The Origins and Rise of Shark Biology in the 20th Century

JOSÉ I. CASTRO

Introduction

Historically, the knowledge of sharks (Elasmobranchii) has always lagged far behind the knowledge of bony fishes and other vertebrates. Several factors made sharks difficult to study. First, they are fast moving and far-ranging fishes in a vast marine environment, and the technology for studying such free-roaming aquatic animals did not exist. Second, it was difficult to obtain study specimens, owing to the historical lack of shark fisheries caused by their low commercial value. Third, the often large size of sharks made it difficult to preserve museum or reference specimens. Fourth, ichthyologists had a general lack of scientific interest in cartilaginous fishes, and few people studied sharks. Consequently, sharks long remained a poorly known group. This paper examines the origins of shark biology and the factors that combined in the second half of the twentieth century to 1) spark interest in sharks, 2) make shark research feasible, and 3) engender shark biology and conservation.

In general, comprehensive biological studies of animal species require both the anatomical examination of sufficient numbers of specimens to understand their adaptations and field studies to reveal the animal's behavior and habits. Over the centuries, most knowledge of animals was obtained through anatomical examination. Field observations of animal behavior were difficult or seldom feasible.

In the case of sharks, biological information could only be obtained through anatomical examination (necropsies) and from the analysis of limited capture or fishery data. In necropsies, stomach contents revealed the diet, and sometimes, by inference, behavioral or feeding patterns; examination of the reproductive tracts could reveal the mode of reproduction, reproductive cycle, gestation period, etc.

Observation and the application of the dictum of "Form follows function" often yielded an understanding of the animal. Analysis of capture data yielded depth and temperature preferences, migrations, nursery areas, etc. But because of the lack of fisheries, these data were scarce, so the biology of sharks remained a mystery.

José I. Castro is with the Protected Resources Division, Southeast Fisheries Science Center, National Marine Fisheries Service, NOAA, 263 13th Ave. South, St. Petersburg, FL 33701 (jose.castro@noaa.gov). The views and opinions expressed or implied are those of the author and do not necessarily reflect the position of the National Marine Fisheries Service, NOAA.

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ABSTRACT—Historically, the knowledge of sharks (Elasmobranchii) has always lagged far behind the knowledge of bony fishes and other vertebrates. In the 1950's, only a handful of researchers were working with or studying sharks. But, in the second half of the 20th century, four factors combined to spark interest in sharks, make shark research feasible, and engender shark biology and conservation.

Those factors were 1) Generous funding of research on shark attacks and the use of sharks for military purposes by the U.S. Navy's Office of Naval Research; 2) A rise in popularity of recreational shark fishing and the development of marking tags that could be used to identify individual sharks; 3) The opening of China to commerce with the United States, resulting in a new shark fishery in U.S. waters and active shark fin markets. In turn, the rapid growth of the shark fin fishery and the geometric increase in the landings resulted in conservation concerns, and the eventual need for fishery regulations; and 4) The release of the movie "Jaws" engendered a fear of sharks and started a shark killing craze that became an ecological disaster.

"Jaws" affected the behavior and attitudes of millions of people toward sharks and the ocean, and the effects lasted for several decades. The effects of the movie were so deep, varied, and long-lasting that they eventually encompassed totally opposite behaviors.

The most significant impact of the movie "Jaws" was caused by the character "Matt Hooper." This character, and its personification, would have a profound and long-lasting effect on the young audience, for it told them that there was such a profession as "shark biologist" and that one could have a career studying sharks.

Youngsters who saw the film often fantasized about being shark biologists. Unfortunately, the sad reality was that there were very few positions available in shark research. A common trait and peculiar aspect of many young people, who were influenced by the movie and wished to become shark biologists, was their general lack of interest in biology or natural history. This was surprising, because curiosity about animals or their natural history has always been the sine qua non of biologists.

In a decade or two (~1995–2010), an unusual transformation occurred in the perception of sharks. In American society, sharks went from being feared animals to protected and even "totemic" animals. Totemism is a complex social phenomenon where individuals or groups form a mystical or emotional relationship with a venerated or sacred object, the totem, usually an animal. When sharks ceased to be fishes and became totemic animals, much of shark biology evolved into advocacy. Most of the logistical difficulties of the past are still with us, and shark research continues to be difficult. Today, much research is mainly concentrated on a few species of sharks, such as the totemic white shark, Carcharodon carcharias, *and the "charismatic" whale shark,* Rhincodon typus.

From the 18th century, the time of Linnaeus, to the 20th century, shark studies were limited to descriptions of the animals or their anatomy. In the early 20th century, Sheldon (1909, 1911) and Parker (1910, 1914) carried out the first sensory laboratory experiments on sharks, using smooth dogfish, *Mustelus canis*. Despite these early experiments, throughout the first half of the 20th century, shark research was usually limited to taxonomic studies; only a few biological studies were carried out (Gudger, 1907, 1949; Gudger and Smith, 1933). Thus, there was little progress in the understanding of sharks.

In the late 1930's and early 1940's, shark fisheries developed in North America as uses for shark leather and liver oil were discovered. Extensive and intensive fisheries developed for the soupfin shark, *Galeorhinus galeus* = *zyopterus*, ranging from California to Washington (Byers, 1940; Ripley, 1946; Westrheim, 1950). On the U.S. east coast, a more extensive fishery developed primarily for the sandbar shark, *Carcharhinus plumbeus*, although the fishery was not as intensive as the west coast fisheries.

These fisheries could have engendered studies on sharks, but at that time few biologists were interested in sharks. Thus, despite the large numbers of sharks taken in the fisheries, only one species, the soupfin shark, was studied. Detailed studies were carried out on the soupfin shark and its fishery (e.g., Ripley, 1946; Bolomey and Sycheff, 1946), although most of the studies were industrial rather than biological.

On the east coast, no agency collected data on the sharks or the fishery. The only person who examined large numbers of sharks at that time was Stewart Springer, who had started as a fisherman for Shark Industries, Inc.[1], and later became a biologist for the U.S. Bureau of Commercial Fisheries (BCF) (Castro, 2013). Springer published what little data existed on the fishery (Springer, 1952). Later he published his monograph on the sandbar shark (Springer, 1960), based on records obtained while employed by the Shark Industries Division of the Borden Company (in the 1940's and early 1950's) and later while conducting exploratory fishing aboard BCF R/V *Oregon*.

In 1937, the Sears Foundation for Marine Research was established at Yale University. One of the Foundation's first projects was a series of scholarly books titled "Fishes of the Western North Atlantic." The first volume of the series, published in 1948, covered lancelets, cyclostomes, and sharks. The shark section was written by Henry B. Bigelow and William C. Schroeder of the Museum of Comparative Zoology at Harvard University.

This publication (Bigelow and Schroeder, 1948), was basically a taxonomic work but also summarized what little was known then about the biology of sharks of the western North Atlantic. The book remained the standard reference on sharks for several decades, and it set such a high standard for the series that subsequent volumes came out at a very slow pace.

The Dawn of Shark Biology

By the 1950's, the shark fisheries were a thing of the past. There were virtually no shark fisheries in North America, and anyone wanting to study or conduct research on sharks had to acquire his or her own specimens. Thus, biological studies of sharks were extremely difficult to carry out and people who studied sharks were rarae aves.

In late 1954, Alfred C. Vanderbilt and Eugenie Clark founded the Cape Haze Marine Laboratory in Placida, Fla. Soon after the laboratory opened, Clark began catching sharks at the request of a fellow scientist, John H. Heller, who had gone to the Caribbean to collect sharks for research and had failed to obtain them. Soon, Clark was the only scientist regularly catching sharks, keeping them in captivity in pens open to the sea, and conducting behavioral experiments on them (Clark, 1959).

Clark and her fishermen set longlines periodically for sharks. Large specimens that were alive on the lines were transferred to the sea pens for experiments; dead sharks were necropsied, and Clark took extensive notes on their anatomy and condition.[2] These studies eventually produced Clark's first reports on learning in sharks (Clark 1962, 1963), and one of the few comprehensive biological studies of the sharks of central Florida (Clark and von Schmidt, 1965). Few other biological studies of sharks were produced at the time because specimens were difficult to obtain because the lack of fisheries.

In the mid-1950's, the main interest on sharks was in developing repellents (Castro, 2013). Recent experiences from World War II in the tropical Pacific Ocean had demonstrated that downed naval aviators and sailors and mariners whose ships had sunk were highly vulnerable to shark attacks (Llano, 1955, 1963). In April of 1958, a conference titled "Basic Research Approaches to the Development of Shark Repellents" was held in New Orleans, sponsored by the American Institute of Biological Sciences (AIBS) and Tulane University, and funded by the Office of Naval Research (ONR) and the Bureau of Aeronautics. A total of 34 participants from across the world attended the conference. The conference proceedings were later compiled into the book "Sharks and Survival" (Gilbert, 1963a). The book is mainly about shark attacks (12 of its 22 chapters), and only 10 chapters can be said to deal with shark biology.

Authors of the biological chapters were Conrad Limbaugh, Stewart Springer, Eugenie Clark, Albert L. Tester, Lester Aronson, Richard Backus, and Perry W. Gilbert. Conrad Limbaugh was a Marine Diving Specialist from Scripps Institution of Oceanography who perished in a 1960 cave diving accident in France. Lester Aronson

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service/NOAA.

[2]Clark's notebooks, with extensive notes on each specimen examined, remain at Mote Marine Laboratory, Sarasota, Fla., and the author used them extensively while writing "The Sharks of North America" (Castro, 2011).

Erasmus Darwin and Sharks

The idea of controlling and harnessing sharks predates the attempts of the Office of Naval Research by nearly 200 years. Erasmus Darwin (1731–1802), was an English physician, botanist, natural philosopher, inventor, abolitionist, and poet; an extraordinary man and one of the influential thinkers of the English Enlightenment. Erasmus Darwin was a founder of three scientific societies, including the famous Lunar Society of Birmingham, a discussion group of experimentalists, inventors, and savants of the age who met during the period of the full moon in the 1770's–1790's (they met during the full moon to facilitate the members' travel home in the days before street lighting).

Darwin was also a prescient and far-sighted individual who foresaw the automobile, the steamboat, the submarine, and the aircraft. A prototype steam vehicle existed in France by 1769, and in 1781, James Watt patented a steam engine that produced continuous motion. Darwin foresaw that steam could soon be applied to many devices: In *Canto X* of The *Botanic Garden*, Darwin (1791) wrote:

"Soon shall thy arm, unconquered Steam! afar
   Drag the slow barge, or drive the rapid car;
Or on wide-waving wings expanded bear
   The flying-chariot through the fields of air.
Fair crews triumphant, leaning from above,
   Shall wave their fluttering kerchiefs as they move;
Or warrior-bands alarm the gaping crowd,
And armies shrink beneath the shadowy cloud.

