Written Testimony of

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Thank you to Chairman Barrasso and Ranking Member Carper for inviting me to testify on the topic of human-predator conflict as it relates to sharks. I am Senior Scientist and Chair of the Fisheries Science and Emerging Technologies (FSET) Program in the Anderson Cabot Center for Ocean Life at the New England Aquarium. The New England Aquarium is a catalyst for global change through public engagement, innovative scientific research, commitment to marine animal conservation, leadership in education, and effective advocacy for vital and vibrant oceans. Our mission is to conduct research on topics related to ocean health and conservation and to develop science-based solutions to marine conservation problems. Specifically, the FSET program has a strong background in utilizing cutting-edge technology to answer important fisheries questions, and sharks are one of its primary areas of focus.

I have studied sharks for over 20 years, starting as an undergraduate at Albion College in Michigan where I spent my summers assisting with a study of nurse sharks (*Ginglymostoma cirratum*) in the Florida Keys. I then spent eight years studying sharks in Hawai'i while earning a Masters degree and Ph.D. in Zoology at the University of Hawai'i at Manoa. I completed postdoctoral research and served as a Staff Scientist at Mote Marine Laboratory in Sarasota, Florida before joining the New England Aquarium (Boston, Massachusetts) and Newport Aquarium (Newport, Kentucky) in a joint appointment. I have published numerous peer-reviewed scientific papers as well as popular shark articles in magazines and the World Book Encyclopedia Online and have also appeared in various television documentaries on sharks. Over the course of my career I have tagged and studied over a dozen shark species, including the three species considered most dangerous to humans: the white shark (also known as the "great white shark," *Carcharadon carcharius*), the tiger shark (*Galeocerdo cuvier*), and the bull shark (*Carcharhinus leucas*).

Shark attacks on humans are tragic events that can have life-altering consequences for the victims, their families, and the community. Although fatalities are rare, averaging 4–6 per year globally, sharks bites can cause lasting injuries that require multiple surgeries and years of rehabilitation for recovery. While it is important to process these incidents in the broader context of science, shark behavior, and public perception, the impact of these incidents on victims cannot be overstated.

The history of human-predator conflict

Conversations about human-predator conflict should note that, from the time of the earliest humans, such "conflicts" have been incredibly one-sided. By virtually any measure, humans are the deadliest animal species that has ever existed. An examination of the fossil record around the world reveals a pattern that repeats itself over and over again: first humans arrive in a new region, then other large animals quickly disappear from that region. We have been so effective at eradicating large animals from early on in our species history that a recent summary concluded that our species "drove to extinction about half of the planet's big beasts long before [we] invented the wheel…" (Harari 2015).

The impact of human-predator conflict on sharks

While marine animals were largely spared eradication by prehistoric humans, technological developments over the past century allowed us to exploit marine resources at a rapid and unsustainable pace. For sharks, this has resulted in the slaughtering of ~100 million animals per year (Clarke et al. 2006). Much like the giant sloths and wooly mammoths we drove to extinction thousands of years ago, sharks are often slow-growing, long-lived organisms that produce relatively few offspring (Musick et al. 1999).

For instance, white sharks, including those swimming off of Cape Cod, Massachusetts, must survive for 26–33 years before they are old enough to start reproducing, and they may live to be over 70 years old if they are not killed by humans (Natanson and Skomal 2015). Once they reach maturity, a female white shark may produce only 7–14 offspring every one to three years (Francis 1996) as opposed to the millions of eggs that can be produced annually by many other fish species. This life strategy has served sharks well throughout their long evolutionary history, but is poorly-suited to withstand fishing pressure from humans. This is because, once the targeted adults are removed from a population, it can take decades for the surviving juveniles to reach maturity and start rebuilding the population. For this reason, shark fisheries have historically shown "boom and bust" patterns, marked by a rapid increase in catch rates at the start of a fishery, followed by rapidly falling catch rates, and collapse of the fishery shortly thereafter. Today approximately one quarter of the world's sharks and rays (close relatives to sharks) are threatened with extinction (Dulvy et al. 2014), with overfishing being the primary driver of population declines, followed by factors related to habitat loss and climate change.

