Length-weight relationships for 13 species of sharks from the western North Atlantic

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The rapid expansion of sport and commercial fisheries for sharks in the western North Atlantic has created the need to manage the stocks of several species of large sharks. A fishery management plan for sharks within the U.S. exclusive economic zone (EEZ) of the Atlantic Ocean (USDOC, 1992) was implemented in 1993. The 39 species of sharks included in the fishery management plan are not managed on an individual species basis, but are grouped into three species groups—large coastal, small coastal, and pelagic. Basic biological information needed for stock assessment is lacking for many of these Atlantic sharks, including minimum, maximum, and average sizes, as well as length-to-weight and length-to-length relationships. These data are essential for understanding the growth rate, age structure, and other aspects of shark population dynamics.

Size conversions also have a practical value in fisheries. One measure currently in practice at nearly all shark tournaments on the Atlantic coast is the establishment of minimum size limits and usually a minimum weight. Since sizes must be estimated at sea, means for converting lengths to weights are essential to anglers. Moreover, the National Marine Fisheries Service (NMFS) conducts an extensive Atlantic Shark Tagging Program using volunteer assistance of recreational and commercial fishermen. Commercial fishermen generally are more confident in estimating the weight of sharks being released, and recreational fishermen in estimating lengths. Conversions are needed to change these estimates into common size units for analysis.

Length data on sharks worldwide have been reported as total length (Strasburg, 1958; Stevens, 1975, 1983; Stevens and Wiley, 1986; Stevens and Lyle, 1989), alternate length (Cailliet and Bedford, 1983; Stick and Hreha, 1989), dorsal length (Aasen, 1963, 1966), precaudal length (Nakano et al., 1985; Cliff et al., 1989), standard length (Guitart Manday, 1975) and fork length (Mejuto and Garces, 1984; Casey and Pratt, 1985; Berkeley and Campos, 1988). Most studies include formulas to convert their measurements to total length. Total length measurements, however, can vary considerably depending on the placement of the caudal fin (Branstetter et al., 1987).

Published size relationships for sharks from various regions of the Atlantic Ocean and Gulf of Mexico include studies on the blue shark, *Prionace glauca* (Aasen, 1966; Stevens, 1975); tiger shark, *Galeocerdo cuvier* (Branstetter, 1981; Branstetter et al., 1987); silky shark, *Carcharhinus falciformis* (Guitart Manday, 1975; Branstetter, 1987; Berkeley and Campos, 1988); bull shark, *C. leucas* (Branstetter, 1981); spinner shark, *C. brevipinna* (Branstetter, 1981); night shark, *C. signatus* (Guitart Manday, 1975; Berkeley and Campos, 1988); oceanic whitetip shark, *C. longimanus* (Guitart Manday, 1975); finetooth shark, *C. isodon* (Castro 1993); shortfin mako, *Isurus oxyrinchus* (Guitart Manday, 1975; Mejuto and Garcés, 1984); white shark, *Carcharodon carcharias* (Casey and Pratt, 1985); porbeagle shark, *Lamna nasus* (Aasen, 1963; Mejuto and Garcés, 1984); bignose shark, *C. altimus* (Berkeley and Campos, 1988); bigeye thresher shark, *Alopias superciliosus* (Guitart Manday, 1975); and scalloped hammerhead, *Sphyrna lewini* (Branstetter, 1987). In response to the immediate needs of tournament officials and fishermen, and for management initiatives, we present length and weight data for thirteen species of large Atlantic sharks collected by the Apex Predator Investigation (API) of NMFS over a 29-year period.

Materials and methods

Length and weight data were collected from sharks caught by recreational and commercial fishermen and biologists along the U.S. Atlantic coast from the Gulf of Maine to the Florida keys during 1961 through 1989. Sharks were caught primarily on rod and reel at sport fishing tournaments and on longline gear aboard research vessels and commercial fishing boats. Some data were obtained from sharks that were harpooned or taken in gill nets. Measurements from a large white shark captured off Rhode Island in 1991 were also

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included in the analysis because of the shark's unusual size. Data were obtained opportunistically throughout each year but most (88%) were collected in the months of June, July, and August off the northeast United States between North Carolina and Massachusetts. Only lengths and weights measured by the authors and other members of the API or by cooperating biologists are included in this report. Measurements of embryos and fish known to be pregnant were excluded from the data set.

