MFR PAPER 1281

Sharks and Their Utilization

LOUIS J. RONSIVALLI

Blue shark

INTRODUCTION

Of all the creatures in the sea, sharks are the most feared by man. Why shouldn't they be? Some of the large sharks can snap off a man's leg with their powerful jaws—jaws that can exert biting pressures as high as 40,000 pounds per square inch (2,812 kg/cm^2). Accounts of the slaughter, by sharks, of hundreds of people who abandoned sinking ships at sea leave no question as to the shark danger to man. However, one must be reminded constantly that the image denoted by the word "shark" is always that of the potentially dangerous species like the white, blue, mako, tiger, and others and that the notoriety gained by these species is unconsciously attributed to all sharks. Actually, there are many more shark species that are not dangerous to man, and most of these are too small to cause serious injury to a person.

Sharks are a nuisance to fishermen because they can wreck fishing gear with their sharp teeth and sharp denticular scales and because they devour the trapped fish. (To run one's hand across the denticular formation of a shark is like running it across the teeth of a freshly sharpened saw.) On the other hand, sharks represent a source of food, pharmaceuticals, and other useful materials for man, as we shall see later.

Louis J. Ronsivalli is the Director of the Gloucester Laboratory, Northeast Fisheries Center, National Marine Fisheries Service, NOAA, Emerson Avenue, Gloucester, MA 01930.

Much has been written about sharks, and two notions eventually become evident to the reader: 1) If anything can be said for certain about the behavior of sharks, it is that one cannot be too certain about it—they can be completely unpredictable; and 2) if anyone allows himself to get too confident about what to expect from the different species of sharks and tends to get careless in the presence of certain species in particular, he is apt to get an accelerated education about shark behavior, which unfortunately may last him only for a very short time.

DESCRIPTION AND PHYSICAL CHARACTERISTICS OF SHARKS

In the scheme of biological classification, the sharks (of which there are about 300 species) belong to the order Selachii—Phylum: Vertebrata, Subphylum: Pisces, Class: Chondrichthyes, Subclass: Elasmobranchii, Order: Selachii.

Sharks are vertebrates with well developed lower jaws and bony teeth. They have two pairs of appendages supported by the pectoral and pelvic girdles and a cartilaginous skeleton. They have no true bones; however, parts of the skeleton may be stiffened by mineral deposits (e.g., calcium fluorophosphate), such as in the spinal column, resulting in a structure that resembles bone so closely that the distinguishing characteristics can only be identified by microscopic examination. Scales are denticular (toothlike) in structure in that they include the mesoderm[1] as well as the ectoderm[2] in their composition. Sharks have two nostrils, a sympathetic nervous system, a multiple-valve heart, a pancreas, and a spleen, but they lack a swim bladder.

Sharks have 5-7 pairs of gills (most have 5 pairs) that are located laterally or

[1]Mesoderm—the middle layer. In the case of teeth, it is the dentine.

[2]Ectoderm—the outer layer. In the case of teeth, it is the enamel.

nearly laterally, and they have movable eyelids. The dorsal and pectoral fins are rigid, and the anterior edges of the latter are not attached to the head. A few genera are luminescent (e.g., *Isistius*) but the majority are not.

The body fluids of marine teleosts (bony fishes) are less salty than seawater, and since they lose water to the sea through the process of osmosis, it is necessary for them to continually drink seawater and to dispose of the excess salts. On the other hand, the fluids of freshwater teleosts are more salty than the water around them, and they absorb water through osmosis constantly. Thus, freshwater fish do not need to drink water. Sharks contain large amounts of urea which, together with trimethylamine oxide, contribute to a salt concentration in their body fluids which is greater than that in the sea around them. So, as with the freshwater teleost fishes, sharks do not have to drink water since they too obtain water from their surroundings through osmosis.

Sharks are known to exist in a state of commensalism with pilotfish. (Commensalism exists between two organisms when one benefits from the other while the other neither benefits nor suffers from the relationship.) Pilotfish about 2 feet (about 0.6 m) in length, are the beneficiaries in this case as they find a measure of protection by the mere fact that they are near the shark, and they eat from the same prey as does their host. Apparently the pilotfish are skillful enough to avoid the shark's mouth. A symbiotic relationship exists between sharks and the remoras, a class of small fish also about 2 feet (about 0.6 m) in length. (Symbiosis exists between two organisms when each benefits from the other.) In this case, the remora fastens itself to the shark by means of a suction cup and feasts on shark prey, and the shark benefits from the fact that the remora eats parasites on its body.

Shapes

The shapes of sharks vary from that of the streamlined mackerel shark to that of the angel shark which is flat and broad, resembling a ray. Four markedly different outlines are illustrated in Figure 1, with outline A labeled so as to provide information on some of the external gross anatomy of sharks in general. There is no known explanation for the development of the unusual lateral distensions of the head of the "hammerhead sharks," many of which are dangerous to man, and some hammerheads are large enough and aggressive enough to butt and capsize small boats from which they have been harpooned or speared. The eyes of hammerhead sharks are at the ends of the distensions (see Fig. 1) and the nostrils are generally at the outer forecorners. The thresher form (Fig. 1C) shows the extreme enlargement of the upper lobe of the caudal fin. The pectoral fins are also enlarged. Other sharks have intermediate enlargements of these parts. The shape of the angel shark (Fig. 1D) illustrates the ray-like form of some sharks.

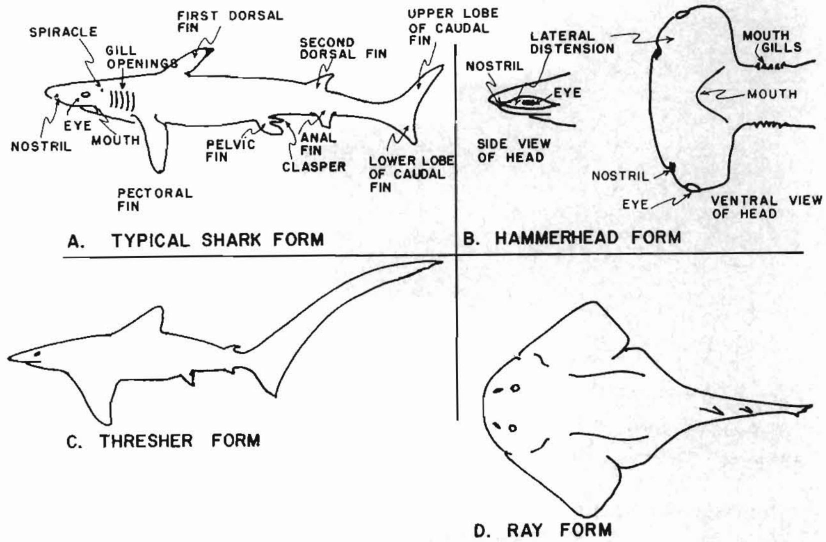


Figure 1.—Outlines of different forms of sharks.

Size and Growth

Shark sizes vary widely. The largest shark, *Rhincodon typus*, commonly called the whale shark, is reported to reach lengths of about 50 feet (about 15 m). The smallest shark, *Squaliolus* can be smaller than 0.5 foot (about 15 cm). In general, adult female sharks are 5 percent longer and 25 percent heavier than adult male sharks. Sharks grow slowly, which suggests that they live a relatively long life. Not enough information has been accumulated to give more details, but in one experiment only a few to 20 inches (51 cm) of growth was noted during a period of 7 years.

Mobility

The mobility of sharks is quite variable. The mackerel sharks, Lamnidae, are fast swimmers, reaching speeds of 40 miles (about 64 km) per hour in short bursts, whereas the Greenland Shark, *Somniosus*, is sluggish and relatively slow. The mako shark, a member of the Lamnidae, is not only a fast, powerful swimmer, but it can leap out of the water covering respectable distances at a leap. Other sharks, including the thresher shark and even the more sluggish basking shark, are capable of leaping out of the water, but the mako shark is a more outstanding and a more spectacular leaper, especially when caught on a fisherman's hook. The only maneuver that a shark is unable to do well is to stop quickly. The reason for this is that its pectoral fins are designed more rigidly than in other fish. The fixed position of the fins is to provide lift while the sharks are in forward motion, much as the flaps on the wings of aircraft provide lift. (In other fish the pectoral fins are movable, and they can be turned to provide a stopping action.) It has been speculated that the unusual head form of the hammerhead sharks acts as a rudder, permitting greater maneuverability.

