mune Response, S. Cohen *et al.*, Eds. (Karger, Basel, 1971), p. 103.
4. F. H. Bach, M. B. Widmer, M. Segall, M. L. Bach, J. Klein, *Science* **176**, 1024 (1972); F. H. Bach, M. B. Widmer, M. L. Bach, J. Klein, *J. Exp. Med.* **136**, 1430 (1972).
5. J. Klein and J. M. Park, *J. Exp. Med.* **137**, 1213 (1973). S. Livnat, J. Klein, F. H. Bach, *Nature New Biol.* **234**, 42 (1973).
6. E. S. Vitetta, C. Bianco, V. Nussenzweig, J. W. Uhr, *J. Exp. Med.* **136**, 81 (1972).
7. J. J. Marchalonis, R. E. Cone, J. L. Atwell, *ibid.* **135**, 956 (1972).
8. J. Klein and D. C. Shreffler, *Transplant. Rev.* **6**, 3 (1971); *J. Exp. Med.* **135**, 924 (1972).
9. D. C. Shreffler and R. D. Owen, *Genetics* **48**, 9 (1963); H. C. Passmore and D. C. Shreffler, *Biochem. Genet.* **4**, 351 (1970).
10. J. Klein, D. Klein, D. C. Shreffler, *Transplantation* **10**, 309 (1970).
11. J. H. Stimpfling and A. E. Reichert, *Transplant. Proc.* **2**, 39 (1970).
12. P. A. Gorer and P. O'Gorman, *Transplant. Bull.* **3**, 142 (1956).
13. D. B. Amos, H. Bashir, W. Boyle, M. MacQueen, A. Tiilikainen, *Transplantation* **7**, 220 (1969). Unabsorbed normal rabbit serum diluted 1:10 was used as a source of complement. The percentage of stained cells was determined after addition of trypan blue.
14. G. Möller, *J. Exp. Med.* **114**, 415 (1961). The fluorescein conjugated, horse antiserum to mouse immunoglobulin was supplied by Roboz Surgical Instruments Co., Washington, D.C. The fluorescence indexes were calculated as follows: the number of negative cells in the sample with control serum minus the number of negative cells in the anti-serum-treated sample divided by the number of negative cells in the sample with control serum.
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Size of the Great White Shark (Carcharodon)

Abstract. *The maximum length of 36.5 feet (11.1 meters) attributed to the white shark (*Carcharodon carcharias*) by Günther and others is a mistake. Examination of the jaws and teeth of the specimen referred to by Günther and comparison with the jaws of white sharks of known length revealed a length of about 17 feet (~5 meters). The largest white shark reliably measured was a 21-foot (6.4-meter) individual from Cuba. Bites on whale carcasses found off southern Australia suggest that white sharks as long as 25 or 26 feet (7½ or 8 meters) exist today. The size of extinct* Carcharodon *has also been grossly exaggerated. Based on a projection of a curve of tooth size of Recent* Carcharodon carcharias, *the largest fossil* Carcharodon *were about 43 feet (~13 meters) long.*

The great white shark, *Carcharodon carcharias* (Linnaeus), is regarded as the most dangerous of all sharks because of its aggressiveness and large size (*1*). In 1870 Günther (*2*) listed jaws of this species (as *C. rondeletii*) from two specimens, *b* and *c*, caught at Port Fairey (?), Australia, and reported to have been 36.5 feet (11.1 m) in length.

Later, Günther (*3*) wrote that the white shark is known to attain 40 feet (12.2 m). Many authorities have given this length or 36.5 feet as the maximum for the species. A few (*4*, *5*) have suggested that the 36.5-foot size may represent an example of gigantism.

The second largest white shark believed to be reliably measured was one taken off Cuba that was 21 feet (6.4 m) long (*4*). Why have no white sharks been recorded by actual measurement between 21 and 36.5 feet in length?

