VII. Reproduction.

A. Mating activity.

1. Few people have witnessed the mating activity of sharks.

   a. In smaller, more flexible species the male coils around the female.

   b. In larger, more rigid species the male orients himself parallel and head-to-head with the female.

   c. During mating, males of many species bite females on the pectoral fins or the middle of the back to hold onto them. Females often bear scars or marks. Upon examination, these marks show they have been made by upper jaw teeth. In some elasmobranchs, males have longer, narrower teeth than females. In some female sharks, such as the blue shark (*Prionace glauca*), the skin on the back and flanks is more than twice as thick as the skin on the males.

2. Shark and batoid eggs are fertilized internally, as opposed to external fertilization in many bony fishes. Internal fertilization is a key adaptation for energy-intensive reproduction .

   a. When born or hatched, young sharks are fully formed and physically able to fend for themselves.

   b. Because these independent shark pups have a better chance for survival, the number of sharks produced in a litter is rarely over 100. The majority of the species bear far fewer pups.

3. Claspers are modified inner edges of the pelvic fins of male sharks and rays. During copulation, the erectile claspers are bent forward. The male inserts one clasper at a time into the female. In some species, claspers contain cartilaginous hooks and spurs that dig into the walls of the female oviduct, anchoring the clasper. Muscles force seminal fluid down a groove in the clasper and into the female oviduct.

B. Embryonic development.

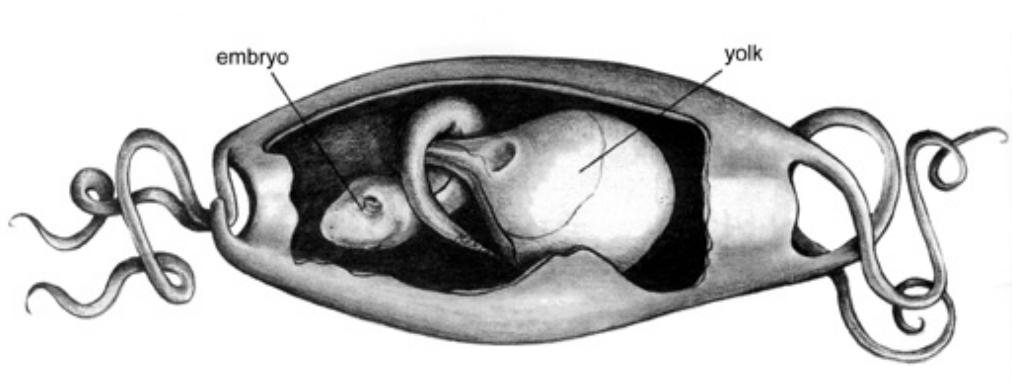
There are three types of embryonic development: oviparous, ovoviviparous, and viviparous.

1. In oviparous sharks, a gland secretes a shell, or case, around the egg as it passes through the oviduct, protecting the shark until it hatches. The mother deposits the egg cases in the sea.

   a. When an egg case is first laid, it is soft and pale; the case hardens and darkens in a few hours.

b. The developing embryo receives nutrients from a yolk formed prior to fertilization .

c. Oviparous sharks include horn sharks and swell sharks (*Cephaloscyllium ventriosum*).



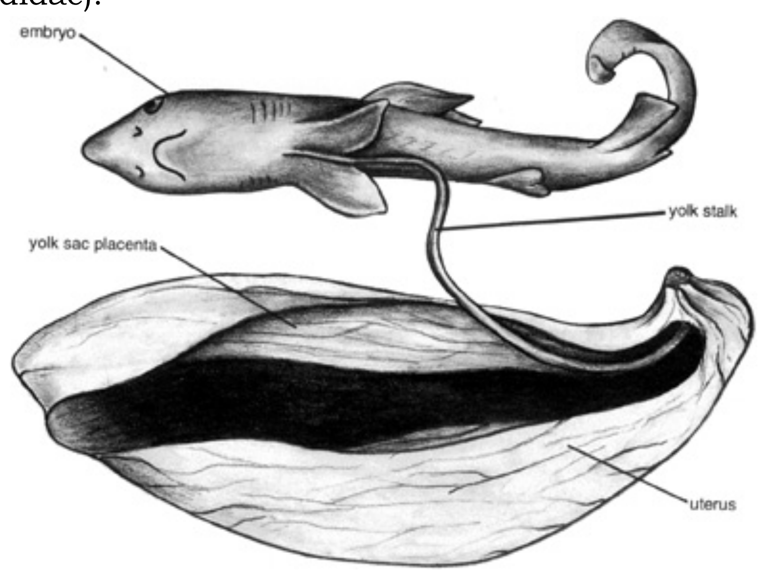
A swell shark (Cephaloscyllium ventriosum) develops within a tough, leathery egg case.

