The delicate constitution of sharks.

by Jane Ellen Stevens

Marine biologists continue to design systems that will support the growth of sharks in captivity. However, the sensitive constitution of sharks has posed major problems for curators, despite their efforts to create a perfect environment for the creatures.

Prospects for keeping the finicky beasts alive in aquaria have improved greatly, but some still do not survive

When Ian Gordon watched a great white shark glide through the tank at OceanWorld in Sydney, Australia, he was ecstatic. For the first time in history, a great white shark (Carcharodon carcharias) had been caught and transported to an aquarium without severe trauma. He bragged to his fellow shark curators that he would be the first in the world to keep a great white--"the Holy Grail" of curators--alive and well in captivity.

Five days later, after the shark had begun slamming into aquarium walls, Gordon sadly released it back into the ocean. And OceanWorld joined aquaria around the world that have tried and failed dozens of times over the last 25 years to keep great white sharks.

The episode last November was testimony to a paradox, says John McCosker, director of the Steinhart Aquarium in San Francisco. "Although sharks are very difficult to kill, in captivity many are just big babies," he says.

Sharks, it seems, have very delicate constitutions. And great whites--the most fearsome beasts in the seven seas--are probably the most delicate of all.

More temperamental than tropical fish, sharks of various species in aquaria today are pampered with the obsequious care more suited to divas of the opera than to cold-blooded predators with a steely reputation for mindless, savage attacks on humans. Feeding frenzies are a thing of the past in modern aquaria such as Sea World (Orlando, Florida) and those in Monterey Bay (California) and Baltimore (Maryland). Attendants quietly hand-feed the large sharks small fish one at a time. The sharks' food is stuffed with specially formulated vitamin pills. The sharks' consumption is carefully recorded and monitored so that they do not become too fat or too thin.

The sharks live in enormous tanks--half a million gallons or more--designed to permit them to carry out their unique swim-glide pattern. The seawater in which sharks live must be the correct temperature, proper salinity, carefully filtered to prevent disease, and, if artificial, the proper chemical formula. Lights must be dim. Electrical hot spots must be eliminated and noisy pumps muted.

With modern care, most aquaria can handle any of at least two dozen species of the approximately 375 species of sharks in the world. The whale shark (Rhiniodon typus) is the largest species successfully handled in captivity. But many desirable species remain elusive.

Designing with physiology in mind

The last 15 years have been the age of aquaria, says Robert Hueter, director of the Center for Shark Research at Mote Marine Laboratory in Sarasota, Florida. "Much more money--$50 million to $100 million--was funneled into the construction of aquaria around the world," he notes. "Better water treatment and space gives you a head start on keeping large sharks healthy."

Determining the perfect environment for captivity came after years of trial and error by curators and from researchers' experiments on shark anatomy and physiology. In the learning process, aquaria curators lost hundreds of sharks. Animals disoriented by sound and an abundance of electrical signals rammed the sides of tanks in a slow suicide. Others lost the ability to swim and rolled over dead. Twenty-five years ago, the average captive life-span of large sharks--those five feet long and up--was just two years.

"No one was doing a good job keeping them," said Frank Murru, the director of animal service for Sea World in Orlando. "Over the last 10 to 15 years ago, we've learned what makes a shark tick in terms of behavior and physiology, and we began to create habitats specifically designed for large sharks."

Shark tanks were redesigned when the relationship between large sharks' lengthy swim-glide pattern and their livers was understood. Unlike bony fishes, sharks do not have air bladders to give them buoyancy. Slightly heavier than water, they rely on their pectoral fins and large livers filled with oil to give them lift. The liver of a large shark can weigh 200 pounds and yield 18 gallons of oil. This liver oil also provides sharks with energy. Curators discovered that some species of large sharks that lived in small rectangular tanks spent so much energy thrashing their way out of the corners of small rectangular aquaria that they consumed their livers. They lost their ballast, thus their ability to swim, and died.

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To prevent such problems, the aquarium at Camden, New Jersey, built a 750,000-gallon tank with 90 feet of straight swimming room. Okinawa, Japan, built a six-million gallon tank. The 600,000-gallon large shark tank at Sea World in Orlando was designed in a modified hour-glass shape with no 90-degree angles so that the animals are not caught in corners. In that special tank, the sharks are forced to change their swim direction, moving left as well as right, a pattern that some curators think helps some species of sharks from losing their sense of balance--a problem that seems to result from swimming in free direction for too long.

To prevent stress and to simulate the night conditions under which most sharks are active, aquaria also now keep tanks dim. The keen eyesight of sharks had, until recently, been underappreciated.

Although sharks look as if they stare blindly into the ocean’s depths, researchers found that their eyes are much like any other vertebrate, with a lens, retina, and pupil that opens and closes quite rapidly. The great number of light-sensitive rods enable most species of sharks to distinguish a moving object in dim light. Like cats, their eyes contain a tapetum lucidum, a layer of cells under the retina that reflects light like a mirror back onto the rods to enable them to see while they feed at night. In bright light, a layer of pigment cells blocks light from reaching the tapetum lucidum.