Erasmus Darwin also conceived the submarine, solving the problem of respiration inside the submarine by means of oxygen gas which had been discovered (as "dephlogisticated air") by his friend Joseph Priestley a decade earlier, and recently (1789) explained by the French chemist Antoine Lavoisier* (McKie, 1952). Knowing that the steam engine could not operate underwater, and the effective internal combustion engine still about a century away, he needed a mode of propulsion for his underwater craft (Slosson, 1923). Then he conceived the idea of harnessing sharks in the manner of horses:

Led by the Sage, lo! Britain's sons shall guide
Huge *Sea-Balloons* beneath the tossing tide;
The diving castles, roof'd with spheric glass,
Ribb'd with strong oak, and barr'd with bolts of brass,
Buoy'd with pure air shall endless tracks pursue,
And Priestley's hand the vital flood renew.--
Then shall Britannia rule the wealthy realms,
Which Ocean's wide insatiate wave o'erwhelms;
Confine in netted bowers his scaly flocks,
Part his blue plains, and people all his rocks.
Deep, in warm waves beneath the Line that roll,
Beneath the shadowy ice-isles of the Pole,
Onward, through bright meandering vales, afar,
Obedient Sharks shall trail her sceptred car,
With harness'd necks the pearly flood disturb,
Stretch the silk rein, and champ the silver curb;
Pleased round her triumph wondering Tritons play,
And Seamaids hail her on the watery way.

In his *Zoonomia* (1794), a two volume rambling work attempting to classify facts about animals and to set out laws of organic life, Erasmus Darwin anticipated evolution by natural selection: "since the earth began to exist…would it be too bold to imagine, that all warm-blooded animals have arisen from one living filament… possessing the faculty of continuing to improve by its own inherent activity, and of delivering down those improvements by generation to its posterity." Over 50 years later, in 1859, his grandson, Charles, who read it and commented on "Zoonomia," would publish his own theory of evolution by natural selection (Darwin, 1859). For interesting biographies of Erasmus Darwin see Darwin (2002), and King-Hele (1963).

*Joseph Priestley was a member of that group. He is credited with the discovery of the component of air that was needed for respiration and life. He called it 'dephlogisticated air," and we now call it oxygen. In 1789, the French chemist Antoine Lavoisier named the gas oxygen and explained that water consisted of hydrogen and oxygen. Erasmus Darwin was evidently aware of these discoveries.

was an anatomist and behaviorist at the American Museum of Natural History (and one of Eugenie Clark's mentors). His contribution to the symposium was a descriptive article on the central nervous system of sharks and bony fishes. Most of his previous works were on poeciliid fishes and domestic cats, *Felis catus*, and he cannot be said to have been a shark specialist. Stewart Springer was a great naturalist and a shark fisherman of considerable experience. He was an autodidact who learned much by butchering and dissecting thousands of sharks. The other four (Clark, Gilbert, Tester, and Backus) were just beginning their shark researches. So, at that time, only a few people in the United States could be listed as researchers of shark biology.

Then, in June 1958, the AIBS Shark Research Panel was established to "1) expedite and activate recommendations formulated at the ONR sponsored conference on Basic Research Approaches to the Development of Shark Repellents and 2) to serve as clearing house for all information related to the field of elasmobranch biology in general and to the shark hazard problem in particular" (Olive, 1971). This panel was chaired by Perry W. Gilbert (Cornell University) and included Sidney R. Galler (ONR), John R. Olive (AIBS), Leonard P. Schultz (USNM), and Stewart Springer (BCF). In subsequent years, Albert L. Tester (University of Hawaii), and H. David Baldridge (USN) were added to the panel. From 1958 to 1970, the panel initiated basic research on sharks, funded research on anti-shark measures or repellents, organized conferences, and maintained the Shark Attack File, a data collection system based on five newspaper clipping services which gathered information on shark attacks worldwide.

From the early 1960's to the mid-1970's, four factors would converge to change the feasibility of shark research. First, generous funding of research on shark attacks and the use of sharks for military purposes by the Office of Naval Research (Castro, 2013) allowed some researchers to keep sharks in captivity and to carry out sensory and physiological experiments on them.

Second, a rise in popularity of recreational shark fishing and the development of marking tags that could be used to identify individual sharks, resulted in popular shark tagging programs that marked thousands of sharks. These efforts produced research specimens and significantly increased the knowledge of sharks and their migrations.

Third, the opening of China to commerce with the United States resulted in the development of a new shark fishery in U.S. waters and active shark-fin markets, producing abundant research specimens. The rapid growth of the shark fin fishery and the geometric increase in the landings also resulted in conservation concerns and the eventual need for fishery regulations to protect the shark stocks. Because fishery management required knowledge of shark species, populations, and landings, this knowledge had to be acquired promptly.

Fourth, the release of the movie "Jaws" in 1975 had significant effects that have lasted for decades: It engendered a fear of sharks and started a shark killing craze that lasted two decades. Shark fishing tournaments proliferated and became an excellent source of specimens for researchers. Additionally, the movie images of the shark biologist would influence a generation of young viewers to seek careers as shark biologists.

The First Factor: ONR, Sharks, and the Military

When World War II ended in 1945, a new world order ensued, with two superpowers of totally different ideologies, the United States and the Soviet Union, struggling for supremacy. For the next decades, the superpowers prepared for the possible next war by developing new weapons (intercontinental ballistic missiles, nuclear submarines, super-aircraft carriers, etc.) while engaging in the confrontations and proxy wars that became known as the Cold War.

In January 1954, the first nuclear-powered submarine, the USS *Nautilus*, was launched. It was a revolutionary new ship that shattered all existing records of submerged speed and endurance. Some 50 years earlier, the British had launched HMS *Dreadnought*, a revolutionary battleship, the first fitted with turbines and larger guns, which made obsolete all previously built battleships.

The *Dreadnought* started a "battleship race," in which, for the next four decades, nations continually endeavored to build bigger, faster battleships with bigger guns than their potential enemies. The *Nautilus* started a similar race where the two superpowers built bigger, faster, and stealthier nuclear submarines armed with increasingly more powerful missiles and torpedoes. This race for better submarines, which has lasted to this day, required new concepts, new materials, and new technologies.

Based on my analysis of the research funded by the ONR, the National Aeronautics and Space Administration (NASA), and the Defense Advanced Research Projects Agency (DARPA), beginning in the 1960's, it appears that the managers expected that much could be learned from the adaptations of sharks. It was recognized that these creatures were the product of millions of years of evolution towards efficient, effective, and stealthy marine predators, and those adaptations perhaps included principles of drag reduction, prey sensing, stealth, etc. that could be applied to military equipment.

Thus, these agencies funded research on shark vision (Gilbert, 1963b), chemoreception (Hodgson and Mathewson, 1978), electric and magnetic senses (Kalmijn, 1978), hydrodynamic aspects of shark scales (Raschi and Musick[3]), and many other projects (and not just in sharks) in search of principles or ideas that could be applied to submarines or other new weapons. The ONR continued to fund shark research for many years and most of the knowledge of sharks acquired in the second half of the twentieth century was based, or at least partially based, on research funded by ONR.

The effects of such funding on shark research cannot be overestimated; ONR funding created and greatly advanced shark biology. The research was generally geared to discovering how sharks were such effective predators, hoping to make submarines more shark-like, but in the late 1960's, research took a new direction: sharks as weapon deliverers.

Sharks as Weapon Carriers: An Analysis

It is likely that no one noticed when in 1967–68, the U.S. Navy assigned two top scientists, Clarence Scott Johnson and Henry David Baldridge, to the then little-known, financially strapped Cape Haze Marine Laboratory in rural central Florida[4]. Johnson had a Ph.D. in Nuclear Physics and was a physicist at the Naval Undersea Warfare Center, San Diego, with a background in the training of marine mammals for military purposes.

[3]Raschi, W. G., and J. A. Musick. 1986. Hydrodynamic aspects of shark scales. NASA Contr. Rep. 3963, Prep. for Langley Res. Cent. under Contr. NAS1-16042, NASA CR-3963 19860013418. Sci. Tech. Info. Br., NASA.

[4]The name of the laboratory was soon changed to Mote Marine Laboratory. ONR funding allowed the laboratory to survive.

Baldridge was a naval captain with a Ph.D. in Organic and Physical Chemistry from the University of California at Berkeley. Why would the U.S. Navy assign such capable and valuable researchers to a sleepy marine laboratory in rural Florida? According to Gerald D. Sturges (1982), these scientists came to Florida to work on "Project Headgear," to "convert the shark into a remote-controlled torpedo that could ram a ship while carrying a load of explosives."

The idea of using animals to deliver explosive or incendiary materials to the enemy was not new. During the early stages of World War II, the Nazi and Japanese juggernauts could not be stopped by the Allied Nations, which had long neglected their armed forces. In those bleak and desperate years, the Allies hatched many schemes to replace the war materiel they lacked with animals as weapons. Thus, the Allies created mine dogs, bat bombs, and exploding dead rats.

The Soviets invented the "mine dogs," anti-tank dogs carrying a mine with a contact detonator strapped to their back. These dogs were trained, often by starvation, to feed under Soviet tanks. The idea was that later they would approach the formidable German Panzer tanks and crawl under them causing the mine to blow up tank and dog.

According to Generaloberst Erhard Rauss (1995), who commanded the 3rd and 4th Panzer Armies in Russia, there is no evidence of any German tank destroyed by a mine dog. On the contrary, it was reported that mine dogs, frightened by the firing and noise coming from the German tanks, fled and sought protection under the Soviet tanks, which promptly blew up, or they ran back to their handlers, with similar results. Rauss (1995:76) concluded that "One thing is certain: the specter of mine dogs ceased just as abruptly as it had begun."

In the United States, a similar idea to the mine dogs was hatched in 1942: to strap small incendiary devices to bats and then release the bats from aircraft over Japan. The bats would then fly down and roost in highly-flammable wooden Japanese structures, causing conflagrations. The "bat bomb" idea (Project X-Ray) proved its feasibility on 15 May 1943 when a few torpid bats, outfitted with live incendiaries for a "photo session," became active and escaped with their deadly devices. Most of the escaped bats landed at the nearby and newly constructed Carlsbad Auxiliary Airfield. Fifteen minutes later, the bats incinerated the airstrip control tower, adjacent barracks, offices, and hangars (Couffer, 1992). The bats, however, were never used operationally. The B-29 Superfortresses, incendiary bombs, and General Curtis LeMay were sufficient to incinerate the Japanese cities.