2. In ovoviviparous sharks, the shell is often just a thin membrane. Sometimes there is more than one egg in a membrane; this group of eggs is called a candle. The mother retains the egg, and the embryo soon sheds the membrane and develops in the mother's uterus.

a. Theoretically, all the embryo's nutrients come from the yolk. In some species, however, the lining of the uterus probably secretes nutritive fluids that are absorbed by embryos.

b. In other species, embryos continue to obtain nutrients after their yolk is absorbed by swallowing eggs and smaller embryos in the uterus. This is termed "intrauterine cannibalism" or ovophagy. In these sharks, usually only one embryo survives in each uterus. (Females have two uteri.)

c. Ovoviviparous sharks include mako sharks (*Isurus* spp.) and sandtiger sharks (family Odontaspididae).



In viviparous sharks, the developing embryo receives its nutrients from its mother via a yolk sac placenta.

3. In viviparous sharks, the yolk stalk that connects the embryo to the yolk grows long in the uterus. Where the small yolk sac comes in contact with the mother's uterus, it changes into a yolk sac placenta.

   a. The embryo receives all its nutrients from the mother in one of two ways:

      (1) Tissues of the embryo and the mother are in intimate contact and nutrients are passed directly from the tissues of the mother to the tissues of the developing embryo.

      (2) The uterine lining secretes "uterine milk," which bathes the developing embryo. The branched yolk stalk absorbs this fluid.

   b. Viviparous sharks include hammerhead sharks.

C. Gestation.

Gestation periods vary among species and between individuals within a species. Since sharks and batoids are cold-blooded, there is no precise gestation time. The rate at which the embryo develops depends on the water temperature. In general, most embryos develop somewhere in the range of two months (for some rays) to two years (for some spiny dogfish).

D. Location.

Sharks generally bear their young or lay their eggs in coastal nurseries where other large sharks are usually absent.

VIII. Anatomy and Physiology.

A. Skeleton.

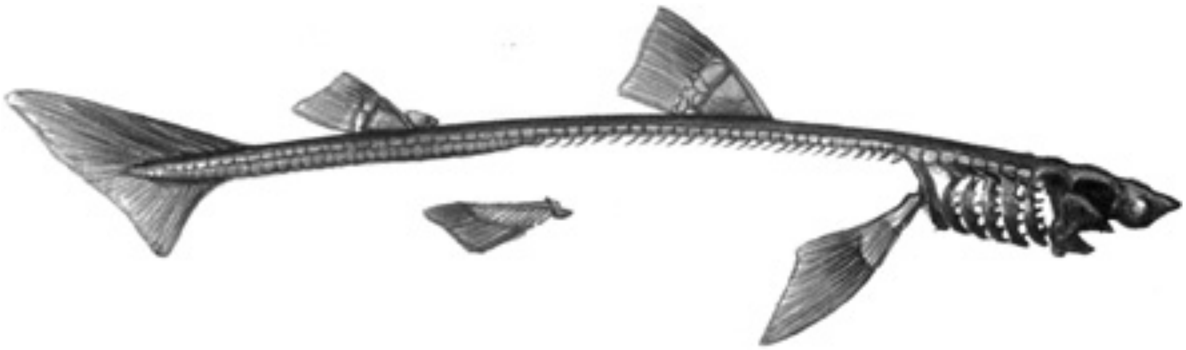
1. The skeleton of elasmobranchs is made of cartilage.

a. The skeleton may be partially calcified to some extent with calcium phosphates and carbonates, particularly in the vertebral column. This calcified cartilage is not true bone.

b. The cartilage of a shark's skeleton may be important in future cancer research. Shark cartilage contains an active ingredient that has been known to inhibit tumor growth. In addition, sharks rarely develop cancer.

c. A shark's cranium is a single compact cartilaginous block which encloses the brain, olfactory, and auditory capsules. Jaws are loosely attached to the cranium.