Body Temperature

Nearly all of the members of Lamnidae maintain body temperatures above that of their environment. Other sharks have body temperatures at or near the temperature of their environment. Pertinent to this situation, it has been shown that the contraction and relaxation of muscle occurs faster as the temperature of the muscle is increased (within limits). Experimental data show that when a muscle is allowed to act for a given period of time at two temperatures that are 18°F (10°C) apart, its activity at the higher temperature is about three times as rapid as its activity at the lower temperature for any given unit of energy supplied to the muscle. However, to maintain warm body temperatures in the cold aquatic environment where heat transfer out of the body could be significant, the body must have an extraordinary ability to retard heat loss. The anatomy of the shark includes the rete mirabile, a network of blood vessels that takes advantage of the principle of counter-current heat exchange which performs this conservation function. In general, sharks can tolerate a wider range of water temperatures than can many of the bony fishes, and this advantage would appear to be related to their ability to control their body temperature.

Relationship Among Body Density, Oxygen Requirement, and Sleep

As sharks have no swim bladder, they cannot decrease their density (which is greater than that of water). Therefore, they must swim constantly to keep from sinking. Their continuous swimming is also necessary, for some sharks, because it is the only way that a constant stream of water can be made to pass through their gills. This is vital to their survival, because they must have the oxygen that is dissolved in the water, and to maintain a sufficient supply of oxygen they must replace the water in their gills continually. Some sharks have spiracles (a hole behind each eye) through which water can enter and pass directly over the gills. These sharks must still swim to keep from sinking, but they can stop and rest on shallow bottoms if they wish since their oxygen supply is not dependent on their motion. Sharks without spiracles are believed to have to swim continuously from birth to death. There are a few reports which indicate that some sharks sleep, but during such periods they are able to pump water through the gills by an apparent automatic mechanism that coincides with sleep.

Sensitivity

Sharks appear to have a low intelligence and to be insensitive to pain. Especially in "frenzied" attacks, they continue their assaults even though retaliatory action is highly injurious or lethal, or even though their attacks bring them in contact with sharp or otherwise injurious materials. Sharks have a keen sense of smell, permitting them to detect substances as dilute as one part per billion. Thus, their olfactory sense, which allows them to detect prey up to several hundred yards away, is a major component of their hunting ability, and at least one genus, *Mustelus,* hunts chiefly by smell.

Sharks have sharp eyes that they can focus and adjust according to available light. There is no evidence to show that sharks can distinguish among colors although they may be attracted to the lighter ones. At close range, eyesight is the most effective sense. While it is generally accepted that their sense of smell is the principal sense that leads sharks to food, a study supported by both the National Science Foundation and the Office of Naval Research (Anonymous, 1964) resulted in convincing evidence that sharks are invariably attracted to the prey by low frequency sounds—7.5 to 100 Hertz (cycles per second)—at distances over 200 yards (about 183 m).

The sounds were made in the absence of any possibility that the sharks could either see or smell the source of the sounds. The sound pulses were varied, allowing two observations: 1) That sharks responded only to low frequency sounds when they were made in bursts. When sound signals were continuous the sharks were not attracted. Prior data showed that struggling and crippled fish emitted low frequency sounds in bursts; therefore it was concluded that sharks are attracted to intermittent bursts of low frequency sounds because they believe these to be the signals to the presence of easy prey. 2) Other fish, such as barracuda, were also attracted to the sounds.

It is believed that the lateral line of sharks is instrumental in their ability to detect a variety of water movements such as might be created by the nearby activities of other marine life. The range of detection does not exceed several hundred feet (1 foot = ca. 0.3 m).

Tiny sensors called pit organs, scattered over the entire surface of the shark, are said to detect changes in salinity and these appear to play a role in regulating the activities of sharks in and near brackish waters. They have small cup-like nerve sensors (called ampullae of Lorenzini) on their noses and along their lateral lines which are reported to be able to detect temperature changes in the water. But more important, it has been determined by experiments that these organs permit sharks to detect other fish through the electric potentials they emit. The ampullae, whose role is not completely understood, exist as subcutaneous nerve centers connected to tiny openings in the surface by canal-like structures containing a gel of low electrical resistance. Supporting evidence for the electrical receptor property of the shark was obtained in experiments in which sharks were able to locate prey which was adequately protected against visual, auditory, and olfactory detection but was not shielded against electrical transmissions. When hidden electrodes were used instead of prey to emit a similar electrical potential, the test sharks attacked the electrodes (apparently convinced that they were attacking a concealed prey). A measure of the sensitivity of these electroreceptors showed that a shark can detect an electrical field of 0.01 microvolt per centimeter (1 centimeter = 0.394 inch). The detection of variations in electric signals among other fishes is promoting speculation among scientists that electroreceptors in fish may be involved in intentional as well as unintentional communications.

Reproduction

Reproduction in sharks involves internal fertilization. The male shark has a pair of grooved copulatory organs called "claspers" that develop as penis-like appendages of the pelvic fin (see Fig. 1A). While the claspers are normally relaxed, they swell and become erect just prior to mating. The erect claspers are inserted into the two sexual orifices in the cloaca of the female. (Often only one clasper is used.) The sperm is guided in by the groove of the clasper(s).

Shark copulation is not simple. The male shark is, as stated above, generally smaller than the female, and he might in some cases end up as food for the female instead of her suitor. At any rate, the male does not have an easy time of it, even though he is equipped with clasper hooks and an array of spurs and spines, in addition to his teeth, that enable him to grab the female and cling to her and then to work himself into position to fertilize her.

In the larger species, the male has an even more difficult time and might not succeed without cooperation from the female. Cooperation may be induced by slashes to the body of the female inflicted by the male. It is during this critical part of the courtship that the female may respond by devouring the male instead of cooperating with him and that the hide of the female is sufficiently damaged as to lower its value for the production of shark leather. Even though the courtship of sharks is obviously dangerous, the propagation of sharks over the many eons of their existence implies that sufficient successful courtships occur.

Sharks vary in their form at birth, and there are three general categories. Oviparous sharks, which include the horn sharks, the cat sharks, and the whale sharks, lay eggs having a tough, leather-like covering and leave them to hatch. Viviparous sharks, which include the hammerhead species, hatch their eggs internally, and, much like mammals, deliver fully formed active pups with placentae. Most sharks, however, are ovoviviparous. In this case the eggs are also hatched internally and the young are fully formed and active, but there is no placental connection between embryos and mother.

Generally the number of offspring produced by sharks and other cartilaginous fishes is relatively small (a few dozen at most) when compared with the number of eggs produced by the bony fishes (up to a few million). However, sharks have a high survival rate since they are born either fully formed and able to fend for themselves, or as eggs they are protected by a tough casing. The survival rate of the offspring of the bony fishes, on the other hand, is very low, since there is a high degree of susceptibility to predation during their early stages of development when they are of relatively tiny size and practically defenseless. Also, because fertilization of cartilaginous fishes is done internally, the probability of fertilizing the eggs is much greater than in the bony fishes where fertilization occurs externally. Generally pups are born in spring to early summer either annually or biennially (depending on the species). The young remain in a nursery area, usually in shallow water, which the adult males do not enter. The adult females leave the nursery area quite soon. Fortunately, the females are not inclined to feed while they are in the nursery area for reason or reasons thus far unexplained; otherwise they might devour the young.

Feeding

Most sharks are carnivorous. Their teeth are razor sharp and numerous, and their jaws are powerful. Some have crushing teeth that enable them to feed on hard-shelled mollusks and crustaceans. The majority of sharks feed on whatever they can get such as small fish, including smaller sharks, squid, and pelagic crustacea. Ironically, the largest species, whale sharks, feeds on minute plankton forms and on small schooling fishes. Sharks have been found to avoid decaying shark flesh. It was once considered that decaying shark might be a good repellent, and further work resulted in the development of "Shark Chaser," which is described later.

