993). This species was also captured from coastal and pelagic, semioceanic, warm-temperate and tropical Atlantic and Indian oceans and the Mediterranean and Red seas (Compagno 1984).

REPRODUCTION. Five males collected in Hawai'i measured 162–202 cm TL, and three females were 197–213 cm TL. All males were immature, with uncalcified claspers that ranged in length from 5.5 to 7.5 cm. All females examined were also immature. Stevens (1984) suggested that males mature at about 250–260 cm TL and females at about 265 cm TL. This species has been reported to exhibit viviparity, with a yolk-sac placenta and litters that ranged from 20 to 49, and a size at birth of 50–61 cm TL (Compagno 1984, Stevens 1984).

DIET. Of the eight smooth hammerhead shark stomachs examined from Hawai'i, six had teleost remains (including Carangidae), five contained cephalopods, and one had isopods. In South Africa, stomachs of sharks <200 cm TL as percentage frequency of occurrence contained 62% cephalopods, 1% chondricthyes, and 38% teleosts (Smale 1991). The diet of 42 sharks from Australia, as percentage frequency of occurrence, consisted of 76% cephalopods and 55% teleosts (Stevens 1984). In the Gulf of California, stomach contents expressed as an index of

relative importance of 27 adult smooth hammerhead sharks included 58% teleosts and 43% pelagic cephalopods (Galvan-Magana et al. 1989).

Distributions of Hawaiian Sharks

The geographic isolation of the Hawaiian Islands provides an ideal location for the examination of patterns of shark distribution. Many factors may influence shark distribution in Hawaiian waters, including food availability, space, associated biota, slope, currents, substrate type, salinity, pressure, temperature, oxygen, and light (Carney et al. 1983). An understanding of the distribution on the Pacific Plate of most carcharhiniform sharks has been hampered by limited access to specimens and misidentifications.

Oceanic sharks (mako, silky, and blue) have wide-ranging distributions in temperate and tropical waters and could easily reach Hawaiian waters by following ocean currents. The primarily coastal blacktip, scalloped hammerhead, and smooth hammerhead sharks, which are commonly associated with land masses and are semioceanic, may have reached Hawai'i by island hopping. Deep-sea sharks (bluntnose sixgill, prickly, and false cat) have been observed by submersible, swimming directly over seamounts (Chave and Mundy 1994) and appear to be associated with canyons and outcroppings. These geographic features may serve as reference points or refuging areas. Smith and Jordan (1988) reported a current total of 30,000 Pacific Ocean seamounts that are more than 1000 m in height; these areas may serve as reference points. It is also possible that submarine ridges serve as steppingstones by means of which deep-sea sharks reach Hawai'i.

Water temperature appears to be a key factor in determining depth distribution. In Hawai'i, water temperature drops abruptly from 20–26°C to 9–12°C at the thermocline (100–400 m) (Chave and Mundy 1994). Deep-sea sharks from this study have been caught below the thermocline, with the shallowest depth of capture at 110 m. All but three were captured in water deeper than 322 m. Conversely, depth distribution of carcharhiniform sharks appears to be associated with water temperatures of 20–26°C, which extend down to the thermocline. The depth of the thermocline around Hawai'i may explain the resulting maximum depth of capture records for the Galápagos shark at 286 m (Wetherbee et al. 1996), the tiger shark at 371 m (Wetherbee et al. 1994), the scalloped hammerhead at 275 m (Clarke 1971), and from this report the blacktip, at 64 m, and the smooth hammerhead, at 68 m.

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