2. Vestigial ribs give no support.



A shark's skeleton is made of cartilage.

B. Muscles.

1. Red muscle is aerobic: it needs oxygen to function. This muscle contains myoglobin, an oxygen-carrying pigment. Red muscle functions for cruising.

2. White muscle is anaerobic: it does not use oxygen. White muscle functions for sudden bursts of speed.

C. Digestive tract.

1. The esophagus is short and wide, barely discernible from the stomach. A U-shaped stomach leads to a spiral valve in many species.

2. A spiral valve is the lower portion of the digestive tract. It is internally twisted or coiled to increase the surface area, which increases nutrient absorption.

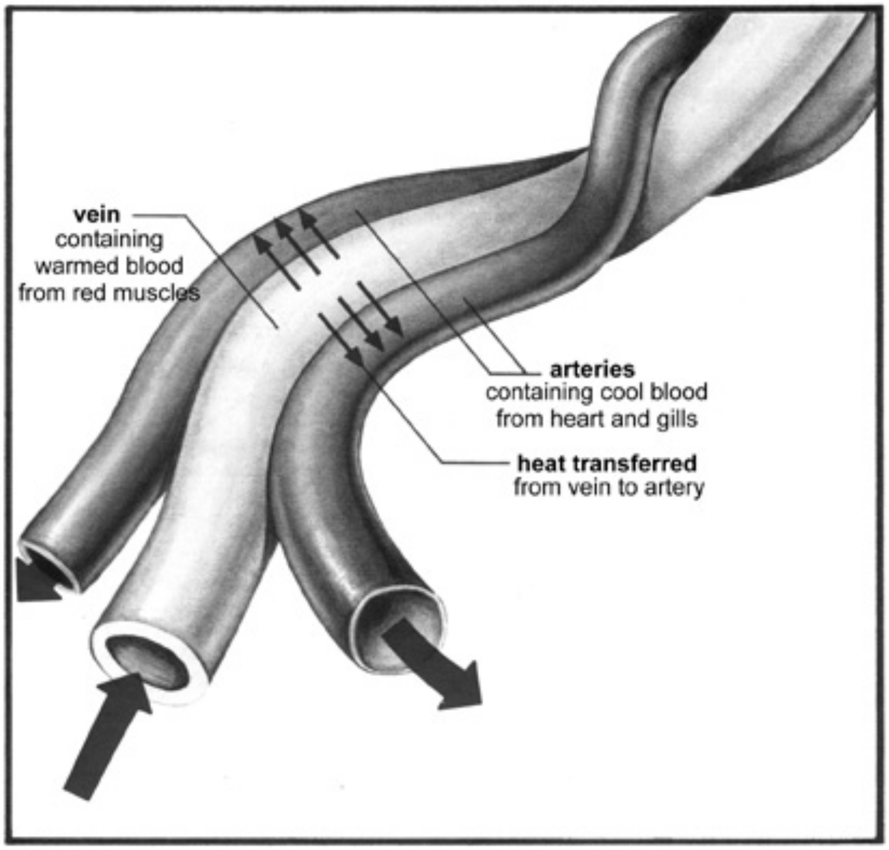
3. After the spiral valve, the digestive tract leads to the rectum and to the cloaca. The cloaca is a common opening for the urinary, digestive, and reproductive systems.

D. Circulatory system.

1. A shark's heart is a two-chambered S-shaped tube, small in proportion to body size. Blood flows from the heart to the gills and then to body tissues.