Who conceived the idea of using sharks as weapons in Project Headgear is not known to the author. It is likely that those who conceived the project were influenced by the World War II precedents of the mine-dogs and the bat bomb, and by the training of marine mammals for naval use. After those precedents, the idea of a shark as a guided animal torpedo likely appeared logical and feasible. Perhaps sharks could achieve something technology could not do at that time. Project Headgear started in the days of the Cold War and the Space Race, and anything that could be used to gain an edge over the Soviets was probably deemed a reasonable effort or expenditure.

Much of the work was carried out in two circular tanks made for the project at Mote Marine Laboratory and at a second facility for shark research at the Lerner Marine Laboratory (Fig. 1), Bimini, Bahamas. The Lerner facility made it possible for the first time to "work experimentally with large elasmobranchs up to 15 feet in length" (Gilbert and Kritzler, 1960:424).

The details of sharks carrying weapons under "Project Headgear" have never been released. It appears that the project remains classified, almost 50 years later, because the author's requests to the Office of Naval Research, including requests under the Freedom of Information Act, have not produced any information. According to the ONR, "There are no responsive records."

However, an analysis of papers published by the Project Headgear researchers confirms Sturges' assertions, and indicates the nature of the problems the investigators encountered and attempted to solve. If sharks were to be used to carry a "payload," there were two problems that had to be solved. First, how do you guide a shark to its target? Second, how much weight can a shark carry? The problems of weapon design would be simple in comparison, and are irrelevant here.

It appears, based on the duration of the project, that the researchers worked on the guidance of sharks first, and initially ignored the second question of how much weight could be carried by a shark. Had they investigated the second question first, the project would have been deemed unfeasible and stopped.

How the movements of a shark could be controlled had been known for a long while. Parker (1910, 1914) demonstrated that a smooth dogfish with an occluded nostril would usually turn toward the side of the non-occluded nostril; that is, towards the side receiving a stimulus. The Parker experiments suggested that by impinging on the shark senses, the direction of the animal's movement could be controlled. Given the anatomy of the shark brain, it would be relatively easy to insert an electrode into the olfactory lobe or the long olfactory nerve, stimulating it and causing the shark to veer towards the stimulated side. Alternatively, other cranial nerves could probably be used with similar results.

Nevertheless, based on the papers written on buoyancy by Baldridge (1970, 1972), the load carrying ability of sharks was eventually investigated. If the researchers looked at the carrying capacity of bats in Project X-Ray or at data on bird flight, they were certainly misled on the potential of sharks as weapon carriers.

In 1943, bat bomb personnel had discovered that a Mexican freetailed bat, *Todarida brasiliensis*, weighing

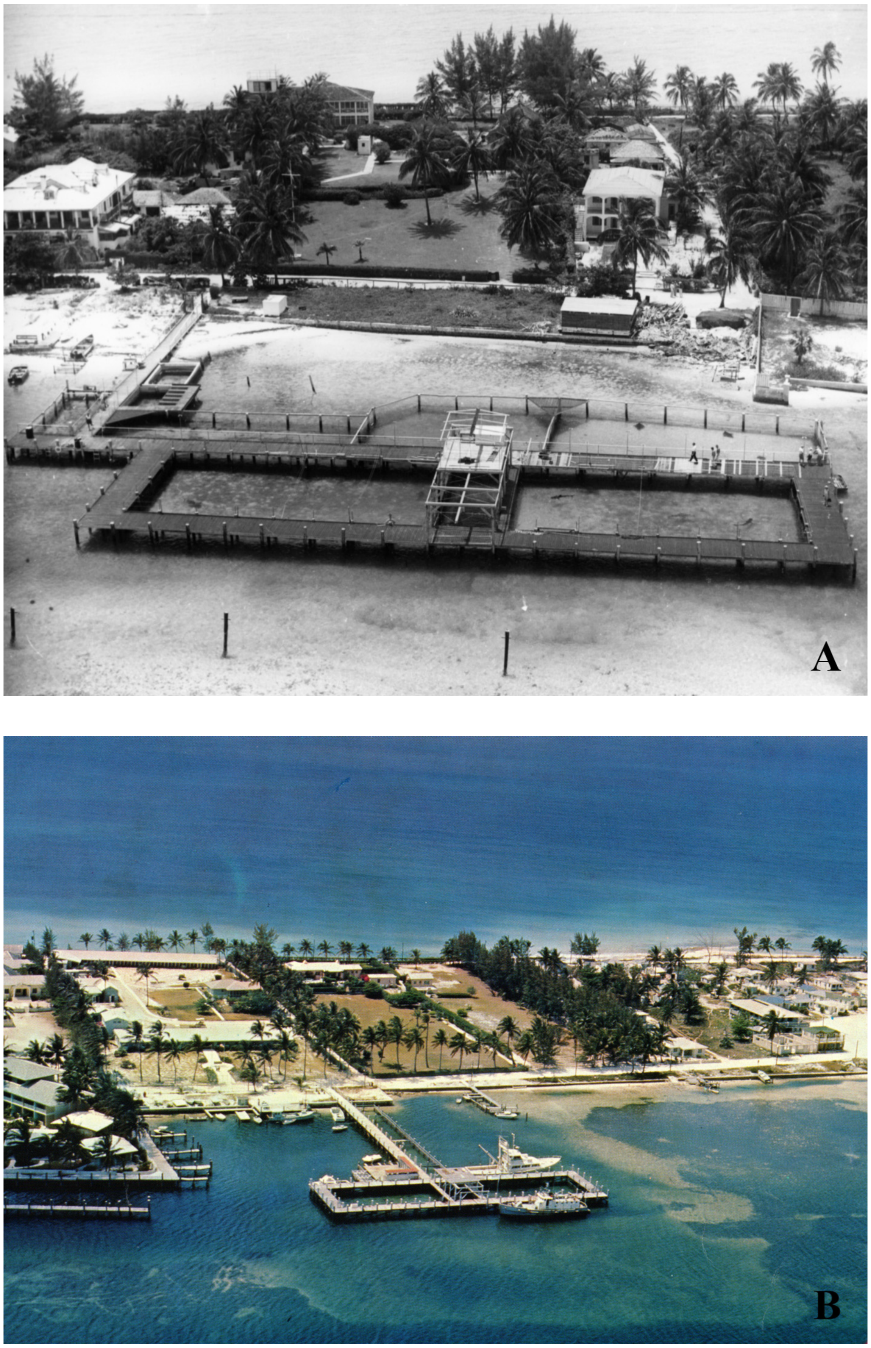

Figure 1.—A. Early shark pens used for Project Headgear at the Lerner Marine Laboratory, Bahamas. B. Improved shark pens for the project. (From Lerner brochures).

10–11 g could carry a weight of 15–18 g, more than its own weight. Thus, a pyrogenic device was designed and constructed that was light enough to be carried by a bat. The bat bomb device, carried by the bats which incinerated Carlsbad Auxiliary Field, consisted of a celluloid case filled with napalm (jellied gasoline), along with its igniter, and weighed only 17.5 g.

Years later, Davis and Cockrum (1964), in tests also funded by ONR, obtained much reduced loads, about 9.3% of the bat weight for the Mexican free-tailed bat. But they also reported that other species of bats could carry up to 73% of their body weight. They stated that the discrepancy may be due in part to the bomb bats being released from considerable heights (and thus just flying downwards). In any case, bats, with their large wings, are great load carriers, but the size of the load is minute due to the small size of the bats. It is likely that the researchers reasoned that, if a little bat could carry such proportionally great loads, a big shark weighing several hundred pounds should certainly carry a heavy load.

However, to carry "a load of explosives," Project Headgear scientists had chosen the wrong type of animal, because sharks are poor load carriers. Let's explain! First, for mechanical purposes, sharks must be regarded as "flying" animals, not swimming animals. It may be best to briefly recall some basic physical principles. Flight is movement through a fluid, be it air or water, where a lift force is generated when an object moves through the fluid, and it is generally directed upward. Drag is a force caused by the fluid in the opposite direction to the movement of the object. Thrust is the force generated by wing or tail flapping and is in the direction of animal's movement.

Flight results from achieving the requisite combination of forces: thrust, lift, and drag, and overcoming gravity. Accumulating all the morphological changes and adaptations through evolution, and achieving the needed combinations that enabled animals to fly must have taken eons. Before an animal could get off the ground or sea bottom, it had to evolve adaptations such as reduction of structural weight (e.g., with air sacs and hollow bones in birds, and lightweight cartilaginous skeletons and oil-filled livers that produce buoyancy in sharks) and reductions in drag (form streamlining, and surfaces that induce laminar flow, such as feathers in birds and skin denticles in sharks).

Flight is a wonderful evolutionary advantage, and, in nature, true flight is a rare adaptation. Most authors consider that true flight (powered or "flapping"), as distinguished from gliding, parachuting, and soaring, has evolved only three times in the long vertebrate histories: in reptiles (in the extinct flying reptiles or pterosaurs), birds, and bats (Romer, 1966; Norberg, 1990). Perhaps these authors should specify "aerial flight," because, for mechanical purposes, sharks fly through the water.

Sharks lack swim bladders, and thus, their specific gravity is greater than that of seawater. Therefore, sharks are incapable of floating like bony fishes.[5] Sharks must keep moving to obtain lift from their fins and body, lest they fall to the bottom, just like a bird or an airplane must keep moving or it falls from the sky. The mechanics of flight are the same for shark, bird, or airplane.

At some point the researchers had to answer the question of what load sharks could carry, and this was probably the fatal question that doomed the project. Evidence indicates that they investigated the load carrying capacity of sharks by measuring the buoyancy of sharks. Baldridge, a first-rate scientist with a brilliant mind, had no training in biology. However, within a couple of years of arriving in Florida, he produced the two classic papers on the specific gravity of sharks and on how the sharks achieve neutral buoyancy: "Sinking factors and average densities of Florida sharks as functions of liver buoyancy" (Baldridge, 1970), and "Accumulation and function of liver oil in Florida sharks" (Baldridge, 1972). Later, Baldridge (1982) wrote an article titled "Sharks don't swim, they fly" where he displays full understanding of the mechanics of swimming and lift in sharks, and demonstrates that he understood, back in the 1970's, that for mechanical purposes sharks fly through the water.

The Baldridge studies also demonstrated that, when compared to other flying animals, sharks are poor load carriers. Perhaps, the relative size of shark pectoral fins (Fig. 2), or their "wings," is much smaller than that of birds and bats, and shark fins do not provide enough lift for carrying extra weight (Lift varies directly with area of the wing, the density of the fluid, the square of the velocity, and angle of attack). There was no need for sharks to evolve load-carrying adaptations.[6] It is likely that, after his buoyancy tests, Baldridge saw the fatal flaw that his colleagues, or the originators of the project, had failed to understand at its inception.