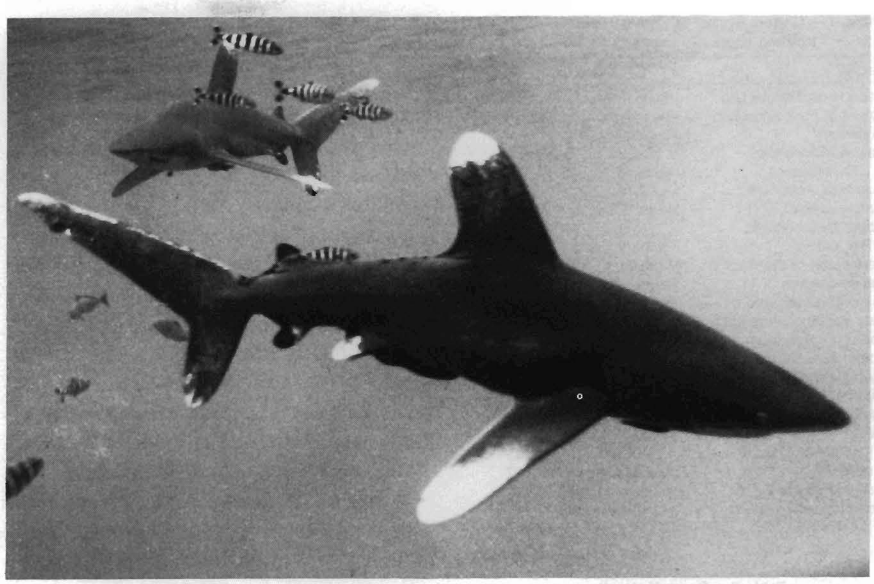
Shark teeth are not set rigidly in the jaws and some are lost from time to time, especially when sharks go into a violent attack pattern in which they tear at steel cables and other hard, tough objects. However, lost teeth are replaced when a row of new teeth from the many rows of replacement teeth with which sharks are endowed takes the place of the old row of teeth. This complete change of teeth occurs quite often—as often as every 2 weeks. Thus, sharks are never without teeth throughout their lives.

The number, size, shape, and set of shark's teeth vary among the different species. One peculiarity reported is that some sharks have protrusible teeth. When a shark having this characteristic opens its mouth to bite, the teeth tilt outward, thus making possible a bite covering a large area and permitting the shark to bite into nearly flat surfaces. As the jaws close to complete the bite, the teeth start to tilt inward, insuring a firm grip on the bite that is being taken.

As the predator of any shark is often a larger shark, it is not unusual to find a hooked shark on a line that has swallowed a smaller shark that was originally hooked to the line or to find a hooked large shark that, in its handicapped position, is ravaged by adjacent sharks. In a feeding frenzy involving large numbers of sharks, some of the feeding sharks are devoured by others. If one species of shark is the dominant predator of the other sharks, it appears that the hammerhead species is in a superior position, and although the reason is not known, it seems to be related to the unique head form (see Fig. 1B).

The feeding of sharks is observed to follow a unique general behavior. It generally starts slowly and gathers momentum, especially as the number of sharks involved increases. Whether hunger is the trigger that starts sharks feeding is not known since they may begin to feed on a full stomach in some cases, and in some cases (males during mating season) will not feed even though they may exhaust nearly all of their liver-stored fats. Some evidence has been obtained which suggests that sharks can detect uneasiness and fear and maybe an odor that emanates as a specific consequence of fear or panic in their prey which motivate them to attack.

Evidently the shark needs to employ most or all of its senses to ascertain the suitability of foods, but sometimes it swallows objects such as bottles, cans, and other debris indicating that it did not wait for proper identification of the food. While indigestible debris often enters the stomach of the shark, it is reportedly easily regurgitated when its accumulation becomes objectionable. There are numerous stories about the odd indigestible items found in the stomachs of sharks, but one of the strangest is a centuries-old account of finding a man encased in armor in a 22-foot shark caught off France.



Whitetipped sharks and pilotfish. (Photo by Reginald M. Gooding.)

OCCURRENCE AND HABITS

Sharks are mainly marine species occurring nearly worldwide, but some species enter brackish waters and even the fresh waters of large rivers. The intrusion of sharks into rivers is not too uncommon; sometimes they swim into the upper reaches of the rivers, and at least one species, *Carcharinus leucas,* otherwise known as the bull shark, is found in Lake Nicaragua, Nicaragua. This lake, over 100 miles long (about 160 km) and nearly 50 miles wide (about 80 km), empties into the Caribbean Sea about 100 miles away (about 160 km) via the Rio San Juan. There has been, and still is, much speculation and controversy as to whether or not the lake shark commutes to the sea. Even though the river has many rapids, it is believed that the sharks which have been seen in the river can easily swim from the sea to the lake. Also, evidence from the gut contents of lake sharks points to excursions by lake sharks to the sea. Pilotfish and remoras that may accompany a shark to a river must abandon their host or perish as neither of these fish can survive in rivers.

Sharks are found in all of the oceans, but the great majority inhabit the tropical and subtropical belts. Only one genus, *Somniosus,* is found in polar seas. Sharks are known to roam the high seas, and some will follow ships to feed in disposed garbage or other marine creatures that might be attracted to the ship's effluents. Most sharks inhabit relatively shallow water; however at least one species, *Centroscymnus coelolepis,* has been reported to go to depths of 1,500 fathoms (9,000 feet or 2,745 m).

Migrating adults usually, but not always, segregate by sex with males favoring cooler, deeper water than the females, but they nearly always segregate by size, except in rare cases. Migrations of sharks seem to be influenced by seasonal temperature changes in the water, but there is some evidence to show that female sharks migrate to specific environments to lay eggs or to give birth to their young. Whether sharks migrate to special mating grounds is not known although this appears to be the case.

The movement of sharks can be determined by a tagging method. To date, more than 10,000 sharks have been tagged by federal scientists and others. The maximum recorded distance to have been traveled by a shark between the point it was tagged (in New England) and the point it was caught (in South America) is 2,070 miles (about 3,330 km). The maximum time elapsed for any tagged shark between the time it was tagged and the time it was recaptured is 7.5 years. The tagging experiments have resulted in the following conclusions:

1. Blue sharks can travel to locations at least 1,000 miles (1,609 km) from any given point within 1 year.
2. Blue sharks and mako sharks follow common migratory routes that are also followed by white marlin and perhaps swordfish.
3. Migratory routes followed by sharks may depend on their size.
4. The growth rate of sharks is slow.

More data on movements as well as on longevity, growth rates, and other important characteristics of sharks are certain to be produced as a result of the tagging experiments now underway.

RELATIONSHIP TO MAN

The objectives in scientific research, especially applied research, are usually relatively important and imply a useful potential for man. Sharks, the object of much applied research, have been studied for their potential as food for man, for their possible nonfood value, for their reputation for attacking man, for the heavy damage they impose on fishing gear, and for their unusual physiological and anatomical characteristics. Some sharks are held in captivity in a number of aquaria throughout

Table 1.—United States facilities reportedly holding sharks in captivity.

Facility	Location
Cape Haze Marine Lab.	Placida, Fla.
Fairmont Park Aquarium	Philadelphia, Pa.
Gulfarium	Fort Walton, Fla.
Hawaii Marine Lab., Univ. Hawaii	Honolulu, Hawaii
Municipal Aquarium	Key West, Fla.
Marine Arena	Madeira Beach, Fla.
Mount Desert Island Bio. Lab.	Salsbury Cove, Maine
Marineland of the Pacific	Marineland, Calif.
Marine Studios	Marineland, Fla.
Miami Seaquarium	Miami, Fla.
New England Aquarium	Boston, Mass.
New York Aquarium	New York City, N.Y.
Ocean Aquarium	Hermosa Beach, Calif.
Shedd Aquarium	Chicago, Ill.
Steinhart Aquarium	San Francisco, Calif.
Theater of the Sea	Islamorada, Fla.
Vaughn Aquarium, Scripps Institute of Oceanography	La Jolla, Calif.
Waikiki Aquarium	Honolulu, Hawaii
Woods Hole Aquarium	Woods Hole, Mass.

the country (Table 1) and considerable information has been gained by observing captive sharks. Scientific study of sharks, however, is carried out in only a few of the facilities listed. Table 2 lists some of the more common sharks and how they relate to man.

Because of the strength and ferocity of sharks, they are among the marine species sought by anglers. The shark species recognized as game for sport fishermen and which are recognized by and listed in the records of the International Game Fish Association are: Blue shark, mako shark, porbeagle, thresher shark, tiger shark, and white shark.