All lengths were measured with a metal measuring tape to the nearest centimeter in a straight line along the body axis; the caudal fin was placed in a natural position. Fork length (FL) was measured from the tip of the snout to the fork of the tail. Total length (TL) is defined as the distance from the snout to a point on the horizontal axis intersecting a perpendicular line extending downward from the tip of the upper caudal lobe to form a right angle.

Total weight (WT) of each shark was measured to the nearest pound and converted to kilograms. The majority of the fish were weighed hanging from the caudal peduncle which allowed any water in the stomach, and in some cases stomach contents, to drop out prior to weighing. Many fish were examined internally and, if unusually large amounts of water or contents were found in the stomach or abdominal cavity, the weights were subtracted to obtain a more accurate weight.

Fork-total length relationships for 13 species of shark (n=5,065) were determined by the method of least squares to fit a simple linear regression model. Linear regressions of fork-to-total length were calculated with their corresponding regression coefficients, sample sizes, and mean lengths. These data were then combined into four family groups: Alopiidae (thresher sharks), Lamnidae (mackerel sharks), Carcharhinidae (requiem sharks), and Sphyrnidae (hammerhead sharks), and linear regressions and TL/FL percentages were calculated for each group.

An allometric length-weight equation was calculated by using the method of Pienaar and Thomson (1969) for fitting a nonlinear regression model by least squares. The form of the equation is $WT=(a)FL^b$, where WT=total weight (kg), FL=fork length (cm), and a and b are constants. Length-weight relationships, mean lengths and weights, and size ranges were determined for 13 species of sharks (n=9,512). Literature values for maximum fork length and fork length at maturity were also included. The regressions of the length-weight equations expressed logarithmically were tested for possible significant differences (P<0.05) between males and females by using an analysis of covariance test for homogeneity of slopes.

Fork length is used throughout this report as the basis for all conversions and comparisons. We have found fork length to be a more precise measurement. For comparative purposes, all values published elsewhere as total lengths were converted to fork lengths by using the species' equations presented in this paper.

Minimum sizes at maturity reported here are from published accounts with their original sources referenced, with the exception of *Alopias vulpinus* and *Carcharodon carcharias*. Minimum size at maturity for the thresher shark and the male white shark were determined by Pratt[1] who used the following criteria: smallest male with calcified claspers that rotate at the base and smallest gravid female. When considerable variation occurred among published accounts, traditional sizes at maturity were chosen primarily from Atlantic populations. The maximum sizes and maximum sizes at birth used here are summarized in Pratt and Casey (1990).

Results and discussion

Linear regressions of fork-to-total length were calculated for 13 species of shark and four family groups (Table 1). The slopes of the regression lines of the four families decrease with the increasing length of the upper caudal lobe. The mackerel sharks have lunate tails with the upper and lower caudal lobes almost equal in size. The requiem sharks, hammerhead, and thresher sharks have heterocercal tails with the upper lobe longer than the lower. The latter group have very long upper caudal lobes with the fork length approximately 60% of the total length. The fork length represents 92%, 84%, and 77% of the total length for the mackerel, requiem, and hammerhead sharks, respectively.

A total of 9,512 sharks representing 13 species were measured, sexed, and weighed. There were no significant differences in slope or intercept of the length-weight relationships between males and females for any of the species and therefore one equation, calculated with the sexes combined, was used to represent the data for each species (Table 2).

Size at maturity for males and females is difficult to determine for pelagic sharks and can vary in different parts of the world (Pratt and Casey, 1990). The discrepancy is due, in part, to the use of variable criteria in determining a precise length at sexual maturity (Springer, 1960; Clark and von Schmidt, 1965; Pratt, 1979) and thus maturity is often reported

[1] H. L. Pratt, National Marine Fisheries Service, Narragansett, RI 02882. Pers. commun., May 1993.

Table 1

Fork length (FL)-total length (TL) relationships for 13 species of sharks and four family groups from the western North Atlantic: $FL = (a)TL+b$. Fork length and total length means and ranges were taken from data presented in this study.