The realization that a large shark could not carry a sufficiently large explosive probably doomed the project. Today, over 45 years later, Baldridge's papers remain the best source of knowledge and empirical data on buoyancy in sharks. Unfortunately, the other experiments carried out during the project have not been published and remain hidden from view.

Other Laboratory Studies

Despite the problems with Project Headgear, project personnel were quite productive and carried out other laboratory activities, probably as a cover for their real mission. Johnson developed the "Shark Screen," a large "imperforate bag formed of thermoplastic material" with inflatable compartments where a shipwrecked person could float and hide from sharks (U.S. Patent #3,428,978, dated 25 Feb. 1969). Johnson and Baldridge later cooperated on the "Electric Anti-shark Dart," a device mounted on a spear shaft, and used for incapacitating sharks and other marine predators (or diver?) by means of an electric current, without creating noise or bloodying the water which often would attract other predators (U.S. Patent #3,771,249, dated 13 Nov. 1973).

Baldridge "conducted research towards basic scientific approaches to the development and testing of both physical and chemical shark deterrents," and compiled and analyzed data on shark attacks throughout the world. Castro (2013) provided details of Baldridge's work on shark repellents. Johnson would later publish papers on cetacean communication and a charming little book on how to train goldfish, *Carasius auratus*, using dolphin, *Tursiops* spp., training techniques (Johnson, 1995).

The ideas of learning some of the secrets of the evolutionary success or predatory efficiency of sharks and of using sharks for military purposes have continued to fascinate the military research agencies for over six decades, and attempts at controlling sharks continue to this day. In recent years, DARPA funded researchers at the University of Michigan to develop "implantable neural interfaces in freely swimming sharks in order to investigate neural coding associated with sensory processing and natural behavior" (Kipke et al.[7]). A press correspondent translated this as "to direct the shark by directly controlling its senses," while a researcher spoke of it as "to direct a shark by remote control" (Cooke, 2004). Déjà vu.

[5]A few sharks, such as the sand tiger shark, *Carcharias taurus*, often seen in aquariums, appear stay almost motionless. Sand tiger sharks are known to gulp air, which must enhance their buoyancy. It has been suggested that sleeper sharks, *Somniosus* spp., might be able to stay almost motionless by seal breathing holes, in wait of their prey. This has yet to be demonstrated.

[6]Unlike birds, sharks evolved viviparity. Thus, females of viviparous sharks are burdened by having to carry to term a brood of large young. How female sharks compensate for this load is unknown.

[7]Kipke, D. R., J. Carrier, and D. J. Anderson. 2007. Implantable neural interfaces for sharks. Final Tech. Rep., Contr. HR0011-05-C-0018, dated 31 May 2007. Defense Advanced Res. Proj. Agency (DARPA), Arlington, Va.

The Second Factor: Tags and the Tagging Era

Early Shark Tags

During 1936–48, Hansen (1963) applied brass tags, known as Petersen discs, to the jaw and pectoral fins of Greenland sharks, *Somniosus microcephalus*, to study their growth and migrations in the Arctic. This appears to be the first use of tags to study sharks, although bony fishes had been marked or tagged for many years (McFarlane et al., 1990).

The tagging of sharks for research purposes did not begin in the United States until nearly three decades later. In 1961, the Department of Interior's Bureau of Sport Fisheries and Wildlife established the Sandy Hook Marine Laboratory, the first federal laboratory in the United States specifically dedicated to study the migratory marine game fishes (Casey, 1985).

In 1960, two shark attacks on swimmers off New York and New Jersey (McCormick et al., 1963), had raised the question of what species of sharks inhabited the area and what level of hazard they represented. This generated support for shark studies at the Sandy Hook Laboratory in 1961. The research vessel *Cape May* was loaned to the laboratory by the Smith Research and Development Corporation of Lewes, Del., for the purpose of a longline survey of sharks between Long Island and Delaware Bay from late August to early October 1961 (Casey, 1985). Over 300 sharks were caught in the survey, including white sharks, *Carcharodon carcharias*; tiger sharks, *Galeocerdo cuvier;* dusky sharks, *Carcharhinus obscurus*, and other large species which were considered potentially dangerous to swimmers (Casey, 1985).

Release of the survey results stimulated a great interest in sport fishing for sharks, rather than an increase in apprehension over shark attacks. Hundreds of fishermen wrote to the Sandy Hook Laboratory requesting information on shark fishing. Subsequently, a recreational shark fishery developed off the northeastern United States,

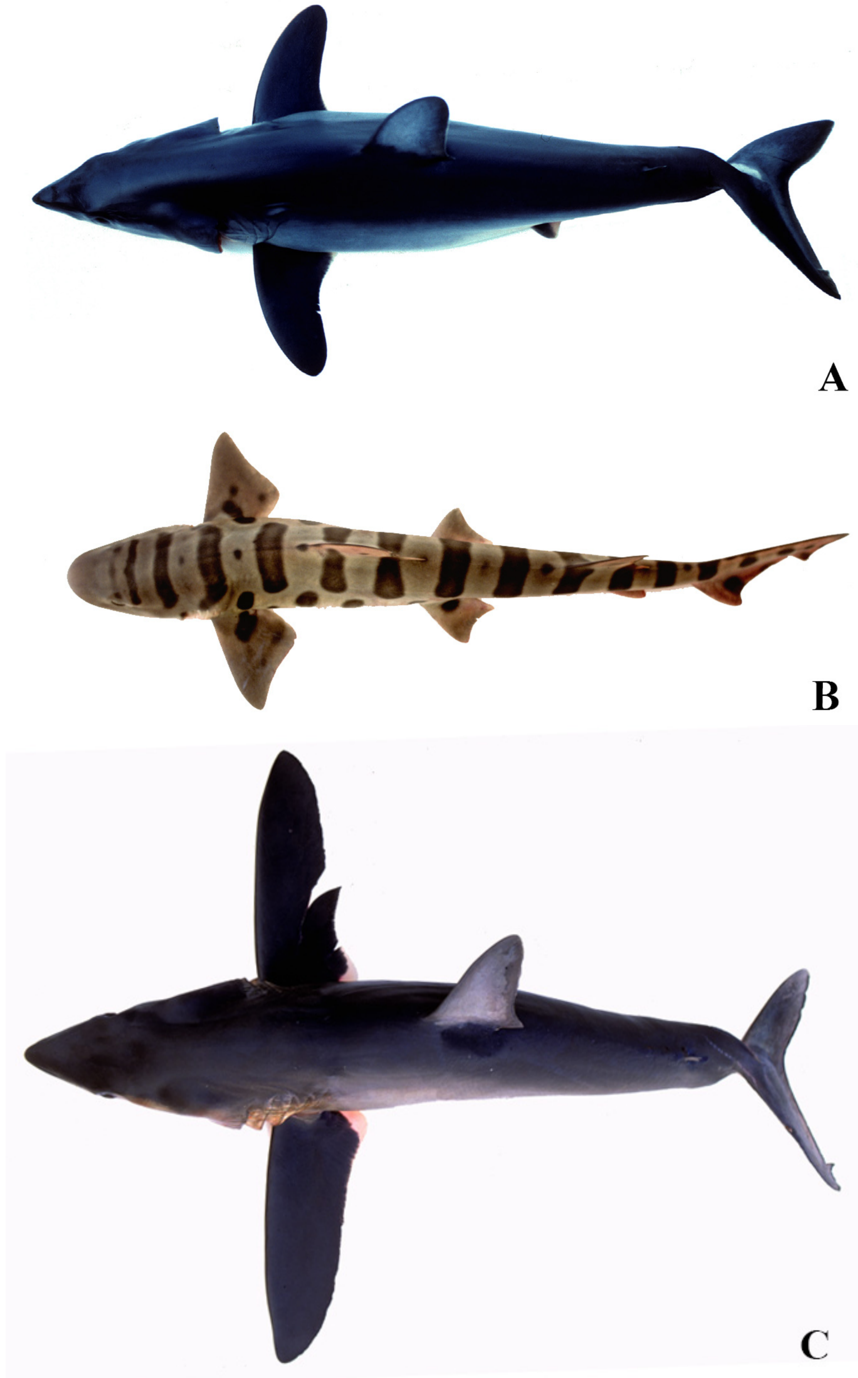

Figure 2.—Dorsal views of different sharks showing the small pectoral fins. A. Shortfin mako, *Isurus oxyrinchus*, B. Leopard shark, *Triakis semifasciata.* C. Longfin mako, *Isurus paucus.*

and expanded along the entire Atlantic coast (Casey, 1985).

In 1962, the growth of the recreational shark fishery made it possible for John G. Casey of the Sandy Hook Laboratory to develop a volunteer-based Cooperative Shark Tagging Program (CSTP) to understand the migrations of sharks (Casey, 1985; Kohler et al., 1998). In 1966, the NMFS tagging studies were transferred to the Narragansett Laboratory, where Casey continued to expand his volunteer program.

Two basic types of tags were used in the early tagging program: a fin tag (known as the Jumbo Rototag), and a dart type (the "M" tag). The M tag had been developed by Frank Mather, III, for use with tunas (Scombridae), and modified by Casey for use in sharks. These tags yielded information only when a tagged fish was recaptured at a later date. Knowing the tagging and recapture locations, the general direction of the animal's movements could be determined. Much later, in the next century, these tags would be referred to in retrospect as the "dumb tags" when compared to the "satellite archival tags" which yielded more extensive tracks of the sharks' movements.

Despite the primitive tags, the CSTP was eminently successful. Between 1962 and 1993, some 6,500 volunteers tagged 106,449 sharks of 33 species. The information obtained through the tagging program allowed biologists to start to understand the complex habits and migrations of sharks. The program also generated a great deal of enthusiasm among sport fishermen for tagging and releasing sharks. The results of this long-term, broad-scale effort were published in a tagging atlas summarizing the migrations of sharks off the eastern United States (Kohler et al., 1998).

The Rise of the Modern Tags

Toward the middle of the twentieth century, a few zoologists armed with binoculars and great patience learned to approach and observe large, free roaming terrestrial animals in their natural habitat. Even large primates such as gorillas, *Gorilla gorilla,* and chimpanzees, *Pan troglodytes*, were studied by Schaller (1963) and Goodall (1986), respectively. However, the observational techniques used at that time could not be applied to all animals or all habitats.

Some very secretive jungle-dwelling animals such as tigers, *Panthera tigris*, and jaguars, *Panthera onca*, or wide-ranging animals such as wolves, *Canis lupus*, and moose, *Alces alces*, were almost impossible to track and observe. Free ranging marine animals were "out of the question" in that era.