World shark landings are reported to be about 400,000 metric tons per year over the last 5 reporting years, 1969-74. The landings show an increase of more than 25 percent over a period of 9 years, with the greatest increases occurring in the catches from the east central Atlantic and West Indian Oceans. There is not sufficient information about the standing stocks of sharks, but Table 3 suggests that the present catch level can be tolerated without threat of depletion of the stocks. However, it must be remembered that sharks have a slow growth rate, implying that their availability and the economics of fishing for them can be altered relatively easily and that the time for replenishment of the depleted stocks would be so long that it could end the fishery.

Table 2.—Some facts about some common sharks.

Common name(s)	Generic name	Features[1]	Danger rating[2]
Basking	*Cetorhinus maximus*	H,O	R
Blacktip (small)	*Carcharhinus limbatus*	G,L	O
Blacktip (large)	*Carcharhinus maculipinnis*		O
Blue (great)	*Prionace glauca*	G	M
Brown, Sandbar	*Carcharhinus milberti*	L,F	M
Bull, (Lake Nicaragua) Whaler (Zambezi) Ganges	*Carcharhinus leucas*		M
Common thresher, Fox Sea fox, Swingle Tail Thrasher, Whip tail	*Alopias vulpinus*	F,G	R
Dusky	*Carcharhinus obscurus*	L,F	R
Great hammerhead	*Sphyrna mokarran*	O,F	E
Great white	*Carcharodon carcharias*	F	E
Greenland	*Somniosis microcephalus*	P	R
Grey nurse	*Odontaspis arenarius*		
Atlantic sand	*Odontaspis taurus*	L,F	M
Lemon	*Negaprion brevirostris*		O
Mako, Bonito, Atlantic mako, Blue pointer Sharpnosed mackerel	*Isurus oxyrinchus*	G,G	E
Nurse	*Ginglymostoma cirratum*	L,F	E
Porbeagle, Mackerel	*Lamna nasus*	F,G	O
Soupfin	*Galeorhinus zyopterus*	F,O	R
Spiny dogfish	*Squalus acanthias*	F,L	R
Tiger	*Galeocerdo cuvieri*	F,G,L	E
Whale	*Rhincodon typus*		R
Common whaler	*Galeolamna mmacrurus*	L	O
Whitetip	*Carcharhinus longimanus*		M

[1]H = hibernate, G= game fish, F = flesh used for food, L = hide good for leather, O = high oil content, P = flesh is poisonous.
[2]E = extreme danger to man, M = moderate danger, O = occasional danger, R= rare danger.

Table 3.—World landings of sharks 1965-73 (in thousand metric tons).[1]

	Years								
Location	1965	1966	1967	1968	1969	1970	1971	1972	1973
NW. Atlantic	10.3	11.1	7.2	8.3	12.0	7.5	14.8	15.2	20.2
NE. Atlantic	64.2	67.6	78.6	74.8	88.7	78.0	66.3	69.4	69.5
W. C. Atlantic	9.2	9.6	10.1	10.6	9.6	6.8	7.3	7.5	9.6
E. C. Atlantic	9.4	8.7	7.3	11.8	12.8	36.7	42.1	48.2	48.4
Mediterranean and Black Seas	10.3	9.4	16.0	11.3	11.1	6.0	9.6	6.8	6.5
SW. Atlantic	14.4	14.8	22.4	23.3	19.8	18.7	19.1	18.2	22.2
SE. Atlantic	3.6	8.4	6.4	6.3	6.9	6.2	3.9	6.3	6.6
W. Indian Ocean	57.9	73.6	78.2	75.1	81.4	75.8	78.9	110.0	150.7
E. Indian Ocean	27.4	26.0	20.6	24.4	29.2	34.3	31.7	28.8	19.9
NW. Pacific	58.7	62.3	62.1	83.7	79.6	81.2	78.9	45.9	42.8
NE. Pacific	0.9	0.8	0.6	0.6	0.3	0.3	0.1	0.2	5.3
W. C. Pacific	10.7	12.7	10.2	14.6	16.1	17.4	15.5	17.3	7.4
E. C. Pacific	12.7	10.1	12.7	9.9	10.5	13.4	12.3	11.6	15.5
SW. Pacific	9.5	11.0	8.8	3.4	2.8	3.3	4.5	3.5	3.6
SE. Pacific	7.0	8.7	13.0	16.4	10.5	13.1	9.8	8.1	19.6
Totals	306.2	334.8	354.2	374.5	391.3	398.7	394.8	397.0	447.8

[1]From: FAO "Yearbook of fishery statistics—catches and landings, 1973." Vol. 36, 1974, 590 p.

Sharks as Food for Man

The utilization of sharks for human food will probably increase in the future. The world's need for protein is growing at a rate greater than the rate of protein production. The pressure to obtain the protein from the sea is increasing. But many of the popular marine species are overfished and since sharks continue to feed on the already shrinking stocks and continue to cause considerable damage to fishing gear (in order to get to the fish held by the gear), it seems inevitable that fishing effort will have to be directed to sharks in order to reduce both the destruction of fishing gear and the predation on fish held in nets, etc., as much as to increase the harvest of marine protein. The yield of shark meat varies between 20 and 60 percent, depending on a number of factors. The yield varies among species, and generally male sharks yield more edible meat than female sharks of the same size. Females carrying unborn offspring have an even lower yield with about 15 percent of their weights attributable to the embryos within them.

Acceptability of Shark Meat

The organoleptic qualities of shark meat vary, depending to some extent on species. Some species have a relatively good acceptability (e.g., spiny dogfish, *Squalus acanthus*), some species taste similar to tuna, halibut, etc., and shark steaks have been sold as halibut or swordfish steaks. But some species are not as acceptable, with objections being attributed to sour and bitter off-flavors and to the odor of ammonia. The development of off-odors and off-flavors can be prevented by proper handling. Therefore, much of the unacceptability recorded is not due to an inherent poor quality of shark meat, but rather to poor handling practices.

Species of sharks considered to have the best eating qualities are mako[3], thresher, soupfin, mackerel, white, and spiny dogfish. The flavor of the blue shark is considered to be undesirable. The most desirable of the edible meat are the fillets and the flesh from the caudal peduncle, which together make up about 55 percent of the total edible portions. The belly flaps are considered a delicacy by the Germans, and the fins of all sharks have commercial value as food for humans, except for the fins of the nurse shark which contain no edible gelatin. The Norwegians use dogfish eggs as substitutes for hen's eggs in puddings and in other food preparations normally requiring eggs.

There are enough sharks in the world's oceans to permit a much greater harvest than is presently taken, but there are several reasons why the shark fishery is not expanding. A major deterrent is that shark flesh generates large amounts of ammonia when it is stored, due to its unusually high content of urea (amounts as high as 0.12 percent have been reported). It has been demonstrated that the conversion of urea to ammonia is due to ureases (urea splitting enzymes) produced by bacteria: $CO(NH_2)_2 + H_2O$ urease $2NH_3 + CO_2$.

The production of ammonia can be minimized by observing maximum sanitation practices in the handling of shark flesh and by keeping the holding temperatures as low as possible. Lowering the pH of shark meat by the addition of acid, such as citric acid, lemon juice, tomato juice, vinegar, etc., has been demonstrated to be effective in the elimination of the ammonia problem. It has been reported that the addition of acid provides an additional unexpected benefit—it improves the texture of the meat. Experiments have shown that the ammonia problem can be mitigated by washing shark meat with water which apparently removes urea. This suggests that a very effective washing would occur in mechanical deboning of sharks where the meat is obtained in a comminuted form with a corresponding large surface to facilitate the washing. As much as 60 percent of the urea has been removed from shark meat by soaking it in solutions of lactic acid (1.5 percent), or salt (1 percent), or in urease extract. Lactic acid seemed to be most effective. Heating the meat also lowers the urea content. A blanching treatment lowers it by about 10 percent. A heat-sterilizing treatment lowers it by about 30 percent. Urea has been removed successfully from shark meat that was salted by immersing in brine and then desalting. For any use of shark meat which requires soaking, however, it is necessary to blanch it first. Otherwise the soaked meat is reported to acquire an objectionable off-taste.