2. Fast-swimming sharks, such as great whites and makos, have a body temperature that can be quite a bit higher than the surrounding water (up to 8°C or 14.4°F higher). This heat is due to the modified circulatory system associated with the red muscle.

   a. As red muscle functions, it generates heat. Muscle-generated heat warms the blood circulating through the red muscle, which then travels back to the heart through veins. Thus, blood returning to the heart from the muscle is warmer than blood traveling from the heart to the muscle.



Due to the nearness of arteries and veins in the red muscle, heat passes from the warmer veins to the cooler arteries within the shark's body, rather than dissipating to the cooler environment.

b. Due to the nearness of arteries and veins, heat passes from warmer veins to cooler arteries within the shark's body, rather than dissipating to the cooler environment. This modified circulatory system retains heat in the red muscle.

3. Sharks have low blood pressure. The walls of the pericardium (the membranous sac that encloses the heart) are rigid, creating a suction within the pericardium to maintain the flow of blood. To circulate blood throughout their bodies, many sharks must swim continuously.

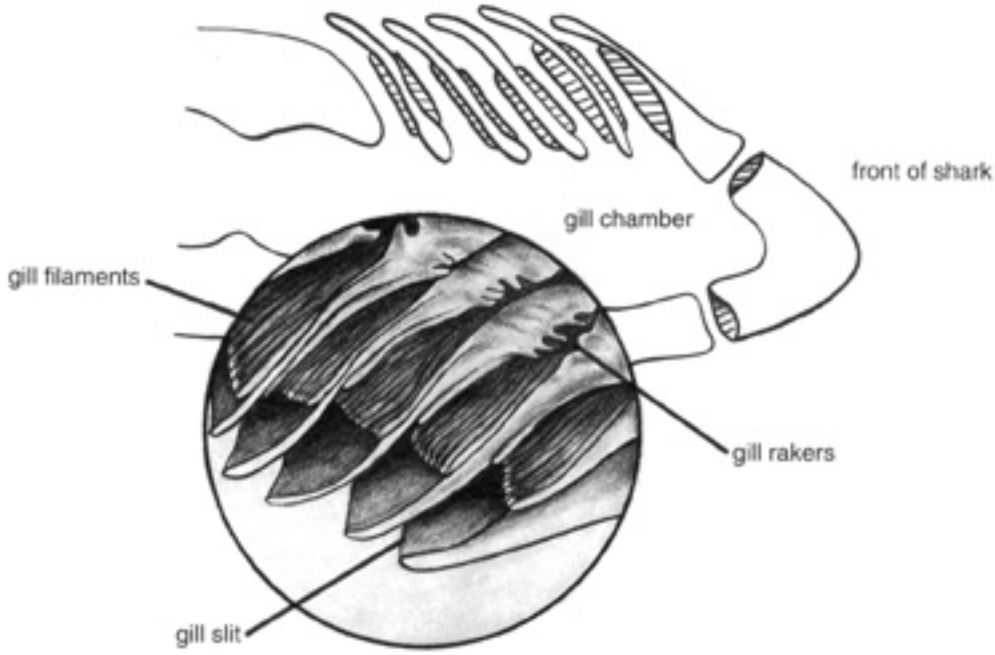
E. Gills and respiration.

1. Water enters the gill chambers through the mouth or spiracles. In the past, it was assumed that all sharks must swim to move water into their mouth and over their gills to respire. We now know that sharks can respire by pumping water over their gills by opening and closing their mouths. However, many sharks do have to swim continuously: due to their low blood pressure, muscular contractions are needed to circulate their blood.

2. Blood in the gill filaments absorbs oxygen from the incoming water.

3. Gill rakers, cartilaginous projections on the gill support structure, protect the delicate gill filaments from particles in the water that might damage them.

4. Water exits through the gill slits.



A shark's delicate gill filaments are protected from particles in the water by gill rakers.

5. In species where they are present, spiracles provide oxygenated blood directly to the eye and brain through a separate blood vessel which is reduced or absent in active, fast-swimming sharks.