In the early 1960's, emerging radio tracking technology allowed scientists to tag, track, and study land animals that were difficult to find in their remote habitats: Cochran (1975) followed a peregrine falcon, *Falco peregrinus*, from Wisconsin to Mexico, and Craighead and Craighead (1972) tracked grizzly bears, *Ursus horribilis*, going to their secluded wintering dens. Secretive animals dwelling in deep jungles, such as jaguars, could be radio-collared, and followed in their ranges, allowing much to be learned about their habits.

Biologists now could track, locate, and observe far ranging mammals in wide open spaces, such as Alaskan wolves (Mech, 1970) and moose (Van Ballenberghe, 2004). Soon many workers were following numerous animals. By March 1979, one of the leading commercial suppliers of radio-tracking equipment had sold over 17,500 radio collars (Mech, 1983). Because radio-tagged animals could be followed on foot, by land vehicle, or aircraft, animals could be followed long distances. When precise locations were obtained, and if the habitat was well understood, then much could be discerned and understood about the animals being studied.

The radio equipment and techniques for tracking land animals could not be applied to aquatic animals because of the strong attenuation of radio waves in water. However, acoustic tracking devices that could work underwater were soon developed, but the problem of attenuation of sound signals underwater could not be solved entirely. At first, the small sound emitting transmitters were externally attached to sharks; later they were surgically implanted into the coelomic cavity.

The early acoustic transmitters had short detection ranges, usually from 1–4 km, depending on location, sea condition, output power of transmitter, receiver used, etc. Because of these limitations, early acoustic tracking of sharks required remaining in close proximity to a shark to keep within detection range, an often difficult and arduous task from a small vessel. Thus, most of the early studies were carried out on sedentary or nonmigratory species, or on sharks which could be counted on remaining in the same area for prolonged times (such as juveniles in nurseries), and thus assuring detection.

One of the earlier shark tracking studies was carried out by Pittenger (1984) on Pacific angel sharks, *Squatina californica*, off California. In this study, 11 angel sharks were equipped with ultrasonic telemetry transmitters attached with "Floy" dart tags on the dorsal surface of the sharks. Transmitter life was 30–90 days, and detection from a boat ranged from 1 to 4 km. This shark is a sedentary species that often returns to the same spot during daytime, so its location was easy to find from day to day.

Morrissey and Gruber (1993) attached small ultrasonic transmitters into the coelomic cavity of juvenile lemon sharks, *Negaprion brevirostris*, in the Bahamas to study their home range. Despite the difficulties of tracking free-ranging large sharks from vessels, interesting studies were carried out. A megamouth shark, *Megachasma pelagios*, was tracked in its pelagic environment for 50 h by Nelson et al. (1997) and found to be a crepuscular vertical migrator.

Eventually, extensive hydrophones/receiver arrays would be built along the coastlines for the detection of tagged fishes, creating a network of passive detection devices that greatly facilitated the tracking of sharks. These networks allowed researchers to produce studies, such as Heupel et al. (2003), which showed that tagged juvenile blacktip sharks, *Carcharhinus limbatus*, responded to a fall in barometric pressure associated with a storm by moving to deeper water.

The problems of following tagged animals by personnel or of animals leaving the area where the tracking receivers were located, were soon solved by satellite tracking technology. By 2005, tracking movements with satellite tags was the preferred method for shark research. These tags were relatively easy to use, and once implanted, the tag would record location, temperature, and depth. The tag could be programmed for release after a specified period of time, usually less than a year, depending on settings and battery life. The tag would then float to the surface and transmit the archived data to a satellite, and then the satellite would send the information to the researcher.

Although the method of tagging sharks with internal transmitters detected by underwater sensors continued to be used, satellite tags became the preferred method because sharks often traveled outside the areas covered by the sensors. Quite often the satellite tags failed to work, or produced little data, but sometimes these studies produced interesting results. When the tags were used in well-designed studies, and when they worked properly, the migratory movements of individual sharks could be followed in great detail, something researchers had never dreamed of even a few years earlier.

Satellite tag derived data demonstrated that the range of many shark species included entire ocean basins (Skomal et al., 2009; Campana et al., 2013), something that had been suspected for a long while (Castro, 1983), but not demonstrated. Shark tagging with satellite tags became immensely popular with the new generation of researchers.

As sharks became totemic[8] animals, tagging became the only acceptable research tool for many researchers who insisted on studying shark species solely by tagging. Necropsies of dead animals taken in fisheries became taboo or largely unacceptable (see below). Shark tagging became an endeavor and not just a research tool. In many projects there was no hypothesis tested or question to be answered, and sharks were often tagged with no knowledge of their sex or reproductive stage. Consequently, when results were obtained, sometimes the result was a set of disparate tracks which attested to the variability and complexity of behavior among different individuals, sexes, life stages, etc., and it was difficult to discern or understand movement patterns.

Another problem of tagging endeavors is the expectation that something other than movements can be discerned from the tagging data. Unlike terrestrial habitats, the ocean realm and marine habitats are not sufficiently known to infer what the animal may be doing in a given area. It is certain that future tags will be more complex and productive, and there is much guesswork of what can be done by "more intelligent tags" which can sense the physiology or behavior of the animals. At this time, this is mere speculation, and such "intelligent" tags remain to be developed.

The Third Factor: The Rise of the Shark Fishery and the Fishery Management Plan

In 1972, after some 25 years of open antagonism and hostility between the United States and The People's Republic of China, and after extensive diplomatic negotiations, President Richard Nixon visited China. This was the first step in the normalization of relations between the two countries. During the next two decades, complex economic and financial ties developed steadily between the two countries. In due time, the combination of Chinese energy and cheap labor and American capital and know-how, made China the manufacturing colossus of the early twenty-first century.

China's economic boom, beginning in the late twentieth century, improved the standard of living for some segments of the Chinese population. A greater proportion of their society was able to afford luxuries that had previously been out of reach. One of those luxuries is shark fin soup. In China, a soup utilizing the fibers (ceratotrichia) found in shark fins has been a symbol of prosperity and health for centuries. The dish is a demonstration of wealth and class served at special occasions such as weddings.

Soon after the establishment of diplomatic relations between the United States and China, American and Chinese merchants were figuring out what businesses could be conducted with each other. At this time, the new Chinese and Asian economic prosperity caused the demand for shark fin soup to increase substantially. Thus, when Chinese merchants expressed a growing demand for shark fins, American entrepreneurs sought to fulfill it.

Sharks were one of the few fish resources not targeted or fully utilized by U.S. commercial fisheries. While there was a strong U.S. recreational shark fishery, in general, the commercial fisheries had not impacted sharks since the late 1940's. The only exceptions were porbeagle sharks, *Lamna nasus*, that were targeted in the early 1960's off New England (Campana et al., 2001).

Shark stocks in southeastern U.S. waters were relatively high because they had not been fished since shark liver oil was in high demand in the 1940's, with the exceptions of dusky sharks, *Carcharhinus obscurus*, and oceanic whitetip sharks, *Carcharhinus longimanus*, which were taken incidentally in large numbers in Japanese tuna fisheries in the Gulf of Mexico in the 1960's.

It took about a decade for business and financial channels to develop, and by the early 1980's substantial changes had occurred in demand for shark fins. China's rising standard of living and new wealth increased demand, and the demand resulted in higher prices paid for shark fins. This encouraged American fishermen to enter the shark fishery. Tuna and swordfish fisheries

[8]See later section on sharks as totemic creatures.

that previously had discarded sharks (dead or alive) now began seeking the fins. However, low prices paid for the meat resulted in fishermen just removing the fins from sharks and discarding the carcasses into the ocean, thus saving freezer space for the more lucrative tunas and swordfish. This wasteful practice became known as "finning" (NMFS, 1992).

The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) is the primary law governing marine fisheries in U.S. federal waters. First passed in 1976, the MSFCMA was written to prevent overfishing, rebuild overfished stocks, and increase the long-term economic and social benefits of the fisheries. It extended U.S. jurisdiction to 200 nmi from its coasts. Prior to the MSFCMA, waters beyond 12 nmi were international waters and could be fished by fleets from other countries. It also established eight regional fishery management councils (FMC), which develop fishery management plans for their respective jurisdictions.

Shortly after the MSFCMA passed in 1976, the Mid-Atlantic Fishery Management Council started work on a shark fishery management plan but stopped owing to inadequate information. Through the 1980's shark catches increased due to the demand for fins and meat. In just one decade, U.S. commercial shark landings grew from 135 t in 1979 to 7,172 t in 1989 (NMFS, 1992). Both conservation organizations and regulatory agencies became concerned about the rapid growth of the unregulated shark fishery.

One of the first organizations to notice and act on the rapidly growing, uncontrolled shark fishery was the Gulf of Mexico Fishery Management Council (GMFMC), based in Tampa, Fla. Lacking the knowledge and data on sharks needed for management, the GMFMC requested bids from environmental companies to write a first draft of a management plan for sharks.

The first draft of the "Fishery Management Plan for Sharks and Other Elasmobranchs in the Gulf of Mexico" was issued in February 1979 by the GMFMC. It had been prepared by Environmental Science and Engineering, Inc., the company that had won the competitive bid for the plan.

A more comprehensive "Draft Fishery Management Plan/Environmental Impact Statement/Regulatory Analysis" was issued jointly by the GMFMC and NMFS in September 1979. This last publication outlined the management objectives: minimize the bycatch of species other than sharks by foreign fisheries, maximize the benefits derived from fishing by domestic fishermen from sharks and other elasmobranchs, minimize conflicts among participants in the shark fishery, and establish a data collection system for future management of the fishery. Conservation of sharks was not an objective of this draft plan, but several more drafts of the plan soon followed.

Because many species of economically important sharks are migratory and cross several jurisdictional boundaries in their seasonal migrations, the five east coast FMC's (New England, Mid-Atlantic, South Atlantic, Gulf of Mexico, and Caribbean) recognized the need for a unified Shark Fishery Management Plan. On 3 June 1989, the five councils requested that the Secretary of Commerce develop a fishery management plan for the shark fishery. Their concern was that it would take too long for the five councils to develop their own individual plans, and that, in view of the rapidly growing fishery, the delay could cause irreparable damage to shark stocks.

A team of NMFS personnel (including the author of this article) was assembled in 1989 to prepare a management plan for sharks of the U.S. east coast. NMFS had limited data on shark catches, and what existed was not broken down by species. Personnel attempted to obtain data on shark landings from the commercial industry. Few data sets were available because, in general, fishermen did not record the information needed for stock assessment purposes (e.g., landings by species, catch per unit of effort, etc.) or for the regulation of the fishery.