There may be a relationship between the human fear of sharks as man-eaters and the human resistance to shark meat as food, but in many areas, this relationship does not exist. For example, the English, Italians, Japanese, French, Swedes, Chinese, and others have no qualms about eating shark. It is reported that the English use about 17 million pounds (about 7,700 metric tons) of dogfish per year. They also consume small amounts of several other species of sharks.

The flavor and quality of shark meat and its products depend on effective bleeding of the shark carcass and sanitary handling practices. Bleeding can be done most effectively when it is done immediately after the shark is caught by chopping off the caudal fin. The heart, which will still be pumping, forces the blood out of the severed major artery. Other bleeding techniques, such as puncturing the heart or severing major arteries in other parts of the body, are much less effective. Sharks should then be eviscerated as soon as possible. At the processing plant or in a factory, the fins are generally removed to be used separately. Large sharks (larger than 3 or 4 feet) are generally cut transversely into steaks. Smaller sharks may be filleted. Shark meat is frozen by the same techniques used for freezing the steaks and fillets of other fish. The shark should be handled as little and as quickly as possible to keep quality deterioration to a minimum.

Preservation Methods

Shark meat may be preserved in a number of ways. It has been canned successfully during wartime, even though early attempts at canning were frustrated. While the formation of ammonia in shark meat is generally attributable to the breakdown of urea by bacterial ureases, it may also be formed in canned shark meat due to the heat which degrades the urea to ammonia. The conversion occurs at temperatures as low as 176°F (80°C). At 212°F (100°C), the conversion is quite rapid. The problem was eventually solved with the addition of acid which combined with and neutralized the liberated ammonia. The acceptability of canned shark meat was enhanced when the meat was packed with olive oil and peas (or beans) in a ratio of meat 50 parts, oil 25 parts, and peas 25 parts. The meat was cut in small pieces and blanched prior to packing.

Shark meat can be cured and smoked, and when processed in this manner the adverse contributions are minimized. Small pieces are soaked in water for about 6 hours then pickled in saturated brine for about 2½ days and smoked for about 1½ days. They are then held in trays at room temperature for about 2 weeks by which time the cure is complete.

Shark meat has been used for making sausages but, generally, required the addition of flesh of other species (e.g., hake) to produce an acceptable product. The Japanese prepare a paste-like product from shark meat after it has been separated from the skin and the cartilage and comminuted. Salt and various other spices are added and the paste is then molded into rolls which are steamed over boiling water for 20 minutes. The product, white in color, is considred to be quite acceptable by the Japanese. The Japanese also produce a smoked canned shark meat in soy marinade.

To produce salted dried fillets, sharks are beheaded, eviscerated, and

[3]Mako shark is also called bonito shark.

bled. They are then washed and stored in ice (belly down) until ready for use. Later they are filleted, and the fillets are cleaned of blood spots, skin, etc., and ragged edges are trimmed. The washed fillets are then drained for a few minutes and layered with salt in boxes containing drain holes, taking care that fillets do not overlap without salt between them. The boxes are held in the shade for about 6 days. At the end of this period the fillets are removed and excess salt is brushed off. The fillets are then dried by any of the available methods (tunnel drying, sun drying, etc.). Sun drying, which takes about 1 week, is the least desirable method because this process subjects the product to various types of contamination, and there is no way to control the precipitation, temperature, humidity, etc. Thus, when precipitation occurs or when the humidity is high, the fish, which are generally dried on racks or trays, must be removed to a covered drier area. In tunnel drying and cabinet drying, the product is protected against contamination and there are various conditions that are controllable (temperature, air flow, humidity, etc.), depending on the facilities. When conditions are controllable, the recommended temperature is about 113°F (45°C), and the recommended relative humidity is about 35 percent. Under these conditions, the drying time is much shorter than that required for sun-drying and the quality of the tunnel-dried product is correspondingly better. Del Valle and Nickerson (1968) developed a quick-salting process for shark meat. The process, requiring only simple equipment, produces an acceptable salted product, inexpensively, and has an excellent potential for preserving and making available a high value protein for inhabitants of developing countries where refrigeration is yet scarce. The process involves grinding shark flesh with the simultaneous addition of salt, pressing to remove water, and drying the pressed cakes in air or by other means when available. The dried product is stable without refrigeration, even at tropical temperatures. To prepare for consumption, the salt is leached out by boiling in fresh water 2 or 3 times. The resultant product remains intact and has a meaty flavor.

Shark meat can be cut into fillets or steaks which can be handled as fresh cuts, or they can be frozen. Shark fillets can be used to produce frozen fillet blocks.

The Norwegians, who export sharks, use an effective preservation process that is reported to keep sharks in prime quality for long periods. They cut away the viscera, including the belly flaps, and they pack the fish in an alginate jelly and place them in frozen storage at about 5°F (−15°C).

Fins are preserved by drying, freezing, or salting. To produce lightly salted dried fins, they must be trimmed of all flesh and skin, washed, and held for about 10 hours in a 3 percent salt solution (about ¼ pound of salt for every gallon of water). The fins are then sun-dried on wire mesh in single layers for about 2 weeks. When the drying is completed, the fins will be very stiff. They are then packed in boxes in which they may be shipped or held until shipped.

Composition and Characteristics

Shark meat contains very little fat (as low as 0.1 percent in some species). A few species may have a fat content higher than 6 percent. Generally, shark meat is darker, coarser fibered, tougher, and stronger tasting than the meat of teleosts. The older the sharks, the stronger the taste. Shark meat is reported to be lower in protein value, contains less quantities of some of the essential amino acids, and has less quantities of total free amino acids than the meat of teleosts, and it has unusually high urea (up to 0.12 percent) and trimethylamine oxide (up to 1 percent) contents. Shark meat is more acidic than that of teleost fishes.

A component of shark liver oil is squalene, an unsaturated terpene hydrocarbon having the formula $C_{30}H_{50}$. It comprises the bulk of the unsaponifiable fraction of the liver oil in some sharks, and it was a by-product of the process that produced vitamin A from shark liver oil prior to the advent of synthetic vitamin A. It is noteworthy that squalene was mixed with cheap vegetable oils and used as an inexpensively produced, illegal, substitute for olive oil. The substitution was an excellent and valuable outlet for an otherwise low-value by-product, and it was made possible by the fact that the Food and Drug Administration (FDA) test for olive oil purity was related to the squalene content of the oil. When the practice was later discovered by the FDA it was, of course, terminated.

Some shark meat is poisonous. For instance, the meat of the Greenland shark, *Somniosus microcephalus,* is quite poisonous to both man and animals. Other species reported to be mildly poisonous are the black-tipped sand shark, *Carcharhinus melanopterus,* the seven-gilled shark, *Heptranchias perlo,* and the six-gilled shark, *Hexanchus grisseus.*

Except for the Greenland shark, the flesh of the sharks cited above are not very poisonous and one report indicates that the causative agent may be sufficiently washed away by rinsing the meat several times. Apparently there is considerable danger in eating the livers of these sharks where the concentration of the harmful substance not yet identified must be in more concentrated form.

Symptoms of poisoning from eating shark develop within 30 minutes. They include nausea, vomiting, diarrhea, abdominal pain, headache, aching joints, tingling about the mouth, burning sensation of tongue, throat, and esophagus, and, later, lack of coordination. If the illness is severe enough, there is paralysis, coma, and finally death. Although vitamin A in high concentrations (such as found in shark livers) is toxic, it is not the agent that causes the symptoms cited above.

Harvesting of Sharks

Fishing for sharks must be closely managed; otherwise, the stocks may be depleted even more easily than those of other species. Such a problem has already occurred with the porbeagle, a shark averaging 5 feet (1.53 m) in length and 250 pounds (114 kg) in weight and fished largely for the European market. Thus, controls have been placed on the fishing effort for this species in some areas. Prominent factors that contribute to easy depletion of the stocks are the small number of offspring produced by each female and their slow growth rate. The spiny dogfish has been fished from time to time, especially to minimize its nuisance effect. However, when a market demand was developed and the fishing effort became intense, the stocks were reduced rather quickly.

The village of Maloy in Norway is called the dogfish capitol of the world. From this port about 40 vessels, 70-90 feet (21.5-27.5 m) long, fish for small sharks. The bait is mackerel or herring, the gear is the long line, the hook is size 7. Each vessel carries 80-100 sections of line containing as many as 1,500 hooks. The lines are set through stern chutes and retrieved by hydraulic power, With crews of 8-10 men, these vessels stay at sea for 7-14 days. The fish are iced whole at sea. The gear that is used to catch sharks has to be constructed of very tough materials; ideally it should be made of steel cable or steel chain.