Climate change is already impacting shark populations and may very well impact human-shark conflicts in prominent ways. Most sharks are ectothermic or "cold-blooded," meaning that their body temperature is the same as the water in which they swim. Warming water temperatures will increase a shark's body temperature thereby increasing its metabolic rate, causing it to burn calories faster, and requiring more food to replace those calories.

What we commonly see in sharks is a relatively narrow range of preferred temperatures, and animals will migrate seasonally to stay within that range. We are already seeing signs of temperature-related changes in shark populations on the East Coast, with several shark species being found further north than what has been historically observed. For instance, a recent study showed that bull sharks have established a nursery in Pamlico Sound, North Carolina over the past eight years whereas their northernmost nursery had historically been the Indian River Lagoon, Florida (Bangley et al. 2018). Also, the large migration of blacktip sharks (*Carcharhinus limbatus*) that makes headlines every year off the coast of

South Florida is known to be driven by water temperature (Castro 1996; Kajiura and Telman 2016), with some indications that this species is shifting northward.

The demonization of sharks in the modern media

Efforts to reduce human impacts on shark populations are hampered by the portrayal of sharks in modern media. Although the public image of sharks has improved substantially since the days of *Jaws*, the news media and popular television shows frequently cover shark incidents in the most sensational terms possible. Public fear of sharks can reliably draw readers and viewers on an otherwise slow news day, even when there hasn't been a shark incident. Television documentaries often feature staged attack re-enactments edited to look like authentic video footage of the original incident, then try to balance their messaging with a couple of sentences about shark conservation at the end of the show. With few exceptions, media coverage of shark bites or even shark sightings continues to be inflammatory and sometimes completely inaccurate regarding basic things such as species identification or descriptions of behavior.

Why humans need sharks

All of this is unfortunate because healthy shark populations are extremely valuable to humans. Economically, commercial shark fisheries are valued at over $1 billion annually when accounting for products that countries consume domestically (Dent et al. 2015; Dulvy et al. 2017), and shark eco-tourism may be worth over $300 million globally (Cinseros-Montemayor et al. 2013). This does not account for the value sharks provide as part of the recreational fishing industry, which is estimated to contribute $125 billion per year in the United States alone according to the American Sportfishing Association.

As apex predators, sharks may have a disproportionate impact on the rest of the food chain. There is evidence suggesting that removing top-level predators causes a "trophic cascade," meaning that the impacts cascade down through lower levels of the ecosystem (Stevens et al. 2000; Ferretti et al. 2010). For example, removing sharks from coral reef ecosystems can lead to overpopulation of mid-level predators, which then causes a dramatic reduction in the population of lower-level, algae-grazing fish species. Depletion of these species allows algae to overgrow the reef, killing the corals that build the reef itself (Bascompte et al. 2005). Sharks also play an oversized role in affecting the marine ecosystem through "indirect effects," such as affecting the behavior and distribution of large prey species (Heithaus et al. 2012).

Sharks represent a crucial part of the marine ecosystem, the health of which will determine if our planet remains habitable for the nine billion or more humans expected by 2050—many of whom are at risk and vulnerable. In addition to producing half of the world's oxygen and feeding billions of people, the ocean absorbs about 25% of the carbon dioxide and has taken up more than 90% of the heat added to the planet by humans (USGCRP 2018).

The Science of Shark "Attacks"

Although shark bites on humans are extremely tragic and can cause bodily injury and even death, these incidents are difficult to study and thus predict/prevent because of their rarity. The International Shark Attack File (ISAF) recorded a total of only 66 confirmed

unprovoked incidents across the entire world in 2018, five of which were fatal. The United States accounted for 32 of these 66 incidents, with half (16) of those taking place in the state of Florida. Other states with incidents included Hawai'i, North Carolina, and South Carolina (3 incidents each), New York and Massachusetts (2 incidents each, one fatal), and three other states (California, Georgia, and Texas) with a single incident each.

Although statistically humans have more to fear from dogs, cattle, and insects than they do from sharks, for most people in developed countries, sharks are the last remaining natural predators they may encounter. This, and the fact that sharks are usually invisible and undetected until the moment of a bite, may be why they inspire so much fear and interest in modern society.