Species	*n*	Mean total length (cm)	Total length range (cm)	Mean fork length (cm)	Fork length range (cm)	$FL = (a)TL+b$ a	b	r^2
Alopiidae	69					0.4882	37.9566	0.8577
Alopias superciliosus (bigeye thresher)	56	312	155–371	192	100–228	0.5598	17.6660	0.8944
A. vulpinus (thresher shark)	13	373	291–450	211	168–262	0.5474	7.0262	0.8865
Lamnidae	324					0.9352	–3.3292	0.9972
Carcharodon carcharias (white shark)	112	204	122–517	187	112–493	0.9442	–5.7441	0.9975
Isurus oxyrinchus (shortfin mako)	199	171	70–368	157	65–338	0.9286	–1.7101	0.9972
Lamna nasus (porbeagle)	13	201	119–247	182	106–227	0.8971	1.7939	0.9877
Carcharhinidae	4561					0.8290	1.1309	0.9963
Carcharhinus altimus (bignose shark)	10	174	132–228	148	112–192	0.8074	7.7694	0.9872
C. falciformis (silky shark)	15	173	90–258	142	73–212	0.8388	–2.6510	0.9972
C. obscurus (dusky shark)	148	153	92–330	125	74–277	0.8396	–3.1902	0.9947
C. plumbeus (sandbar shark)	3734	123	51–249	103	42–211	0.8175	2.5675	0.9933
C. signatus (night shark)	38	154	72–235	130	60–195	0.8390	0.5026	0.9883
Galeocerdo cuvier (tiger shark)	44	247	145–375	203	116–318	0.8761	–13.3535	0.9887
Prionace glauca (blue shark)	572	214	64–337	179	52–282	0.8313	1.3908	0.9932
Sphyrnidae	111					0.7756	–0.3132	0.9868
Sphyrna lewini (scalloped hammerhead)	111	206	82–278	160	64–216	0.7756	–0.3132	0.9868

as a size range rather than as a specific length. An individual author's definition of maturity is sometimes ambiguous or obscure. The sizes at maturity (Table 2) are from multiple reference sources and therefore may be mixed in definition and criteria. The original published sources should be consulted as the basis for defining sexual maturity among different authors.

An attempt was made to obtain samples representative of the full size range of each species. The minimum, maximum, and mean lengths and weights by species of sharks examined in this study are reported (Tables 1 and 2). A reliable maximum size is difficult to verify. Lengths or weights, or both, for large fish are often reported inaccurately and published accounts usually qualify maximum lengths with such words as "probably reach," "possibly to," or "may grow up to." Maximum lengths (FL) reported in Pratt and Casey (1990) are included for comparison with the sizes measured in this study (Table 2). With the exception of the porbeagle and the tiger shark, our data are within 62 cm (2 ft) of published maximum sizes. The porbeagle shark is less common in our study area; fewer specimens were examined (<30), and therefore the full size range of this species is not represented. Although the tiger shark is purported worldwide to grow to 469 cm FL (15.4 ft) (Castro, 1983; Compagno, 1984; Pratt and Casey, 1990),

Table 2

Fork length (FL)-total weight (WT) relationships for the 13 species of sharks from the western North Atlantic: $WT = (a)FL^b$. Fork length and weight means and ranges were taken from data presented in this study. The maximum fork length and sizes at maturity for each species were obtained from the literature.