There are five generally accepted methods for fishing sharks with variations to suit different situations:

1) Set gill nets are used inshore. The nets are of webbing 10- or 11-inch (25.5- or 28-cm) stretched mesh, hung 20-30 meshes deep, and 2,000-2,500 feet (610-760 m) long. This length is attained by joining a number of nets. The upper part of the net is held up by uniformly spaced cork floats while the bottom is stretched downwards by lead weights. The amount of stretch imposed is such that three meshes occupy the lateral space of two fully stretched meshes. The net, anchored and marked with a buoy, is pulled aboard the boat once each day or less often, depending on the abundance of fish and the weather. If the net is hauled in much sooner, the catch may not be large enough to warrant the effort. If the net is not hauled in soon enough, the catch may be eaten by fish that are too small to trap and these would include small sharks, hagfishes, etc.

2) Drift gill nets are used in deep offshore waters and they may be strung 50-60 meshes deep. The web is hung so that two meshes occupy the lateral space of one fully stretched mesh, and the length of the net is about three times longer than the set gill net. Because of the extreme stresses placed on the drift gill net during hauling, especially in active or rough seas, the horizontal top line has to be extra strong.

Dogfish shark. (Photo by William L. High.)

3) Otter trawls are used for dogfish. The otter trawl is a cone-shaped net dragged with the large end forward, and the opening is maintained by "doors" which are placed in such a way that the forward motion tends to make them spread apart from each other, thus spreading open the mouth of the net.

4) Harpoons may be used to capture the large sharks.

5) The hook and line method involves the stringing of long lines (up to 2,000 feet (610 m) long) carrying baited hooks set about 12 feet (3.65 m) apart. This form of fishing is now less popular than gillnetting. Some longlining similar to that used for catching tuna may be used to capture medium-sized sharks.

Nonfood Uses of Shark

Sharks have unique characteristics that have promoted their utilization in a variety of nonfood uses which include the production of shark leather, pharmaceuticals, at one time vitamin A, and other miscellaneous uses.

Leather

The skins of many sharks can be processed to produce high quality leathers. In most cases the denticles are removed because their presence makes it very difficult to cut and stitch the leather, but in a few cases the denticles are not removed. However, in the latter case, the sharp denticles must be made dull; otherwise, the consumer would certainly be injured by them. It is when the denticles are left in that the leather is quite skidproof because even though their points are dulled, they still provide a considerable clinging ability. To remove the skin from a shark is said to tire the strongest men and to dull the sharpest knives, and it takes an expert at least 15 minutes to skin a shark. The toughness and wearability of shark skin leather is such that it outlasts steerhides and pigskins by about 100 percent. The tensile strength of shark leather is about 150 percent that of steerhide and pigskin. Because of the high costs of preparing shark skins, only those from the larger sharks (over 5 feet (1.53 m) in length) are used. However, theoretically, the skins of even the smallest sharks can be used when the economics of preparing them are feasible.

The production of leather from shark skins is similar to the process used for other marine fishes as well as marine mammals and land animals. This description will apply to the production of shark leather only, and for a more general description of the processing of hides and skins into leather, the reader is referred to O'Flaherty et al. (1956-1965). For details on the production of shark leathers the reader is referred to Rogers[4] and Kohler[5].

[4]Rogers, A. Sharkskins preparatory to tanning. U.S. patent 1,338,531 (1920). Preserving sharkskins and the like. U.S. patent 1,395,773 (1921). Treating sharkskins and the like. U.S. patent 1,412,968 (1922).

[5]Kohler, T. H. 1925. Tanning and dearmoring fish skins. U.S. patent 1,524,039, January 1927.

School of dogfish sharks. (Photo by William L. High.)

Leather production is a series of steps which includes preparation, tanning, and finishing. The skins of sharks are difficult to preserve because of the structure of their denticular scales which protect microbes lodged among them. The most desirable method for preserving shark skins would seem to be with ionizing radiation since this form of energy could destroy all deteriorative microorganisms no matter how well protected they might be from other preservation treatments. Radiation was demonstrated to preserve animal hides for long periods at room temperatures but its use has not been adopted for this purpose, as far as I know. The preserved skins may be stored until they are to be processed.

To remove the skin from a shark, the tail is cut at about the beginning of the caudal peduncle as the skin over this area is not used. (The fins of sharks are removed first since they can be readily sold as food in a number of overseas markets.) The skin is cut, starting at the holes left by the removal of the dorsal fins, along the backbone from end to end. A cut is then made over the top of the snout. This cut is then continued toward the back along the side of the head in a line just above the gill slits around the pectoral fin and back towards the front in a line that runs under the gill slits and parallel to the line above the gill slits. The cut continues along the lower jaw near, and following, the opening of the mouth where it meets the cut made on the other side of the head. Next the skin is gripped with one hand and pulled as the knife is used with the other hand to cut the skin away from the meat, the first hand continually pulling in a peeling action. An important factor in keeping the peeling time down to a minimum and in producing well-cut hides is the sharpness of the knife. It must be very sharp. However, it is because of this, precisely, that extreme care must be taken if accidental cutting of the skin (which detracts from its value and might even ruin it) is to be avoided. Thus, it is better to cut a little deeper even though this means more meat must be trimmed from the skin than to try to cut a clean skin (with no meat attached to it) and run the risk of cutting the skin.

As soon as the skin is removed from the shark, it must be washed to remove the blood and slime. It is then immersed in a vat containing about 3.5 percent sodium chloride (table salt). The skin is held in the brine 3-8 hours and then the flesh is removed. After fleshing, the skin may be trimmed, if necessary, and then given a final wash. The skins are then layered with salt in piles about 3 feet (0.92 m) high on platforms that are slightly inclined so that all liquid will be drained away from the bottom layers of skins. They should not be placed in the sun. After 4 or 5 days the skins are cured (they should not remain in the pile for longer than 1 week).

Following this, each hide is shaken to remove excess salt. It is then placed flesh side up, sprinkled with new salt, and its edges are folded in to make a square. The square is then made into a roll and tied. The individual bundles are packed in bags of burlap or sisal or in barrels. They are held or shipped to the tannery in this form.

To produce leather from skins, they are soaked to remove salt and/or to rehydrate them (depending on the preservation process used). They are then put in vats containing lime (calcium hydroxide), usually in concentrations such that the weight of the lime is about 10 percent of the weight of the hides. The pH of the solution should be about 12.5. The lime soak is used to loosen the denticles. Sodium sulfate in an amount equal to about 2 percent of the lime (by weight) is also added to enhance the effectiveness of the lime. Several lime treatments (using fresh lime in each case) may be required.

Any flesh that remains on the skins is trimmed off and the skins are then bated. Bating involves the use of proteolytic enzymes to hydrolyze the fibers which enhances swelling of the skin. Since bating acts best at pH 8.5, acid is added to the bating solution in order to lower the pH of the skins to the desired level.

Tanning enables the skins to resist degradation from many environmental conditions as well as from microbes. Because of the unique characteristics of shark skin, it is tanned only by the vegetable tanning process. Vegetable tanning employs the extract of either the bark or of the bark and wood of a variety of trees that include oak and hemlock. This part of the process is carried out in vats and takes 1 or more weeks, depending mainly on the types and physical characteristics of the skins.

After tanning, the skins are lubricated with oils and greases to replace natural fats that were removed in the preparation and tanning processes. This step, called "fat-liquoring," improves the strength, resistance, and flexibility of the skins. The skins may then be dyed using a variety of aniline dyes. The skins are then shaved to the desired thickness and passed between rolls that press out excess water and iron out wrinkles. They are then dried by pasting them on flat surfaces and passing them through drying tunnels. The dyed skins are then given a surface finish either by hand or by machines which may or may not include a glaze.

Brody (1965) quotes an official of the Ocean Leather Corporation[6], a manufacturer of shark leather, as reporting that when the toe part of children's (especially boys') shoes are made of shark skin such shoes do not abrade or scuff as do shoes made of conventional leathers. Since the toe part of the shoes of children receives the most wear, the shark skin shoes last significantly longer than shoes made with conventional leather only.