In the late 1970s, scientists also began to appreciate sharks’ sensitivity to electric fields, a factor that must be carefully controlled in captivity. A. J. Kalmijn started testing the sensitivity of bottom-feeding dusky smoothhound sharks (Mustelus canis) to electrodes placed in the sands off Cape Cod. He found that within the frequency range of direct current up to approximately eight hertz (cycles per second), sharks respond to fields of voltage gradients as low as a hundred-millionth of a volt per centimeter.

Kalmijm estimated shark sensitivity to be equivalent to the field of a flashlight battery connected to electrodes spaced 1000 miles apart in the ocean. The sharks are sensitive enough to detect changes in the earth’s magnetic field as they swim from one area to another. (The earth’s magnetic field changes, along contours, geographically.) In fact, in the 1980s, Peter Klimley, a marine animal behaviorist at the Bodega Marine Laboratory at the University of California, Davis, deduced that hammerhead sharks (Sphyrna lewini) use the magnetic field of the earth to navigate.

Sharks detect electrical fields with organs called ampullae of Lorenzini, bulbous canals connected to nerve endings beneath the skin. The canals emerge in pores on the snouts of sharks. With their additional electrical sensors in the lateralis system, which extends from the head down the sides of their bodies, sharks can detect the weak electrical fields generated by wounds and heartbeats from dozens of feet away. Combine this trait with their sensitive ears that can pick up low-frequency sounds from great distances, and you have a creature that is an easy mark for a nervous breakdown in a tank equipped with noisy pumps, surrounded by people bumping into glass walls, and filled with electrical signals from motors and electrical wiring.

Even a few drops of leaking salt water creating a spot of rust in a tank wall may emit enough of an electrical signal to "drive a shark nuts," says McCosker. "It would be like you or me living at a rock concert day in and day out and screaming, ’Is our keeper deaf?’"

To keep noise at a minimum, some aquaria use people movers to carry spectators in a fiberglass tunnel through the tank, and aquaria staff enforce good visitor behavior. All electrical outlets and wires are insulated and isolated so that no leaks can penetrate the tank. Above the tank, where the shark attendants stuff the week’s vitamins into the gills of mackerel and squid before they hand-feed the sharks, the room is as quiet as a morgue.

Reeling in big fish

Keeping sharks in captivity involves more than redesigning tanks. Curators discovered that many species of large sharks go into shock when they are captured. Although many species of sharks do not need to swim to breathe, those that do suffocate in nets. Some that survive capture, die while being transported to an aquarium, and others have difficulty making the transition to a new environment.

By combining empirical and scientific data, curators and scientists have isolated several steps in the process of capturing a shark and keeping it in captivity, says Hueter. Most species must be caught gently with a hook and line instead of a net to prevent them from going into shock from stress or from suffocating. They must be handled carefully and kept in a horizontal position so that their organs, which are not well attached, do not fall out of their mouths. Some species must be transported from the ocean to an aquarium’s tank as quickly as possible in an environment that mimics, as closely as possible, their own.

"You can lose some species very rapidly, in minutes," says Hueter. "Hammerheads are very sensitive. Nurse sharks [Ginglymostoma cirratum], on the other hand, are ridiculously easy--you can almost put them into a rolled-up wet newspaper and they’ll survive."

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Some sharks are immediately given an intravenous drip of sodium bicarbonate in their caudal artery to buffer the lactic acid they dump into their blood streams when they are under stress. They are placed in special high-tech tanks that pump super-oxygenated, filtered seawater over their gills. If they are still in bad shape when they arrive at an aquarium, they are placed into a small hospital tank.

"We treat them like a triage patient," says McCosker. "We've designed a shark brassiere that fits over their pectoral fins and is attached to a harness with elastic bungees so the shark can swim in place." Then oxygenated water can be pumped over its gills, an IV put in its fin, and shots of antibiotics or steroids can be administered without injuring the shark or its attendants.

In adapting the sharks to captivity, says Mike Shaw, curator of fishes at Sea World in San Diego, aquaria staff have learned that "sharks are a very diverse group of animals. The difference between some species of sharks is like the difference between a bat and an elephant."

"Each species has its own swim patterns and behavior," says Marsha Englebrecht, curator at Marine World Africa/USA in Vallejo, California. "And within each species, you have individual animals that seem more outgoing, or shyer, to put it in human terms."

A bamboo shark spends most of its life lying quietly on the bottom, while a brown shark needs a roomy tank in which to swim continually to breathe and stay alive. Murru learned that tiger sharks tend to be loners when one captured by Sea World cowered against the walls or knocked itself out against the glass and walls trying to get out of the way of smaller sharks of other species. At Disneyworld in Orlando, a tiger shark that lives nearly a solitary life is doing quite well, he says. Hammerheads like to hang out with each other. In some tanks, lemon sharks (Negaprion brevirostris) get along fine with blacktip reef sharks (Carcharhinus melanopterus). In others, they bite them in half.