F. Liver.

1. A shark's liver is made of two large lobes that concentrate and store oils and fatty acids. The liver functions in energy storage and buoyancy.

2. A shark's liver is relatively large, making up 5% to 25% of its total body weight.

IX. Hydrodynamics.

A. Body shape.

Sharks typically have an elongate fusiform body (rounded and tapering at both ends). This body shape reduces drag and requires a minimum of energy to swim. Swimming is essential for buoyancy.

B. Caudal fin.

Unlike most bony fishes, the upper lobe of a shark's caudal fin is larger than the lower lobe. As the caudal fin moves back and forth to propel the shark forward, it also moves upward. As the caudal fin continues to lift, the shark's head points down. The overall effect of the motion of the caudal fin results in a forward and downward motion.

C. Pectoral fins.

The pectoral fins compensate for this downward motion. One function of the rigid pectoral fins is to provide lift in the forward region of the shark's body. This counteracts the overall downward force caused by the caudal fin and results in horizontal passage through the water.

D. Horizontal keel.

The horizontal keel on the caudal peduncle of some sharks is an adaptation for fast swimming. It reduces turbulence.

E. Placoid scales.

As a shark or batoid swims, placoid scales may create a series of vortices or whirlpools behind each scale. This enables a shark to swim efficiently.

F. Swimming speed.

Generally sharks swim at speeds less than 5 kph (about 3 mph). For the most part, bottom-dwelling sharks are slow-swimming. Makos are among the fastest sharks, reaching speeds up to 48 kph (30 mph).

X. Longevity and Causes of Death.

A. Longevity.

1. Little is known about the growth and age of elasmobranchs. Many of the conventional methods for aging animals, such as examining teeth, will not work with elasmobranchs.

2. Sharks grow slowly compared to bony fishes, possibly due to sharks' slow digestive time and feeding rates. There is considerable variation in age and growth rates between species and even between populations of the same species.

B. Aging studies.

1. Growth rings are periodically deposited on the vertebrae of some sharks. Vertebrae can be stained and examined for these growth rings. Growth rings may stop developing in older sharks.

2. Examining the vertebrae of captive-born sharks after their death enables researchers to compare the number of growth rings with the shark's known age.

3. In some areas, tagged sharks are providing information about growth rates. Once a shark is caught, it is measured, tagged, and released. The shark is measured again when it is recaptured. Researchers correlate the measurements with the number of years since recapture and calculate a yearly growth rate.

C. Predators.

Depending on the species, sharks and batoids have several predators, including other sharks, elephant seals, and killer whales.

D. Human interaction.

1. Sharks are vulnerable to overfishing. Because sharks are slow-growing and a single female produces only a few hundred pups or less in a lifetime, depleted populations may take years to recover.
   a. Recreational and commercial shark harvesting has increased in the past several years due to an increased demand for sharks and shark products.
   b. Each year, thousands of sharks are taken unintentionally in nets set out to catch other types of fish.
   c. One particularly wasteful type of shark fishing is known as finning. Only the fins of the shark, which will be sold for use in sharkfin soup, are removed.
2. Fisheries management programs are necessary for a sensible shark harvest.
   a. The National Marine Fisheries Service (NMFS) develops management plans for sharks, setting catch quotas for target shark species.
   b. On April 26, 1993, NMFS implemented a plan to manage U.S. shark fisheries of the Atlantic Ocean, Gulf of Mexico, and Caribbean Sea. The plan includes the following features:
      (1) Annual commercial quotas, which are divided into half-yearly quotas.
      (2) Provisions for closing a fishery for a species group when the semi-annual quota is met.
      (3) Catch limits for recreational anglers.
      (4) Permit requirements for commercial vessels that catch sharks.
      (5) A requirement that vessels land fins in proportion to carcasses (effectively prohibiting the practice of shark finning).
      (6) A requirement that when sharks are not kept, they are released in a manner that ensures the probability that they will survive.
3. Future research into the population dynamics of commercially important shark species will yield important information about longevity, reproduction, and growth. This information can be used to design effective fisheries management programs.