The skins of the male sharks are preferred to those of female sharks. The reason for this is that the hides of the females usually contain mating scars which at best result in visible imperfections in the leather and at worst result in holes in the leather (see section on Reproduction).

Pharmaceuticals

Sharks have been studied for their pharmaceutical value, and heparin-like compounds have been found in nearly all parts of dogfish (a small shark) that have potencies far in excess of that of commercial heparin, while at the same time the shark compounds cause less undesirable side effects than does heparin. Commercial heparin, a derivative of body tissues, especially the liver, is produced from animals. It is prescribed for individuals who have a tendency to form blood clots.

In the late 1930's the discovery that dogfish liver oil contained about 10 times the amount of vitamin A contained in cod liver oil, followed by the discovery that the liver oil of the soupfin shark contained about 100 times the amount of vitamin A contained in cod liver oil, started a shark-fishing activity of such intensity that it was likened to a gold rush. By 1942 the price of sharks had risen to $1,500 per ton from a price of about $10 per ton in 1938. The oil obtained from the liver of sharks has been used in tanning as well as a source of vitamin A. The value of fish oils as a source of vitamin A has been reduced sharply since the advent of the process for producing synthetic vitamin A in the late 1940's. However, there is a concern among some that the synthetic substitute may be inferior to the fish liver oils because it lacks minerals, amino acids, and possibly other unidentified nutrients. Prior to the changeover to synthetic vitamin A, shark livers sold for as high as $1.50 per pound, depending on the vitamin content. The vitamin A content of shark livers covers a broad range, and the richer oils have been reported to contain up to 340,000 U.S.P. units per gram of oil.

In order to preserve the quality of the liver oil, it must be recovered soon after the sharks are slaughtered. When livers cannot be processed, their quality will diminish unless they are effectively preserved. Held in frozen storage, the livers will retain their good quality for months. Livers may be preserved also by salting (finished concentration to be about 10 percent by weight), by the addition of Formalin (about 0.25 percent by weight), and by other miscellaneous methods, but the freezing preservation is the most effective process for protecting the quality of the livers.

Prior to processing the livers, they must be cleaned of all other material. The livers are then comminuted and this can be accomplished by a variety of machines such as hammermills, disintegraters, choppers, etc. The comminuted livers are then heated in pots, jacketed kettles, or by direct steam injection which renders out the oil which can then be decanted or centrifuged. The oil may also be rendered by hydraulic pressure or under heat and pressure. It may also be recovered through an alkali digestion method or by an enzyme/alkali digestion method (alkali digestion methods are the most popular ones). In most cases a centrifuge is used to separate the oil from the aqueous layer. Once the oil is recovered it must be preserved to retain its quality until it is used. It is best stored in drums with no head space and in a cool area.

The oil must meet stringent physical and chemical specifications. The oil is processed into liver oil capsules or in multiple vitamin capsules containing other vitamins. When the vitamin A of an oil is relatively low, it can be concentrated by the saponification process which carries the vitamin A in the unsaponifiable fraction from which it can be recovered in a concentrated form by solvent extraction and further purification.

In some work conducted when shark liver oil was used as a source of vitamin A, it was observed that the shark liver oil promoted the growth of white blood cells. Although there is no evidence to support the theory that shark liver oil contains an anticancer agent, sharks apparently do not develop tumors of any kind, and this fact continues to generate hopeful interest in finding the reason why sharks are not vulnerable to one of man's most dreaded diseases. In some work conducted by John Heller, Executive Director of the New England Institute for Medical Research in Ridgefield, Conn., shark liver extract was reportedly used successfully to treat cancer in mice, rats, and chickens. It is suggested by some researchers that sharks are immune to other diseases as well as to cancer and that they do not show old age weaknesses. In one study the addition of antibodies from shark blood to a growth medium inhibited the growth of a variety of microorganisms that cause diseases in man.

Miscellaneous Uses

Sharks have other miscellaneous uses. The teeth of sharks have been used for producing novelty items, knives, shark tooth gauntlets, as well as other weapons of defense. Because the scales on shark skins are hard, sharp, and close together, shark skins have been used in the past by wood-workers for abrading wood. However, this use is neither economical nor practical in light of the modern effective sandpapers available today. Shark skins have been used to polish marble. Because of the nonskid property of shark leather, it was used for making sword hilts to insure retention of possession of the sword for its owner. This property has been used to produce pickpocket-proof wallets. The use of urea in shark meat

[6]Reference to trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

has been considered as a feed component for farm animals. Ruminants such as cattle and sheep can utilize the urea in sharks in limited amounts (less than 0.025 percent). Even chicks have been reported to utilize urea; however a protein deficiency might result without an added protein supplement.

Danger to Man

The danger of sharks to man is real although it may not be as prodigious as their notoriety would imply. Most sharks are too small, too sluggish, or are just not that dangerous. However, some species (e.g., white shark and tiger shark) are large enough, fast enough, powerful enough, and aggressive enough to be extremely dangerous to man. About 35 species of sharks are considered to be potentially dangerous to man so it is not unreasonable to find that there are about 50 cases of shark attacks on people reported annually of which less than 50 percent are fatal. One can only guess at the number of shark attacks that are not reported. Shark attacks occur more frequently in warm waters than in cold waters and seem to occur more often at night than during daylight. The reason for the former is that the dangerous species are natural inhabitants of warm waters. The reason for the latter may be due to higher nocturnal activities of sharks or the inability of many to sight sharks at night, or both. It is relevant to note, however, that in a study of shark behavior, it was observed the sharks in one area migrated to offshore during the day and came close to shore during the night where they remained until daybreak. This pattern was observed over a number of days and nights. The pattern indicated that the sharks had set up a territory that ranged from inshore to offshore. It is suggested by some that the reason for at least some shark attacks on man are due to the territorial jealousy of sharks that makes them interpret man's presence as a threat to their waters. This concept is believed to be supported by the fact that when bathing beaches are protected by entrapment nets, the number of sharks trapped is reduced with time, until eventually there are no sharks caught. There seems to be no doubt that the presence of blood incites sharks to ferocious attacks on any object near the blood, at any time, day or night.

The damage inflicted by sharks is not limited to their numerous sharp teeth, powerful jaws, and, in some cases, spikes. The sharp denticles on their skin can also inflict considerable damage on bare skin. The great shark scare during the first 12 days of July in 1916 off the New Jersey coast was not just a scare. It cost the coastal cities about $1 million in cancelled reservations as well as the lives of several citizens that were killed by sharks on New Jersey beaches. In at least one of these cases, both the tibia and fibula (leg bones) were actually snapped off below the knee, giving proof the awesome crushing power of the jaws of the shark. It was concluded that white sharks were involved since one of them, which was later caught in the general area of the attacks, contained parts of human anatomy in its stomach. In 1959, California suffered a similar shark scare in which again several people were killed. Again white sharks were involved.

The most devastating shark attacks on man have occurred when large vessels have been sunk in shark-infested waters. In some of these cases, the number of people killed by sharks have numbered in the hundreds. In the sinking of the U.S. cruiser *Indianapolis,* during World War II, nearly a thousand men were lost at sea. Although the toll taken by sharks is not known exactly, nearly 100 shark-mutilated bodies were later recovered. In the sinking of troopship *Nova Scotia,* in the same war, about 1,000 men were lost, and in this tragedy many bodies were recovered, still in their life jackets, but without legs. Sharks apparently attack the limbs because they appear easier to sever than the torso. Yet, there are a large number of reports that sharks were discouraged by different actions taken by potential victims. The accounts do not enable one to arrive at any pattern that could be used to defend against sharks, but nude persons are more readily attacked than clothed persons.

There seems to be no conclusive evidence that sharks attack those that emanate fear signals, although some incidents might suggest this. On the other hand, it has been observed that when a shark closes in on a group of bathers, it generally selects one and continues to attack his selected victim in spite of the presence and even the actions of the others. This may only seem so, since blood, usually drawn at the first attack even if made randomly, would then attract the shark to the bleeding person. There is evidence to suggest that sharks attack light-skinned people more readily than they attack dark-skinned people. When all factors, clues, facts, etc., are analyzed and evaluated, we can only conclude that shark behavior and motivation are unpredictable, and sharks just cannot be ignored if there is any chance that they may be near bathers. The term "rogue shark" has been used in the literature. A rogue shark is a lone hunter who usually has attacked at least one human being and has the inclination to attack others.