I examined the jaws cited by Günther at the British Museum (Natural History). One, marked *c*, consists of only the upper jaw. It measures 1035 mm along the perimeter of the jaw (*6*); the largest tooth is 57 mm in height. The second set of jaws, labeled *b*, is larger (Fig. 1) (*7*). The perimeter of the upper jaw is 1180 mm; the largest upper tooth is 68 mm in height, of which 50 mm is enamel (*8*). Earlier measurements of this tooth have been "nearly 3 inches" (76 mm) (*9*), and "2½ inches" (63.5 mm) (*10*); one author (*11*) stated that *C. carcharias* reaching a length of 35 feet has teeth barely an inch in length.

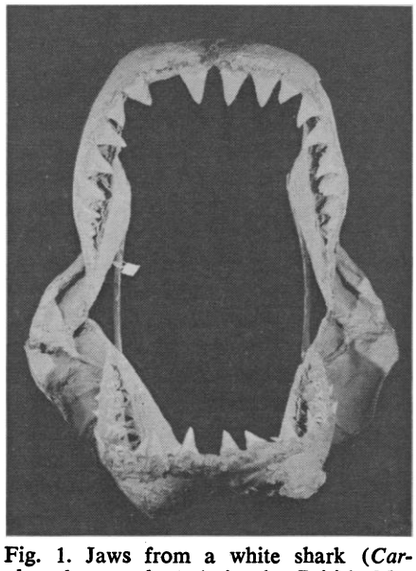

Fig. 1. Jaws from a white shark (*Carcharodon carcharias*) in the British Museum (Natural History) reported as 36.5 feet (11.1 m) in length. The distance between the upper and lower jaws at symphysis (disregarding the teeth) is 593 mm.

Although these jaws are impressive, they do not approach the size one would expect for a shark 36.5 feet long. It is possible that a mistake might have been made in recording the shark's length. P. W. Gilbert independently examined the jaws, and he has suggested that there might have been a printer's error; the length should perhaps have been 16.5 feet (5 m) (*12*). However, Günther still used the 36.5-foot length in the second publication on the subject 10 years after his *Catalogue of Fishes* appeared. Furthermore, he illustrated a tooth from the jaws in natural size (62 mm). This is smaller than the largest tooth, but it corresponds in size to the second largest, which is missing from the upper jaw (see Fig. 1). Nevertheless, Gilbert's postulated 16.5-foot length for the jaws labeled *b* is close to my two estimates, given below.

The vertical height of the enamel of the largest upper tooth and the perimeter of the upper jaw were determined from jaws of white sharks of known length at the Museum National d'Histoire Naturelle, Paris; Scripps Institution of Oceanography, La Jolla; Northeast Fisheries Center, Narragansett; and especially the California Academy of Sciences, San Francisco (jaws collected and prepared by W. I. Follett). In addition, J. T. Veitch of Port Lincoln, Australia, provided measurements from the teeth and jaws of two large sharks. The height of the enamel and measurements of the upper jaw for all these sharks are plotted against total length in Fig. 2, A and B, respectively. From Fig. 2A I estimate a length of 5.6 m (17 feet 9 inches) for a shark with an enamel height of 50 mm, and from Fig. 2B a length of 5.2 m (17 feet) for a shark with an upper jaw perimeter of 1180 mm. I conclude, therefore, that the shark with jaws *b* in the British Museum (Natural History) was about 5.4 m in total length.

Ostle (*13*) reported that the largest white shark taken in the last few years off Western Australia was 19 feet (5.8 m) in length. However, five bites from a larger shark noted on the carcass of a whale which was lost overnight on 26 May 1972 measured 19 inches (483 mm) in height and 24 inches (610 mm) in width. Ostle stated that the bite of a shark of 14.5 to 15 feet long is about 10 by 12 inches, and that

of a 16-foot shark is about 11 by 13 inches. It follows that a shark about 25 to 26 feet (7.8 m) long would inflict a bite of 19 by 24 inches. Even larger bites were observed on a whale in 1968 but they were not measured (*13*). Thus, it seems likely that white sharks more than 21 feet long swim in our seas today and remain to be captured.