Today, shark curators point with pride to species that were rare in captivity ten years ago: sleek, beautiful blacktip reef sharks in nearly every aquaria; scalloped hammerheads at Sea World in San Antonio, Texas; massive whale sharks in Okinawa, Japan; and a tiger shark at Disneyworld, in Orlando, Florida. And they boast of sharks that have lived in captivity for eight, nine, even a dozen years. In addition, many species--including brown, sandtiger (Eugomphodus taurus), lemon, and blacktip reef--have reproduced in captivity.

Curators have been able to set up breeding programs for some species, such as bonnetheads (Sphyrna tiburo), to distribute to other aquaria, and have begun long-term hormonal studies in others, such as lemon sharks, to unravel basic reproductive mysteries, including when the animals become sexually mature. They have conducted physiological studies, such as collecting blood samples and charting growth rates, to establish base-line data on healthy sharks for diagnostic purposes. "Twelve years ago, when we took a blood sample, we had no idea what it meant," says Murru. "Now, we have a good picture and can treat them if we see something wrong."

Aquaria curators work closely with scientists who study the large captive sharks' reproductive physiology, growth rates, hematology, behavior, and other areas that contribute to the general understanding about sharks. This knowledge also helps fisheries regulators to make decisions about catches of sharks, whose stocks have been sorely depleted. Murru says that it was not known how long it took for bull sharks to become sexually mature, for example, until observations in captivity determined it was approximately seven years.

The ones that get away

Talk to curators about free-ranging mako (Isurus paucus) and blue sharks (Prionace glauca), however, and they go back to describing life-and-death struggles. Great white sharks make curators toss up their hands in exasperation.

Nobody knows why no great white sharks have survived in captivity, and Gordon's attempt just added to the puzzle. Shark experts speculate that, like other temperamental shark species, great whites must be caught on specially designed hook and line, must be captured relatively close to an aquarium, and should be placed in a large, cold-water tank without electrical fields. Gordon met the first two requirements. "Nobody's put all three things together," says Jerry Goldsmith, director of San Diego Sea World's aquarium department.

Most great white sharks that have ended up in aquaria have been caught in gill nets that stop the shark from swimming, and, thus, breathing; most are half-dead by the time they are put in a tank. They need colder water--probably no warmer than 60 [degrees] F--than most aquaria can provide. Because they regulate their body temperatures to be warmer than most species of sharks, they probably need more food. Because they are probably the most sensitive of all the sharks to electrical signals, some scientists speculate that the only way they will survive is in a giant glass bowl.

The attempt to keep the great white shark at OceanWorld probably failed because of the tank. McCosker says, "OceanWorld is an old aquarium. It's got rock piles, electrical fields. It wasn't a good tank."

Great white sharks will probably be more comfortable in tanks that are well lit because their retinas contain a higher density of cones, used for daytime vision, and they have fewer rods than do sharks that feed mostly at night. Great whites feed mostly during the day, on seals and sea lions, which are active during daylight hours, notes Klimley.

Some scientists speculate that parts of shark anatomy and physiology that are not understood may have some impact on the ability of great whites to live in captivity. Tiny ducts on the shark's ear, called endolymphatic ducts, extend from the ear sacculus to small openings on the shark's head. The function of the ducts are unknown. The function of another sensory system--pit organs on the body and lower jaws--is also unknown. Another mystery is how the great white's basic genetic programming impels it to range widely, a factor that may affect its ability to live in captivity. "We know from other free-ranging sharks, especially those that migrate hundreds or thousands of miles, that after a while, they begin to look for a way out of the tank, no matter how large it is, and they stop eating," says Hueter.

The impetus to capture and keep a great white shark in captivity comes, in part, from curators who know that such a specimen will attract crowds of paying customers. It also comes from biologists who want to demystify the animal so that it will not be killed after every popular movie that depicts great white sharks as crazed, out-of-control killers. After the movie "Jaws" came out, fishermen in California and South Africa nearly wiped out local great white shark populations.

During six years of studying great white sharks at the South Farallon Islands, the best pinniped feeding grounds on the West Coast, Klimley identified only a dozen individual sharks and estimated that another dozen were in the area. Although little is known about great white shark reproduction, scientists estimate that females do not become sexually mature until they are 12 to 14 years old, and then they give birth every second or third year to only a few young. "The threats posed to the shark by people--a few attacks worldwide each year, most of them nonlethal," notes Klimley, "may turn out to be small in comparison to the threat people pose to the shark."

Most shark curators and scientists agree, however, that before any aquaria will be successful in keeping a great white shark, more needs to be learned about the species--its swimming characteristics, electrical sensitivity, and preferred light, depth, and temperature levels. As with any shark, says David Powell, director of the department of husbandry at the Monterey Bay Aquarium, "we've got to try and duplicate what we see them doing in the wild."

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