A few data sets were obtained, notably from fishermen Chris M. Brannon of Bayou La Batre, La., and Eric Sander of Daytona Beach, Fla. After much work and consultations, a shark fishery management plan was prepared (NMFS, 1992) and published on 10 Dec. 1992. The plan was data-deficient for the above cited reasons, and some of its predictions would prove wrong. But the key to its success was a provision for change and improvement by designating an "Operational Team" which could amend the plan's regulations and quotas as new data were obtained. Over the next two decades the plan was emended and amended many times.

The plan not only protected shark stocks by restricting both recreational and commercial fisheries, but it ushered in a new era of research on sharks. NMFS needed shark data upon which to base shark regulations. Landings by species information was needed, and that meant that fishermen, dealers, and enforcement agents had to be able to identify species within the catches. Management agencies needed reports on catches, and assessment of the stocks had to be carried out. The councils and granting agencies made shark research a priority, and funds for shark research flowed through programs such as Marine Fisheries Initiative (MARFIN) and the Saltonstall-Kennedy (S-K) Grants Program.

In the 1990's, scientific and public interest on sharks and the availability of research funds resulted in the appearance of shark research groups. In 1990 the Bimini Biological Field Station was established by Samuel Gruber of the University of Miami. In 1992 a consortium, involving personnel from Mote Marine Laboratory in Sarasota, Fla. (under Robert E. Hueter); Moss Landing Laboratory, at Moss Landing, Calif. (under Gregor Cailliet); Virginia Institute of Marine Science at Gloucester Point, Va. (under John A. Musick); and the University of Florida in Gainesville, Fla. (under George Burgess) was "established by the U.S. Congress" and named the National Shark Research Consortium.

The group was funded through political "earmarks" for a number of years.

In 1993, a Shark Research Group was established at the Hawai'i Institute of Marine Research (under Kim Holland) in Kane'ohe Bay, Oahu. In 1998, a Canadian Shark Research Laboratory, at the Bedford Institute of Oceanography in New Brunswick, was established by Steven E. Campana. In the same decade, many conservation organizations set up shark conservation programs with officers dedicated to those programs, and they became quite active in drafting protective legislation.

Most of these groups flourished in the late 1990's and early 2000's because of the combination of talent and available funds. However, by 2015, much of the institutional interest in sharks had waned, and due to lack of funding (e.g., loss of "earmarked" money), or retirements, most of the research programs were greatly reduced, some groups being reduced to an investigator and an assistant, often on soft money. One of the most productive programs, the Canadian Shark Research Center, had ceased operations due to its leader taking a position elsewhere.

Similarly, the interest of the large conservation organizations in shark conservation and programs only lasted through the heyday of shark conservation and had waned by 2010, when many organizations had abandoned their shark programs and moved on to other endeavors. Legislation protecting sharks had been enacted in the United States, and the fisheries had been curtailed. Other countries and the United Nations had passed legislation or protocols for the protection of shark stocks. However, the protection was very limited or mainly illusory. Unregulated shark fisheries continued to kill untold numbers of sharks to supply fins for Asian markets, with the basic problem being the killing of sharks on the high seas and in coastal zones of countries where law enforcement did not exist. These were very tough, long-term problems that few conservation organizations could or wanted to tackle. The era of the shark research laboratories and the big-organization shark conservation movement was essentially over.

The Fourth Factor: The "Jaws" Phenomenon

In 1974, Peter Benchley's great novel, "Jaws," was published, followed a year later by the movie of the same title. Directed by Steven Spielberg, the movie became one of the most influential in history. "Jaws" affected the behavior and attitudes of millions of people towards sharks and the ocean, and the effects lasted for several decades. The effects of the movie were so deep, varied, and long-lasting that they eventually encompassed totally opposite behaviors.

The movie "Jaws" is a modern "Moby Dick" story (Melville, 1879) and there are remarkable parallels between the two novels. Both novels revolve around very large specimens of their kind, a huge white sperm whale, *Physeter catodon*, and a huge white shark. In both works, the human protagonist is a boat captain bent on revenge against the sea monster. Also in both novels, after a prolonged chase, in the final encounter, the monster rams the vessel, the captain is entangled in the ropes and is dragged to his death, and the monster then dies. The lone survivor, buoyed by flotsam, survives.[9]

There is also a similarity between the movie plot and actual events in 1916, when a series of shark attacks along the New Jersey shore, caused town fathers to try to downplay or keep them secret so as not to ruin the local tourist season. McCormick et al. (1963:15) recount that "After losses estimated at $1,000,000 in canceled reservations, the mayors of 10 New Jersey resort towns met at Beach Haven, where the first shark attack had occurred, and pleaded for an end to the panic. They asked newspapers to refrain from publishing stories that 'cause the public to believe the New Jersey seacoast in infested with sharks, whereas there are no more than in any other summer.'"

[9]In the movie "Jaws," there are two survivors; one in the original novel.

Melville's 1851 novel "Moby Dick" was originally a commercial failure (Maxwell, 1986), and so was his writing career. In difficult financial circumstances after "Moby Dick" was published, Melville became a customs inspector for the last 20 years of his life, and died in obscurity in 1891. "Moby Dick" was not considered as one of the "greatest American novels" until the mid-twentieth century. By contrast, Benchley's novel and the subsequent movies based on the novel were great financial successes, and the effects of the original movie were significant and felt for many decades.

Why did the movie have such impact and why did it have such diverse and long lasting effects? The first reason was the vivid, unforgettable scenes. The mechanical shark used for filming "Jaws" is seldom seen in the film; and when the shark does appear, it is not very realistic. The mechanical shark, said to have been a trouble-prone device for the film crew, was used sparingly but still most effectively.

The scenes terrified movie-goers, despite the obviously fake shark and lack of the constant blood and gore of present-day high-tech movies. Countless children and many adults were fascinated, or traumatized, by the image of the voracious man-eating shark. As a result, sharks would be perceived as malevolent, man-eating creatures for several decades. Three or four decades after the release of the film, many movie-watchers would recall the powerful images every time they entered a beach. Others told the author that the catchy *"Jaws"* tune still plays in their heads whenever they enter a beach.

The movie had other unexpected long-term effects. In a country where fiction depicted on movies or television screens is easily taken for truth by a gullible public, the movie set off a shark killing frenzy that lasted nearly two decades. Sport fishing for sharks had gained popularity in the 1960's. Shortly after the movie appeared, shark fishing as a sport increased greatly, and in the next decade, dozens of shark fishing clubs and tournaments sprang up along the U.S. east coast. These tournaments were often held monthly during the summer at many seaside locations, from New York to Florida (Fig. 3).

The movie caused such antipathy toward sharks that some tournaments had prize categories for "the most sharks caught" and the "greatest number of pounds of shark landed." Emulating Quint, the fisherman in "Jaws," shark fishermen saw themselves as heroes ridding the seas of dangerous sharks.

In 1990–91, this author participated in the public hearings conducted during the preparation of the shark fishery management plan, which would place restrictions on the rapidly growing shark fishery. Commercial shark fishermen, opposing the enactment of legislation, often claimed that any restrictions on their fishery would result in dozens of shark attacks in coastal waters, their logic based on what they had seen in the "Jaws" movie.

This unfortunate attitude and ecological havoc persisted for nearly two decades. The ecological effects of the removal of large numbers of predators from the environment were not studied or recorded, because of the limited understanding of the biology of sharks and their ecological relationships. The U.S. recreational shark catch increased from 265,000 sharks in 1981 to a high of 746,600 sharks in 1983. After that year, the catch started to slowly diminish, and it had decreased to 66,300 sharks by 2004 (Cortés and Neer[10]).

Figure 3.—Shark fishing tournament, Port Salerno, Fla., Sept. 1986. Large crowds came to view the dead sharks.

Shark Television

The movie *Jaws* also engendered a new television genre. In 1988, the public fascination, or obsession, with sharks caused by the movie led the "Discovery Channel" to produce "Shark Week," a week-long series of programs based on sharks. The shows were instantly successful. In time, "Shark Week" would become the longest-running program on cable television, having lasted 28 years as of 2016.

In the early years, the shows were loosely based on natural history or conservation of sharks and were fairly realistic. Perhaps catering to what was attractive to the audience, programs soon became centered on white sharks or bull sharks, *Carcharhinus leucas*, and their attacks on people. Eventually, one show descended to toothy mechanical sharks propelled against watermelons filled with a red fluid. When hit by the mechanical sharks the watermelons exploded, splashing red fluid in all directions, a cinematographer's concept of a shark attach that could not fail to impress little children.

As satellite tags were developed and became widely used, filmmakers turned to shark tagging to replace the

[10]Cortés, E., and J. Neer. 2005. Updated catches of Atlantic sharks. SEDAR (Southeast Data Assessment and Review) 11, Doc. LCS05/06-DW-16, NMFS Panama City Lab., Southeast Fish. Sci. Cent., NOAA.

superannuated shark attack programs. The tagging of a large shark is always an exciting event and could produce the action footage that the networks loved. Because of the high cost of satellite tags, film producers could always find a willing researcher lacking funds or seeking publicity, although most of the time the "researchers" were usually unknown to those actually studying sharks. The "researcher" could assume heroic poses in the tagging film, which could be finished with the perennial "high fives" of such films. The networks loved it!

Tagging white sharks with satellite tags soon became a favorite subject of film producers and networks because it could be made into television programs complete with websites dedicated to tracking the tagged sharks. The public could then view the movements of a given white shark along the coast. Although more in the realm of entertainment than research, these programs served to educate the public that white sharks roamed our coasts and interacted with swimmers only infrequently.

In efforts to improve their ratings, some network programmers shifted more toward entertainment and "docufiction," where fiction was presented in the manner of documentaries. The first of these programs presented the discovery of mermaids (on "Animal Planet" in June 2012), and it was so "successful" that others of that ilk soon followed. Another piece of "docufiction" followed in "Shark Week" in August 2013, a program titled "Megalodon: The Monster Shark Lives," supposedly demonstrating the existence today of the extinct giant shark, *Carcharodon megalodon*.

These faux-documentaries, which included interviews with supposed experts (really actors), were somewhat confusing and misleading. But the presentation was so "effective" that it fooled naive adults and even some educated people into believing in the existence of giant sharks. School teachers at times called the author asking how to counteract these programs that confused their pupils.

The Rise of "Personal Shark Conservation Groups"

The most significant impact of "Jaws" was caused by the character "Matt Hooper," the irreverent shark biologist played by Richard Dreyfuss. This character, and its personification, would have a profound and long-lasting effect on the young audience, for it told them that there was such a profession as "shark biologist" and that one could have a career studying sharks.