Weights were available for many of the sharks whose jaws and teeth were measured. In addition, weight data were obtained for 44 specimens from South Australia and South Africa (*14*), as well as from the literature (*4, 15*). These weights are plotted against length in Fig. 2C, except for three from Bigelow and Schroeder (*4*), which seem much too great for the lengths given (8 feet 3 inches, 600 pounds; 9 feet 8 inches, 960 pounds; and 13 feet 3 inches, 2176 pounds). The source for the latter was the *London Illustrated News*, 14 July 1928. Also two other weights were omitted [7100 pounds (3220 kg) for the 21-foot shark from Cuba and 4500 pounds (2350 kg) for a 17.5-foot (5.3-m) shark from New York (*16*)] because their inclusion would require too great a reduction of the remaining lower part of the length-weight curve. The two points that would represent these weights lie in the path of the steeply ascending upper part of the curve.

The paucity of weight data for large specimens of *C. carcharias* reflects not only their rare occurrence and infrequent capture but also the lack of a suitable scale to weigh such massive fish. Usually only estimates have been made of the weight of large white sharks, but none of these have been included in Fig. 2C.

Bigelow and Schroeder (*4*) reported the smallest free-living white shark as "about five feet" (1.5 m) long. Fitch (*17*) illustrated a 4.5-foot specimen from California. Two from Durban, South Africa, were 5 feet in length; each weighed 56 pounds (25.4 kg) (*14*).

These data indicate that there was an error in recording a weight of 108 pounds (49 kg) for each of the nine 2-foot young from a 14-foot white shark taken near Alexandria, Egypt (*4*). Also, either the length of the female or her weight of 2.5 tons must be a mistake. It is regretted that more reliable information was not obtained for this shark, because this record is the only one I could find of the embryos of this species.

The teeth of *Carcharodon* have been found in fossil deposits on all continents, some from as far back in time as the Upper Cretaceous (*18*). Seventy nominal species and varieties have been proposed for fossil *Carcharodon* (*19*), based largely on teeth. Some of these teeth have been of extraordinary size. Estimates of the length of the sharks which possessed them have varied between 60 and 100 feet (18.3 to 30.6 m) (*10, 11, 20*). These estimates, however, are largely the result of calculations based on the teeth of the shark erroneously reported as 36.5 feet by Günther.

The enamel height of the largest fossil tooth at the American Museum of Natural History, New York (specimen No. 10356), is 115 mm, and that of the largest tooth in the United States National Museum, Washington, D.C. (specimen No. 25730), is 117.5 mm. An extrapolation of the line of Fig. 2A to these enamel heights reveals a corresponding shark length of about 43 feet (13 m).

A reconstruction of the jaws of *Carcharodon megalodon* at the American Museum of Natural History (*21*) has provided a concept of the enormous size of these extinct leviathans. This reconstruction, however, has been shown to be at least one-third too large because all the teeth were regarded as nearly the same size as the large ones medially in the jaws (*22*). Actually, the most lateral teeth are very small compared to those at the symphysis (Fig. 1).

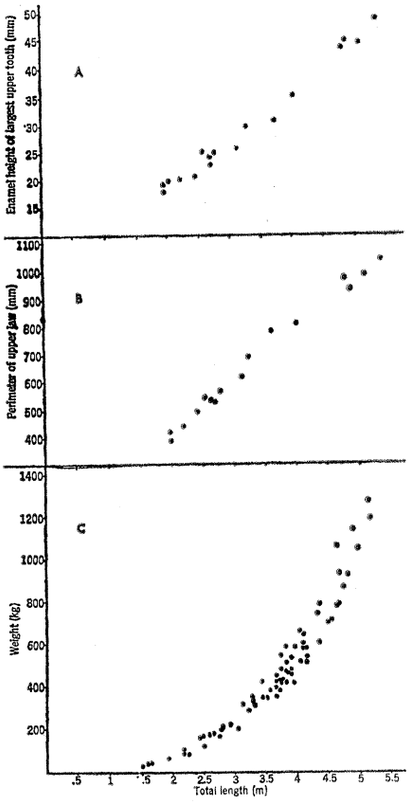

Fig. 2. (A) Relation of the enamel height of the largest tooth in the upper jaw to total length for the white shark (*Carcharodon carcharias*); (B) relation of the perimeter of the upper jaw to total length for the white shark; and (C) length-weight relation of the white shark.