Species	Sex	n	Mean fork length (cm)	Fork length range (cm)	Max fork length (cm)	Fork length at maturity (cm)	Mean weight (kg)	Weight range (kg)	$WT = (a)FL^b$: a	b	r^2
Alopias	Combined	55	190	100–228	270[1]		99	11–170	9.1069×10^{-6}	3.0802	0.9059
superciliosus	Male	34	188	100–221		180[1]	92	11–150			
(bigeye thresher)	Female	21	194	123–228		214[1]	110	23–170			
A. vulpinus	Combined	88	201	154–262	276[4]		122	54–211	1.8821×10^{-4}	2.5188	0.8795
(thresher shark)	Male	46	197	154–228		184[2]	116	54–181			
	Female	41	207	155–262		226[2]	129	59–211			
Carcharodon	Combined	125	186	112–493	555[3]		141	12–1554	7.5763×10^{-6}	3.0848	0.9802
carcharias	Male	65	203	117–493		332[3]	208	16–1554			
(white shark)	Female	59	168	112–310		454[12]	69	12–297			
Isurus oxyrinchus	Combined	2081	172	65–338	336[4]		63	2–531	5.2432×10^{-6}	3.1407	0.9587
(shortfin mako)	Male	1007	169	70–260		179[5]	59	2–210			
	Female	1054	174	65–338		258[5]	68	3–531			
Lamna nasus	Combined	15	185	106–227	329[1]		83	19–143	1.4823×10^{-5}	2.9641	0.9437
(porbeagle)	Male	13	180	106–216		159[6]	77	19–113			
	Female	2	214	201–227		204[6]	117	91–143			
Carcharhinus	Combined	38	151	97–210	235[1]		42	6–143	1.0160×10^{-6}	3.4613	0.8958
altimus	Male	12	158	115–205		182[7]	45	14–99			
(bignose shark)	Female	26	148	97–210		190[7]	41	6–143			
C. falciformis	Combined	85	118	73–212	253[8]		22	4–88	1.5406×10^{-5}	2.9221	0.9720
(silky shark)	Male	39	117	73–196		178[11]	22	4–88			
	Female	46	119	78–212		186[11]	22	4–88			
C. obscurus	Combined	247	162	79–287	303[7]		69	5–270	3.2415×10^{-5}	2.7862	0.9649
(dusky shark)	Male	103	136	79–276		231[8]	39	5–216			
	Female	144	181	83–287		235[8]	90	6–270			
C. plumbeus	Combined	1548	129	44–201	198[7]		30	1–104	1.0885×10^{-5}	3.0124	0.9385
(sandbar shark)	Male	577	115	45–183		150[8]	20	1–68			
	Female	961	138	44–201		152[8]	36	1–104			
C. signatus	Combined	124	111	60–203	235[1]		15	3–102	2.9206×10^{-6}	3.2473	0.9502
(night shark)	Male	69	112	93–195		—	14	8–64			
	Female	55	111	60–203		150[7]	16	3–102			
Galeocerdo	Combined	187	203	92–339	469[1]		110	5–499	2.5281×10^{-6}	3.2603	0.9550
cuvier	Male	92	209	95–318		258[9]	113	7–348			
(tiger shark)	Female	92	197	92–339		265[9]	107	5–499			
Prionace glauca	Combined	4529	195	52–288	320[1]		52	1–174	3.1841×10^{-6}	3.1313	0.9521
(blue shark)	Male	3095	205	54–288		183[10]	59	1–174			
	Female	1398	172	52–273		185[10]	34	1–140			
Sphyrna lewini	Combined	390	158	79–243	239[11]		47	5–166	7.7745×10^{-6}	3.0669	0.9255
(scalloped	Male	189	166	107–224		139[11]	53	11–126			
hammerhead)	Female	199	151	79–243		194[11]	41	5–166			

[1] Castro (1983).
[2] Pratt (personal commun.).
[3] Randall (1987).
[4] Pratt and Casey (1990).
[5] Stevens (1983).
[6] Aasen (1961).
[7] Compagno (1984).
[8] Springer (1960).
[9] Branstetter et al. (1987).
[10] Pratt (1979).
[11] Branstetter (1987).
[12] Casey and Pratt (1985).

Atlantic specimens may not attain that size. Our longest tiger shark was 339 cm FL (11.1 ft) (Table 2). The maximum reported length examined by Branstetter (1981) in a study of tiger sharks in the north central Gulf of Mexico was 346 cm FL (11.4 ft). The maximum reported length for the U.S. Atlantic coast is 391 cm FL (12.8 ft) (Bigelow and Schroeder, 1948). These lengths are more in agreement with individuals sampled in this study.

Specimens from three species of sharks exceeded the maximum reported lengths (Table 2): sandbar shark, shortfin mako shark, and scalloped hammerhead shark. The 211 cm FL (6.9 ft) female sandbar shark in this study (Table 1) was measured by one of the authors (J. Casey) and is the largest measured sandbar reported to date. This fish was caught in September of 1964 by a sport fisherman approximately 10 miles east of Asbury Park, New Jersey. Unfortunately, the fish was not weighed. Two mako sharks measured in this study were longer than the 336 cm FL (11.0 ft) maximum size fish published in the literature. Both of these fish were 338 cm FL (11.1 ft) females caught by sport fishermen south of Montauk Point, New York. One was landed in July of 1977 and weighed 471 kg (1,039 lbs). The other was caught in August of 1979 and weighed 382 kg (841 lbs). The largest scalloped hammerhead (243 cm FL, 8.0 ft; 166 kg, 365 lbs) was measured at a sportfishing tournament in July of 1985 and was caught 36 miles southeast of Highlands, New Jersey.