Appendix: Classification

Superorder Selachii

Order Hexanchiformes
Family Hexanchidae (cowsharks, six-gill and seven-gill sharks)
Family Chlamydoselachidae (frilled sharks)

Order Squaliformes
Family Squalidae (dogfishes)
Family Echinorhinidae (bramble sharks)
Family Oxynotidae (rough sharks)

Order Pristiophoriformes
Family Pristiophoridae (sawsharks)

Order Squatiniformes
Family Squatinidae (angelsharks)

Order Heterodontiformes
Family Heterodontidae (horn sharks)

Order Orectolobiformes
Family Orectolobidae (wobbegong sharks)
Family Ginglymostomatidae (nurse sharks)
Family Rhincodontidae (whale shark)*
Family Parascylliidae (collared carpet sharks)
Family Brachaeluridae (blind sharks)
Family Hemiscylliidae (bamboo sharks)
Family Stegostomatidae (zebra sharks)

Order Lamniformes
Family Odontaspididae (sand tiger sharks)
Family Mitsukurinidae (goblin shark)
Family Lamnidae (mackerel sharks)
Family Cetorhinidae (basking shark)
Family Alopiidae (thresher sharks)
Family Pseudocarchariidae (crocodile sharks)
Family Megachasmidae (megamouth shark)

Order Carcharhiniformes
Family Scyliorhinidae (catsharks)
Family Proscylliidae (ribbontail catsharks)
Family Pseudotriakidae (false catsharks)
Family Leptochariidae (barbeled houndsharks)

Family Triakidae (smoothhound sharks)
Family Hemigaleidae (weasel sharks)
Family Carcharhinidae (requiem sharks)
Family Sphyrnidae (hammerhead sharks)

Superorder Batoidea

Order Rajiformes
Family Rajidae (skates)
Family Rhinobatidae (guitarfish)

Order Torpediniformes
Family Torpedinidae (electric rays)

Order Pristiformes
Family Pristidae (sawfish)

Order Myliobatiformes.
Family Dasyatidae (stingrays)
Family Myliobatidae (eagle rays)
Family Mobulidae (devil rays)
Family Rhinopteridae (cownosed rays)
Family Urolophidae (round stingrays)
Family Gymnuridae (butterfly rays)
Family Potamotrygonidae (river rays)

*Some sources use the scientific name Rhiniodontidae for the whale shark family, and the genus name Rhiniodon for the whale shark. We chose the names used by the American Fisheries Society, who based their usage on the opinion of the 1984 International Commission on Zoological Nomenclature.

BIBLIOGRAPHY

Budker, Paul. *The Life of Sharks*. New York: Columbia University Press, 1971.

Bunting, Anne Eve. *The Sea World Book of Sharks*. San Diego: Sea World Press, 1979.

Burbank, Jeffrey. "Shark Tales." *Zoo Life* 2(2), Spring 1991, pp. 64-71.

Castro, Jose 1. *The Sharks of North American Waters*. College Station: Texas A & M University Press, 1983.

Chovan, Judith L. and Sara E. Crump. *Sharks. Fact and Fantasy*. Los Angeles: Natural History Museum of Los Angeles County, Education Division, 1990.

Compagno, Leonard J.V. *FAO Species Catalogue, Vol. 4. An Annotated and Illustrated Catalogue of Shark Species Known to Date*. Rome: FAO, 1984.

Compagno, Leonard J.V. *Sharks of the Order Carcharhiniformes*. Princeton: Princeton University Press, 1 988.

Crockett, Jim. *The Great White Shark*. New York: Arch Cape Press, 1989.

Dingerkus, Guido. *The Shark Watchers' Guide*. New York: Julian Messner, 1985.

Ellis, Richard and John E. McCosker. *Great White Shark*. New York: Harper Collins, 1991.

Ferguson, Ava and Gregor Cailliet. *Sharks and Rays of the Pacific Coast.* Monterey, California: Monterey Bay Aquarium, 1990.

Gordon, David G. "The Spiny Dogfish." *Oceans* 19(1), Jan.-Feb. 1986, pp. 56-58.