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References and Notes

1. J. A. F. Garrick and L. P. Schultz, in *Sharks and Survival*, P. W. Gilbert, Ed. (Heath, Boston, 1963), p. 3.
2. A. Günther, *Catalogue of the Fishes in the British Museum* (Taylor and Francis, London, 1870), vol. 8.
3. ———, *An Introduction to the Study of Fishes* (Adam and Charles Black, Edinburgh, 1880).
4. H. B. Bigelow and W. C. Schroeder, *Fishes of the Western North Atlantic*, part 1, *Sharks* (Sears Foundation Marine Research, Yale University, New Haven, 1948).
5. P. Budker and P. J. Whitehead, *The Life of Sharks* (Columbia Univ. Press, New York, 1971).
6. The perimeter of the upper jaw was measured by laying a string over the curvature of the upper jaw just above the base of the teeth, from one extreme corner of the mouth to the other.
7. The jaws marked *b* were displayed for many years in the gallery of the British Museum. After World War II they were moved back to the scientific collection, and the coelacanth *Latimeria* was displayed in their place. They still have the metal brackets on the back which were used to hold them vertically when on exhibit.
8. The enamel height was measured from the tip of the tooth vertically to a line connecting the two most ventral extensions of the enamel.
9. J. R. Norman and F. C. Fraser, *Giant Fishes, Whales and Dolphins* (Putnam, London, 1937).
10. M. Tweedie, *Animals* **10**, 258 (1967).
11. D. S. Jordan, *Amer. J. Sci.* **3**, 338 (1922).
12. P. W. Gilbert and C. K. Gilbert, *Underwater J.*, in press.
13. C. Ostle, Department of Fisheries and Fauna, Albany, Western Australia, personal communication.
14. J. T. Veitch, Port Lincoln, South Australia, personal communication, including data from G. L. Biden.
15. E. H. LeMier, *Copeia* (1951), p. 249; L. W. Scattergood, P. S. Trefethen, G. W. Coffin, *ibid.*, p. 297; R. H. Backus, *ibid.* (1960), p. 243; W. I. Follett, *Pac. Discovery* **19**, 18 (1966).
16. T. H. Lineaweaver, III, and R. H. Backus, *The Natural History of Sharks* (Lippincott, Philadelphia, 1969).
17. J. E. Fitch, *Calif. Fish Game* **35**, 135 (1949).
18. A. S. Romer, *Vertebrate Paleontology* (Univ. of Chicago Press, Chicago, 1933); 5-inch *Carcharodon* teeth from Lake Bonney, South Australia, in the South Australian Museum, are reported by J. T. Veitch (personal communication).
19. H. W. Fowler, *Quart. J. Taiwan Mus.* **20**, 320 (1967).
20. B. Dean, *Amer. Mus. J.* **9**, 233 (1909); L. Hussakof, *Sci. Amer.* **73** (Suppl.), 225 (1912).
21. See cover, *Science* **174**, (No. 4005) (8 October 1971).
22. S. P. Applegate, *ibid.*, p. 893.
23. I thank M. L. Bauchot, A. J. Bass, J. G. Casey, W. N. Eschmeyer, P. W. Gilbert, G. J. Nelson, C. Ostle, H. A. Rehder, R. H. Rosenblatt, V. G. Springer, W. A. Starck, II, J. T. Veitch, and A. C. Wheeler for assistance and information.

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