The lower ends of the length-weight curves also compare well with published estimates of size at birth for each species of shark. Pratt and Casey (1990) give maximum size at birth in TL for 11 of the 13 species of sharks sampled here and all except the thresher shark are within 40 cm (16 in) of those sizes. Our smallest thresher shark is 64 cm (25 in) larger than the reported birth size.

All of the larger fish were female with the exception of the white and the blue shark (Tables 1 and 2). The larger size attained by females is typical of sharks in general (Pratt and Casey, 1983; Hoenig and Gruber, 1990), and thus larger female blue and white sharks very likely occur outside of our western North Atlantic sampling area which only covers a small portion of their extensive oceanic range.

Blue sharks have a complex life history cycle and large females are infrequent visitors to the continental shelf and slope waters off North America. The shelf area serves as a mating ground where the catch consists primarily of juvenile males and females, subadult females, and adult males (Casey, 1985). The occurrence of considerable numbers of the larger females (>240 cm, 7.9 ft) is rare in the western North Atlantic, but numerous large gravid females have been reported in the eastern Atlantic from the Mediterranean Sea and around the Madeira and Canary Islands (Aasen, 1966; Pratt, 1979).

The white shark distribution pattern may be as complex as that of the blue shark but is more obscure. Although no mature female white sharks were examined, adult females have been reported from the western North Atlantic. Casey and Pratt (1985) describe a 483 cm FL (15.8 ft) fish harpooned off Montauk, New York, in 1964 and a 526 cm FL (17.3 ft) female which became entangled in a gill net near Prince Edward Island, Canada, in July, 1983. Elsewhere, large female white sharks have been reported in the Gulf of Maine (Bigelow and Schroeder, 1948; Skud, 1962), in the Mediterranean Sea (Ellis and McCosker, 1991) and off the west coast of Florida (Springer, 1939). Catching a large white shark of either sex, however, is an uncommon event. White sharks are likely to occur singly or as scattered, unassociated individuals over vast geographical areas (Casey and Pratt, 1985). Owing to their immense size, they are difficult to catch and are capable of breaking free of most conventional fishing gear.

Factors affecting weight

Weights of individual sharks of the same length may differ depending on several factors, including the amount of stomach contents, the stage of maturity, the liver weight, and the condition of the shark. The effects of stomach contents on the weight of the fish were minimal in this study. In many instances, the sharks everted their stomachs prior to being weighed. For the bigger fish, when large amounts of food were present, the weight of the stomach contents was subtracted to obtain the total body weight. Since not every shark was examined internally, some pregnant fish may have been inadvertently included in the database.

Differences in body weight also reflect differences in the condition of an individual. Sharks have large livers which store high energy, fatty acids for buoyancy and for use as a food reserve (Bone and Roberts, 1969; Oguri, 1990). The weight of this organ is thus a good indicator of the health or condition of a shark (Springer, 1960; Cliff et al., 1989). The liver is the largest organ by weight in the shark and can vary from 2–24% of the body weight depending on the species (Cliff et al., 1989; Winner, 1990). Variation in the liver size accounted for the majority of the weight difference in individuals of the same species with corresponding lengths. In six of the eight largest white sharks, the liver weights ranged from 14.6–22.7% of the body weight (hepatosomatic index, HSI) (Table 3). The 458 cm (15.0 ft) FL white shark in this group had the lowest HSI value (14.6%) although it was longer than four heavier fish. The difference in body weight between the 458 cm (15.0 ft) FL and the 463 cm (15.2 ft) FL fish is 360 kg (793 lbs). When the weights of sharks without livers are compared, the difference between these two fish is reduced to 239 kg (526 lbs). Thus, eliminating the liver accounted for 34% of the weight difference between these two sharks of similar length. The same is true for large mako sharks. The HSI for one of the longest mako sharks (338 cm, 11.1 ft FL; 382 kg, 841 lbs) was 5.4% as contrasted with 17.9% for the 323 cm (10.6 ft) FL fish weighing 490 kg (1,080 lbs). When the two makos are compared without livers, the difference in body weights is reduced from 108 kg (239 lbs) to 41 kg (91 lbs).

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Table 3

Fork length, body and liver weight, and hepatosomatic index (HSI) for large white sharks, *Carcharodon carcharias*, from the western North Atlantic.

Fork length (cm)	Whole body weight (kg)	Liver weight (kg)	HSI (%)
463	1,245	250	20.1
458	885	129	14.6
446	1,261	206	16.3
444	1,320	232	17.6
437	1,084	246	22.7
425	941	179	19.0

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