Gruber, Samuel H., ed. *Discovering Sharks*. Highlands, New Jersey: American Littoral Society, 1991.

Hall, Howard. *Sharks*. San Luis Obispo, California: Blake Publishing, 1990.

Harding, John H. "Return of the Gray Nurse Shark." *Sea Frontiers* 36(4), July-August 1990, pp. 30-33.

MacLeish, William H., ed. *Sharks*. Oceanus 24 (4), Winter 1981/82.

Manire, Charles A. and Samuel H. Gruber. "Many Sharks May be Headed Toward Extinction." *Conservation Biology* 4(1), March 1990, pp. 10-11.

Matthews, Rupert. *How They Live. Sharks*. New York: Mallard Press, 1989.

Moss, Sanford A. *Sharks, an Introduction for the Amateur Naturalist.* Englewood Cliffs, New Jersey: Prentice Hall, Inc., 1984.

Reader's Digest Services. S*harks, Silent Hunters of the Deep*. New York: Reader's Digest, 1986.

Server, Lee. *Sharks*. New York: Crescent Books, 1989.

Springer, Victor G. and Joy P. Gold. *Sharks in Ouestion. The Smithsonian Answer Book*. Washington, D.C.: Smithsonian Institution Press, 1989.

Stafford-Deitsch, Jeremy. *Shark. A Photographer's Story*. San Francisco: Sierra Club Books, 1988.

Steel, Rodney. *Sharks of the World*. New York: Facts on File, Inc., 1985.

Stevens, John D., ed. *Sharks*. New York: Facts on File, Inc., 1987.

Wilson, E.O. "In Praise of Sharks." *Discover* 6(7), July 1985, pp. 40-53.

Wood, Larry. "Megamouth. New Species of Shark." *Sea Frontiers* 32(3), May-June 1986, pp. 192-1 98.

BOOKS FOR YOUNG READERS

Arnold, Caroline. *Watch Out For Sharks!* New York: Clarion Books, 1991.

Behrens, June. *Sharks*. Chicago: Children's Press, 1990.

Blumberg, Rhoda. *Sharks*. New York: Franklin Watts, 1976.

Campbell, Elizabeth. *Fins and Tails, A Story of Strange Fish*. Boston: Little, Brown and Co., 1963.

Carrick, Carol. *Sand Tiger Shark*. New York: Seabury Press, 1976.

Cerullo, Mary. *Sharks-Challengers of the Deep*. New York: Cobblehill Books, 1993.

Coupe, Robert and Sheena Coupe. *Sharks*. New York: Facts on File, Inc., 1990.

Freedman, Russell. *Sharks*. New York: Holiday House, 1985.

George, Jean Craighead. *Shark Beneath the Reef*. New York: Harper Trophy, 1989 (fiction).

Gibbons, Gail. *Sharks*. New York: Holiday House, 1992.

Gustafson, Sarah. *The Shark Dictionary*. New York: Checkerboard Press, 1992.

Maestro, Betsy. *A Sea Full of Sharks*. New York: Scholastic, Inc., 1990.

Mahy, Margaret. *The Great White Man-eating Shark*. New York: Dial Books for Young Readers, 1990 (fiction).

McGovern, Ann. *Sharks*. New York: Fourwinds Press, 1976.

McGowen, Tom. *Album of Sharks*. Chicago: Rand McNally, 1977.

Rabin, Staton. Monster Myths. *The Truth About Water Monsters*. New York: Franklin Watts, 1992.

Riedman, Sarah. *Sharks*. New York: Franklin Watts, 1977.

Spinelli, Eileen. *Sharks*. Children's Nature Library. Lincolnwood, Illinois: Publications International, Ltd., 1991.

Steele, Philip. *Sharks and Other Creatures of the Deep*. New York: Darling Kindersley, Inc., 1991.

Waters, John. Hungry *Sharks*. New York: Thomas Y. Crowell Co., 1973.

Wexo, John Bonnet. *Zoobooks 2. Sharks*. San Diego: Wildlife Education, Ltd., 1986.

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