Kids who saw the film often fantasized about being shark biologists. They were motivated by the imaginary social aspects of being a shark biologist, and their interest in sharks was often confined to the white shark. Years later, many would pursue careers in shark biology, and many of the people in shark biology today attest to seeing the movie and then deciding that they would be shark biologists. Unfortunately, the sad reality was that there were very few positions available in shark research.

A small number of the newly trained biologists found niches in academia, where they could pursue their research interests on sharks when their teaching load or grant money allowed. A smaller number would find employment in the government agencies or contract research companies conducting fishery research or sampling. Others, sometimes lacking the traditional training in biology or other sciences, would opt for careers in conservation or management, but sharks would remain their main interest.

Some would wait years for an academic or government position in shark research to become available or to be offered to them, often working on soft money or adjunct positions at institutions that would give them a desk and an adjunct title only if they brought grants that would pay for the overhead or rent. Yet others would work, in positions well below their qualifications, for many years to support their avocation, such was their commitment to their endeavor.

The flood of young people, influenced by the movie and determined to "do something with sharks," or wanting "to study behavior of white sharks," and searching for jobs with shark conservation groups far exceeded the number of positions or funding available in the large, well-established organizations. Thus, for many people there was only one way to self-actualize or to achieve their goals of "doing something" with sharks: to create one's own organization, or team up with similarly minded folks or a few acolytes, and create a new shark conservation group.

The result was the formation of a large number of shark conservation or protective groups, and a brief Internet search revealed dozens, if not hundreds, of such entities. The size of the organizations is quite variable; a few are large groups, many others are composed of only a few people, sometimes only one or two, with a web site. Their members may seldom interact with the scientific community, but some offer educational websites of varying quality. They often deliver their shark conservation message to children in grade schools, where teachers are only too glad to have someone come in and entertain their charges.

The Rise of Sharks as Totemic Animals

A common trait and peculiar aspect of many young people who, influenced by the movie "Jaws," wished to become shark biologists, was their general lack of interest in biology or natural history. This was surprising, because curiosity about animals or their natural history has always been the sine qua non of biologists. However, my many personal observations and conversations with shark-enthusiasts revealed that many were not interested in the natural history of sharks or any other animals. (Knowledge of natural history is necessary to ask the questions that provide hypotheses that can be scientifically tested.) To them sharks were attractive and "cool" animals rather than objects of scientific curiosity.

While based at a marine laboratory for well over a decade (2000–2013), I often brought rare sharks to the laboratory for examination. I used to announce to scientists and interns when I would have the shark available for viewing and when a necropsy would be performed. Hardly anyone ever came to see these rare fishes. When interns came, they came briefly, just long enough to take a "selfie" next to the shark, and left without bothering to examine it.

In a decade or two (~1995–2010), an unusual transformation occurred in the perception of sharks. In the society, sharks went from being feared animals to protected and even totemic animals. In the shark-enthusiast community, the combination of interest or mild obsessions with sharks, the desire to do something and protect sharks, and mysticism, resulted in sharks becoming totemic animals. Even for some in the field of ichthyology, sharks ceased to be "fishes" and became totemic animals.

Totemism is a complex social phenomenon where individuals or groups form a mystical or emotional relationship with a venerated or sacred object, the totem, usually an animal. Totemism was once considered a stage of religion through which all societies must proceed, a stage where animals, plants, and heavenly bodies were conceived as gods, before the advent of anthropomorphic gods (M'Lennan, 1869–70; Frazer, 1887).

Today, totemism, with its symbolism, is viewed as a culturally variable phenomenon (Leví-Strauss, 1963), and not as a general stage of man's cultural development (Haekel, 1986). I use the concept of totemism here because the behavior of many people towards sharks matches nearly all the characteristics of totemism given by ethnologists, and because of lack of a better concept to explain the facts.

As M'Lennan (1869–70) stated "what the Totem is cannot be conveyed in one sentence…and we must go somewhat into details." A survey of the literature on totemism (Radcliffe-Brown, 1965; Haekel, 1986) reveals some common characteristics to totemic phenomena:

1) There is an emotional relationship between a person, or group, and an animal (a kind of animal or a species), the totem.
2) The totem is sacred and revered, venerated, admired, or viewed with awe.
3) There is usually a prohibition (taboo) against killing, eating, or even touching the totem, especially if it is dead.
4) The totem may be a protector or may be protected.
5) Totemism often involves the use or wear of totemic emblems or designs.
6) The person, or group, shares the totem with other members of the group or clan.
7) Organization into totemic clans with defined rules of kinship and exogamy.

Most of the literature on totemism dates back to the late 19th or the early 20th centuries, when Europeans were learning about the "primitive" cultures they were destroying.[11] A form of totemism is common in modern societies, in the naming of sports teams, where aggressive animals are chosen as the totem, the animal's name is taken for the group or clan, and their totemic emblems are worn or displayed by members of the group.

As one would expect, the white shark became the most totemic of sharks. As such, it became the icon and the subject of many articles: from a yearly average of 2 articles on white sharks a year in "Zoological Record" during 1975–79, to an average of 5.8 articles a year during 1980–89, to an average of 32 articles a year in 2010–15, with a record 64 articles in 2015 (Fig. 4). Some authors published voluminously on the white shark, one author alone accounting for 10 (45%) of the 22 articles on white sharks published in 2004 of varying import.

The taboo against killing, eating, or touching the totem caused a change in the methods used to investigate the biology of sharks. Necropsies had been the foundation for most shark research and knowledge for decades. However, because the taboo included touching dead sharks, shark necropsies became unacceptable to many shark enthusiasts. Although research specimens could be easily obtained from the fisheries, as sharks continued to be fished for or were taken as bycatch, few of the enthusiasts would consider complementing their researches with necropsies. Other researchers have reported this taboo against killing sharks.

Heupel and Simpfendorfer (2010: 1213) wrote "Growing concern for shark populations appears to be increasing pressure not to kill these animals. This raises concern about how research on sharks is regarded and implications of publicity on the decline in shark populations. One noticeable result of the increase in concern about sharks is that more students inquiring about graduate school who are interested in working on sharks are indicating that they are not willing to participate in projects that may harm sharks. This occurs before they know which species are involved, the status of that species, or what benefits could be gained from lethal sampling. This suggests their perspective is not rooted in science, but is ethical, political, or emotive." Similarly, at a recent meeting of the American Elasmobranch Society (2016), the emphasis on using "non-lethal methods" was so great that speakers felt it necessary to state that "no sharks were harmed in this investigation."

Thus, tagging, DNA analysis, and stable isotope analysis became fashionable and the only acceptable modes of research for the shark enthusiasts, because these could be accomplished without violating the taboos. Taking a "fin clip" or blood samples from live animals were the only samples permissible. This meant that the diet of

[11]The topic seems to have gone out of fashion with ethnographers. Most of the recent literature consists of discussions or footnotes on Leví-Strauss (1963). According to Leví-Strauss, the term totemism covers only cases in which there is "a coincidence of" 1) a frequent identification of human beings with plants or animals, and which has to do with very general views of the relations between man and nature; 2) a designation of groups based on kinship, which may be done with the aid of animal or vegetable terms, but also in many other ways.

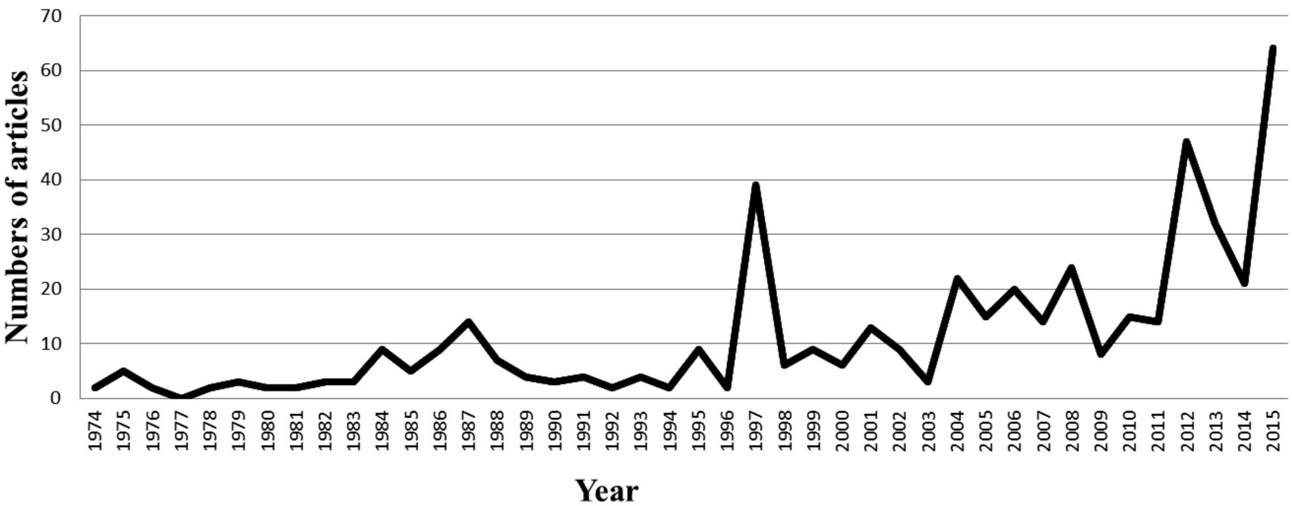

Figure 4. —The number of articles on the white shark per year 1974–2015. The peaks of 1986, 1996, and 2012 were caused by the publication of the white shark symposia. The peak for 2015 cannot be attributed to such cause.

sharks could only be analyzed through stable isotope analysis, with all the vagaries of the method, even when stomach contents analysis could be easily performed in specimens freely available in local fisheries.

In true totemic fashion, enthusiasts or clan members wear shark shirts, hats, pins or have tattoos of sharks (Fig. 5). They adopt names such as "Shark man" or "Shark Lady" or common names of shark species, e.g., "mako girl." Their calling cards invariably depict a shark.

Shark Biology Becomes Shark Advocacy

When sharks ceased to be "fishes" and became "totemic animals," much of shark biology evolved into advocacy. Although there were sufficient scientific, ecological, and economic reasons to protect sharks, a totemic relationship requires that the totem be protected and be a protector of the clan. Thus, it was necessary, in the advocates' view, to dispel "the myths created by Jaws," or the idea that sharks are, or could be, man-eaters.

The notion of sharks as man-eaters was not compatible with the relationship desired with the totemic animal. Furthermore, if sharks were man-eaters, or potential man-eaters, they would not be tolerated and could not be protected in a society where most people are not aware of the differences among domesticated, tamed, and wild animals. So, in the advocates view, totemic sharks could not be man-eaters. Thus, a change in perception was needed, and sharks had to be portrayed as harmless to humans.