The military, especially, has been interested in sharks because of the hazard to downed flyers and to naval personnel that either accidentally or by necessity must spend time in the water without the protection of any type of vessel. Until World War II, the danger of sharks to man was not fully appreciated, but following unexpected losses of Navy personnel to sharks, the U.S. Navy became concerned and launched research to find shark repellents.

In 1944, the Navy disclosed "Shark Chaser," a water-soluble cake consisting of black dye (about 80 percent) and copper acetate (about 20 percent). The purpose of the dye was to obscure man from sharks and the copper acetate was found to repel sharks in initial experiments. In subsequent uses of shark chaser, it was found to work sometimes, but not always. It is not considered effective against the white shark, nor is it effective when shark activity is aroused. Some experiments showed that human sweat repelled sharks, but not reliably. Of the many shark repellents and shark barriers tested, none have been proven 100 percent effective. Injections of numerous poisons, enough to kill large animals, did not kill sharks. Only strychnine was effective, but since the sharks took up to 30 seconds to respond, the question is how much damage can a shark do in 30 seconds?

The most effective barrier at beaches is believed to be wire mesh. For protection of humans in the ocean, an opaque inflatable bag is believed to be effective. The device keeps the person at the surface while at the same time he cannot be seen or smelled by sharks. However, bags have been bitten by sharks and the effectiveness of the bags as protection against sharks is yet to be determined. "Kevlor", a synthetic bullet-proof fabric manufactured by the DuPont Company, has been demonstrated to be effective against tearing by sharks. This is still under study.

The only truly effective protection for humans is the cage. Made of steel bars, it is used to enclose those engaged in underwater photography, etc. A new and promising repelling device called "the Hicks repeller" produces pulsed electromagnetic fields that are said to cause sharks such unbearable annoyance that they move quickly away from the repeller. Although the device emits explosive sounds, its effectiveness is believed to be due to the electrical effect on the ampullae which is described, literally, as a nervous breakdown.

A most promising repellent reported in the literature to date is a naturally occurring one. It is a highly lethal milky toxin secreted from surface glands along the dorsal and anal fins of a small flatfish, *Pardachirus marmoratus,* that inhabits the Red Sea. It is called the "Moses sole" by the Israelis who find it to be good eating. Since the fish is cooked prior to consumption, its toxin is presumably destroyed by heat. In experiments conducted by Clark (1974), sharks that attempt to devour this flatfish seem to undergo an immediate paralysis of the jaw in the open position because the observer reported that the attacking shark did not close its mouth even after it had retreated from its prey. Repeated experiments produced the same results—in no case was the little fish in any danger. This apparent shark repellent is so powerful that even in very dilute amounts it kills small marine animals. Laboratory studies of its action indicated that the toxin appears to attack the nerves and, in addition, it destroys red blood cells.

Of the weapons used to kill sharks, the most desirable one seems to be the carbon dioxide dart gun. By this means, the shark is killed and inflated with carbon dioxide gas which floats the shark to the surface where it can be seen and taken out of the water if it is advantageous to do so. An additional feature to this weapon is that it does not shed blood. This is important when there are other sharks in the vicinity since the presence of blood in the water incites them to violent attacks. Other effective weapons are "death needles" loaded with strychnine and the "powerhead", a device to be used like a hammer which fires a 12-gauge shotgun shell, usually to the shark's brain.

The American Institute of Biological Sciences maintains a Shark Research Panel that records information relative to shark attacks on man and defenses against shark attacks and promotes research to broaden the information base on sharks.

LITERATURE CITED

Anonymous. 1964. Sharks. Comm. Fish. Rev. 26 (12):59-60.
Brody, J. 1965. Fishery by-products technology. Avi Publ. Co., Westport, Conn., 232 p.
Clark E. 1974. The Red Sea's sharkproof fish. Natl. Geogr. Mag. 146:718-727.
Del Valle, F. R., and J. T. R. Nickerson. 1968. A quick-salting process for fish. 1. Evolution of the process. Food Technol. 22(8):104-106.
O'Flaherty, F., W. T. Roddy, and R. M. Lollar (editors). 1956-65. The chemistry and technology of leather. Vols. 1-4. Reinhold Publ. Corp., N.Y.

REFERENCES

Anglo-American Caribbean Commission. 1945. Guide to commercial shark fishing in the Caribbean area. U.S. Fish Wildl. Serv., Fish. Leafl. 135, 149 p.
Anonymous. 1957. The shark fishing industry. Ocean Leather Corp., Newark, N.J., 15 p.
Bigelow, H. B., and W. C. Schroeder. 1948. Fishes of the western North Atlantic, Part One, 576 p. Sears Foundation for Marine Research, Yale Univ., New Haven, Conn.
Budker, P. 1971. The life of sharks. Columbia Univ. Press, N.Y., 222 p.
Bullock, T. H. 1973. Seeing the world through a new sense: Electroreception in fish. Am. Sci. 61:316-325.
Butler, C. 1955. The fish liver oil industry. U.S. Fish Wildl. Serv., Fish. Leafl. 233, 104 p.
Casey, J. G. 1964. Angler's guide to sharks of the northeastern United States, Maine to Chesapeake Bay. U.S. Fish Wildl. Serv., Circ. 179, 32 p.
Cousteau, J., and P. Cousteau. 1970. The shark. Doubleday & Co., Inc., Garden City, N.Y., 277 p.
Gilbert, P. W. (editor). 1963. Sharks and survival. D. C. Heath Co., Boston, 578 p.
________, R. F. Mathewson, and D. P. Rall (editors). 1967. Sharks, skates, and rays. John Hopkins Press, Baltimore, 624 p.
________, L. P. Schultz, and S. Springer. 1960. Shark attacks during 1959. Science (Wash., D.C.) 132:323-326.
Gordievskaya, V. S. 1971. Shark flesh in the food industry. Pacific Scientific Research Institute of Marine Fisheries and Oceanograph (TINRO), Vladivostok, Russia, 26 p. (Transl. from Russ. by Isr. Prog. Sci. Transl., Jerusalem, 1973.)
Halstead, B. W. 1959. Dangerous marine animals. Cornell Maritime Press, Cambridge, Md., 146 p.
Holmsen, A. A. 1968. Harvesting and processing dogfish. Univ. Rhode Island, Dep. Food Resour. Econ., Occas. pap. 68-275, 19 p.
Jensen, A. C. 1965. Life history of the spiny dogfish. U.S. Fish Wildl. Serv., Fish. Bull. 65:527-554.
Lineweaver, T. H., III, and R. H. Backus. 1970. The natural history of sharks. J. B. Lippincott Co., Philadelphia, 256 p.
McCormick, H. W., T. Allen, and W. E. Young. 1963. Shadows in the sea. Chilton Book Co., Philadelphia, 415 p.
Myrberg, A. A., Jr. 1970. The behavior and sensory physiology of sharks. Univ. Miami, Rosenstiel School of Marine and Atmospheric Sciences, Miami, Fla., 19 p.
Osterhaug, K. L. 1961. A literature review on possible uses for dogfish. U.S. Fish Wildl. Serv., Tech. Leafl. 16, 43 p.
Pope, P. 1973. A dictionary of sharks. Great Outdoors Publ. Co., St. Petersburg, Fla., 88 p.
Roedel, P., and W. E. Ripley. 1950. California sharks and rays. Calif. Div. Fish Game, Fish. Bull. 75, 88 p.
Thomson, J. R., and S. Springer. 1965. Sharks, skates, ray, and chimaeras. U.S. Fish Wildl. Serv., Circ. 228, 18 p.
Tressler, D. K., and J. M. W. Lemon. 1951. Marine products of commerce, 2d ed. Reinhold Publ. Corp., N.Y., 782 p.
Wagner, M. H. 1966. Shark fishing gear: A historical review. U.S. Fish Wildl. Serv., Circ. 238, 14 p.

MFR Paper 1281. From Marine Fisheries Review, *Vol. 40, No. 2, February 1978. Copies of this paper, in limited numbers, are available from D822, User Services Branch, Environmental Science Information Center, NOAA, Rockville, MD 20852. Copies of* Marine Fisheries Review *are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 for $1.10 each.*