One example of this desired change in perception is illustrated by the article by Neff and Hueter (2013), where they proposed "reclassifying human-shark interactions." These authors pointed out that there were different types of shark attacks and that the term "shark attack" carried the perception of fatal outcomes and was "outmoded." These authors suggested that human-shark interactions that resulted in fatalities should be termed "fatal shark bites" and that "the term 'shark attack' be avoided by scientists, government officials, the media, and the public, in almost all instances of human-shark interaction." Based on the response in many Internet sites, the idea was warmly received by many shark enthusiasts and advocates.

To attack is to set upon with sudden violence or force. Animals, domestic, tamed, and wild, can and do attack people (pit-bull terriers being a main culprit these days, accounting for a fatality every 21 days in the United States[12]). Attacks on humans by sharks are rare. The ranges of sharks and humans overlap only occasionally, in the beaches and coastal zones during people's leisure activities or in the open ocean after shipwrecks or the ditching of an aircraft. The causes of these attacks, varied and difficult to predict, have been described by Baldridge (1974) and need not be reviewed here.

Most situations of injuries to humans by sharks, called "shark attacks," are just bites. When a surfer's hand gets slashed by a shark, or when a man gets bitten while feeding sharks, it should not be classified as an attack. To call such events "attacks" is inaccurate and wrong, as Neff and Hueter pointed out, and an example of poor logic or reporting.

Similarly, when a person is swimming off a beach, or a ship-wrecked sailor is floating in the ocean, and is attacked by a large shark and maimed, killed, or devoured, it would be inaccurate and misleading to call that a "bite" or even a "fatal bite." Those terms are

[12]For statistics on fatal dog attacks in the United States see DogsBites.org.

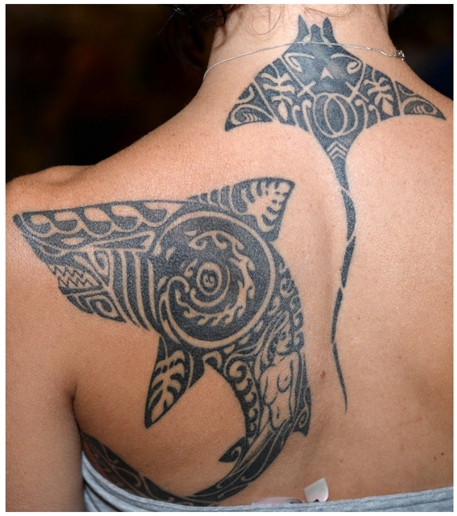

Figure 5.—Tattoos displayed by shark enthusiasts and biologists.

best used for interactions with creatures such as venomous snakes.

When a person steps on a cobra and gets bitten, it is referred to as "a bite" or "a fatal bite." No one refers to it as "a cobra attack." One must also note that in cases where crocodiles or bears attack and consume people, no one is suggesting that those attacks be termed "fatal crocodile bites" or "fatal bear bites" because those animals, although potential totems, are not totemic animals today.

Shark Literature in the Age of Advocacy

In an eloquent essay about fisheries in general, Hilborn (2006), noted the encroachment of advocacy into fisheries science: "This faith-based fisheries movement has emerged in the last decade, and it threatens the very heart of the scientific process-peer review and publication in the top journals…I assert that the peer review process has now totally failed and many of these papers are being published only because the editors and selected reviewers believe in the message, or because their potential newsworthiness…Critical peer review has been replaced by faith-based support for ideas and too many scientists have become advocates."

The problems of the shark literature in the Age of Advocacy are compounded by the lack of qualified reviewers, a perennial problem of the shark literature (Castro, 2011), and by the imposition of so-called "ethical standards" by editors. Today the logistics of shark research continue to be difficult, and with many researchers limiting their methodologies to tagging or getting blood samples, there are fewer researchers with the broad experience and technical expertise needed to properly review papers.

The increase in the numbers of journals that has occurred in the last decade, due to the rise of online journals, has resulted in greater competition for articles and for readers. These factors lead some editors to seek articles that will meet the advocates' approval, and to use unqualified reviewers who share their ideologies, and who are too happy to be considered qualified for the task. Examples are given below:

The cover of "American Scientist" of the March–April 2014 issue bears a photograph of a diver and a whale shark, *Rhincodon typus*, with the headline "Can tourism save the whale shark?" The author states, "The hunting of the whale sharks for their meat and oil-rich livers was once globally wide-spread although this practice has now largely stopped. Like other elasmobranchs…whale sharks have slow growth rates and reach sexual maturity late, making them particularly vulnerable to overfishing." And, "Evidence for declining catches over the past 15 to 20 years has placed the species on the Red List of Threatened Species, generated by the International Union for Conservation, and on the appendixes for several international conservation conventions." (Davies, 2014:118).

Is the whale shark threatened by any fishery? In reality there have been few fisheries for whale sharks. There have been none in the Western Hemisphere, and the ones from the Eastern Hemisphere (Taiwan, India, Philippines) have been small and localized. None operate today, although a few whale sharks are probably taken at remote locations by tribesmen in the Philippines.

Contrary to the implication of the statement of the species being "on the Red List of Threatened Species," the whale shark is listed only as "Vulnerable," a play on words to make the species appear threatened and support the author's unwarranted statements. To my knowledge, the oil of the whale shark has never been utilized commercially (although there was an unverified Internet report of use by the Chinese in 2014).

And the whale shark is one of the fastest growing sharks although the age at maturity is unknown. The "evidence" for declines must refer to one site in Taiwan, a fishery that operated in the 1990's and closed in 1998. Whether such lapses are due to researchers attempting to make their work appear novel, their ignorance or that of reviewers or editors, or the article agreeing with the ethical standards or marketing goals of the editors is unknown.

Another characteristic of the new publishing is the presentation of old knowledge as if it were new. For example, a 2013 article by Oliver et al. (2013) in "PLOS One," bears the title "Thresher sharks use tail-slaps as a hunting strategy," and concludes "The evidence is now clear; thresher sharks really hunt with their tails." The article is based on observations and films of threshers attacking prey. However, the fact that thresher sharks do use their tails to slap and stun prey has been known with certainty for nearly a century.

Allen (1923) provided a good description of a thresher shark using its tail to stun fish. And most modern books on sharks or shark biology refer to thresher sharks using their tail to obtain prey, e.g., "These sharks use their long, powerful tails to stun prey with sharp blows (Castro, 1983); "The caudal fin is also used as a whip to stun and kill prey, and threshers are commonly tail-hooked on longlines after striking the bait with the caudal tip" (Compagno, 1984); "Prey are rounded up near the surface and stunned by the shark's thrashing tail" (Last and Stevens, 1994).

There is also a long review of the knowledge of the use of the tail in prey capture by thresher sharks in Castro (2011:243–245). Were the authors or reviewers ignorant of the fact that thresher sharks use their tails to kill prey?

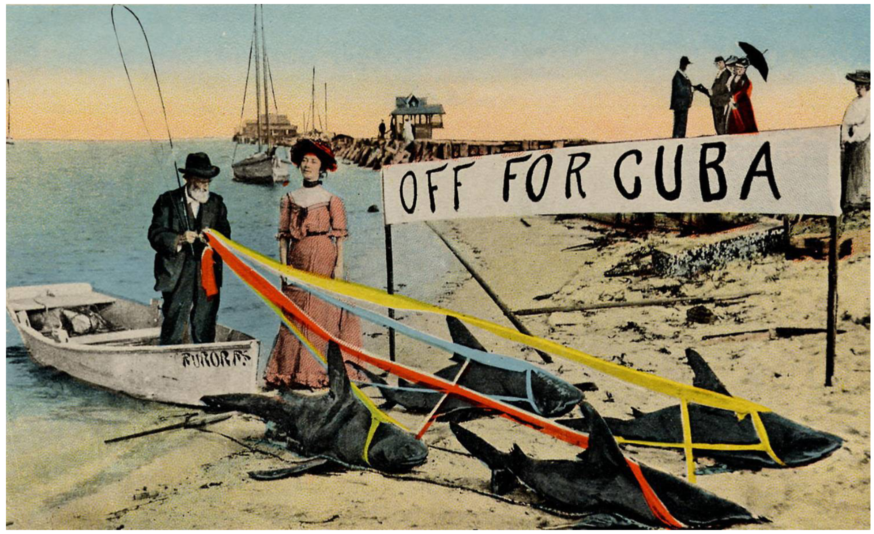

Figure 6.—Postcard from the early 20th century, said to be from the St. Petersburg, Fla., area, that demonstrate the idea of harnessing sharks as if they were aquatic horses.

Shark Research Today

Most of the logistical difficulties of the past are still with us, and shark research continues to be difficult. Today, much research is mainly concentrated on a few species of sharks, such as the totemic white shark and the "charismatic" whale shark. We have had countless articles on the white shark, and three symposia dedicated to the species in 1983, 1993, and 2010, resulted in three comprehensive publications (Sibley, 1985; Klimley and Ainley, 1996; Domeier, 2012a). But, despite more than 30 years of enthusiastic research attempts on these and a few other species, our knowledge is still fragmentary.

We have learned much about the migrations of white sharks in the northeastern Pacific through tagging in the last decade (for a summary see Domeier, 2012a). We know that U.S. west coast white sharks often travel to an area between the California coast and Hawaii that has been named the "Shared Offshore Foraging Area"[13] (Domeier, 2012b), but we do not know why. We have a generalized idea of where its west coast nurseries are, but where are the gravid females? We know little of its reproductive processes, and we still do not know its reproductive cycle or gestation period: "current estimates of gestation are guesses based on very little empirical data" (Domeier, 2012b:217). Age at maturity and longevity estimates vary widely, and always increase with the latest estimate. We know that white sharks usually die suddenly in captivity, but we do not know the physiological reason. Of the U.S. east coast population we know little. We do not even know where it gives birth (probably in the northern Caribbean).

[13]Also dubbed "the white shark café."

Of the whale shark, we know much less, and what we know was learned several decades ago. We do not know its life history, age at maturity, longevity, reproductive cycle, gestation period, migration patterns, location of its nurseries, physiology, etc. Yet, while so many researchers concentrate on the white shark or the whale shark, many other interesting or commercially important species are ignored, such as the ubiquitous shortfin mako, *Isurus oxyrinchus*.

Given the present reliance on tagging as the main research tool, it is unlikely that we will soon acquire a reasonable knowledge of the life history of the shark species we investigate or answer the many questions that exist about them. And it is unlikely that the emphasis on tagging sharks will change until the television stations and the public tire of programs of people tagging sharks.

Perhaps new tags will be developed that can increase our knowledge of these animals, but this remains to be seen. However, given the present trends, it is likely that progress will be slow until the field returns to scientific methods and hypothesis testing, and methodologies are aimed to answer the specific questions asked about these great fishes.

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