In reality, shark bites on humans usually lack the passion and ferocity depicted in attack re-enactments on television, or that one might expect from a charging grizzly bear. This is not to diminish those instances of rare, but deadly, shark incidents—but the vast majority of shark bites on humans are likely "investigatory bites" in which a shark uses its mouth in an attempt to identify an unknown object, much the way humans might use our hands to examine something new. Sharks are capable of surprising dexterity with their mouths and teeth, frequently biting each other during mating, for instance, without causing serious damage (e.g., Pratt and Carrier 2001; Whitney et al. 2004). Further evidence for this lies in the clean puncture wounds seen on many shark bite victims, with no evidence of a stronger bite or head-shaking behavior that would be expected if the shark was trying to remove tissue. Although even these "bite and release" events can produce serious and devastating injury, they are often notable for their lack of severity given sharks' capabilities.

For this reason, most shark scientists now refer to shark "bites," rather than shark "attacks," and the American Elasmobranch Society, the world's largest group of shark scientists, has adopted a resolution calling for the Associated Press Stylebook and the Reuters Style Guide to do the same (Neff and Hueter 2013).

Other bites may take place when sharks are already in a feeding behavioral mode, perhaps because there are baitfish, seals, or other natural prey nearby and humans are mistaken for prey. In these instances, sharks are likely to behave far more aggressively. The best way to avoid these situations is to be aware of one's surroundings and avoid areas where baitfish are aggregating (often visible from fish jumping or sea birds overhead), where people are fishing or cleaning fish, areas near river mouths that may carry dead animals and other prey, or areas near known seal haulouts.

There is no evidence that supports the persistent—yet false—belief that sharks are territorial and will defend an area from other sharks or other animals for any period of time. While certain sharks will commonly "give way" to other (usually larger) sharks when they encounter each other, this does not equate to territoriality. In fact most large sharks are highly migratory and can move hundreds of miles in a matter of days. Although virtually every part of the world where humans encounter sharks has local stories of an individual shark (usually nicknamed) that "patrols" a specific area, further investigation almost always reveals that multiple sharks are moving in and out of the area frequently. There have been cases of sharks showing fin- and body-flexing postures and even biting when pursued by humans, but this is exceptionally rare and seems to happen when a human has followed the shark for an extended period or cornered it.

This leads to perhaps the most common way that people are injured by sharks, which is through "provoked attacks." The ISAF reported 34 provoked incidents globally in 2018 (compared to 66 unprovoked), but the vast majority of these likely go unreported. Sharks are intelligent predators that easily learn to associate certain stimuli or locations with food. Most fishing piers in the world likely have sharks nearby that have habituated to feeding on discarded catch or carcasses. Spearfishers commonly report sharks approaching in response to the sound of an underwater speargun being fired, even before any fish have been speared. These and other human activities greatly increase the likelihood of being bitten, and thus "provoked incidents" include bites on fishermen, people attempting to feed sharks, or divers that have tried to touch or harass sharks. Unfortunately, shark scientists engage in some of these behaviors by the nature of our work, and the various shark bites that I have been witness to or a "victim" of have all fallen under this provoked category.

White sharks around Cape Cod

Regarding shark-human interactions in the United States, the most recent area of focus has been in New England and the growing number of white shark sightings near the shores of Cape Cod, Massachusetts. This situation has been brought to light by five shark bites on humans in the area since 2012, including a fatality in 2018 that was the state's first shark-related death since 1936. The increase in white shark presence along the Cape is thought to be driven largely by the growing population of grey seals (*Halichoerus grypus*) that had been decimated in the area but started recovering after passage of the Marine Mammal Protection Act in 1972. Seals are a preferred prey item for white sharks, which are also showing signs of population growth since receiving protection in federal waters in 1997, and Massachusetts state waters in 2005 (Skomal et al. 2012; Curtis et al. 2014), though stock status is uncertain.

Overall the recovery of Atlantic white sharks and grey seals is considered a wildlife management success story, but one that has increased the likelihood of human conflicts with wildlife. In response to this, the Massachusetts Division of Marine Fisheries (MA DMF) has been conducting white shark research to understand increased shark activity and inform shark safety strategies. Starting in 2019, MA DMF partnered with the Atlantic White Shark Conservancy (AWSC) and the New England Aquarium to apply the latest in high-tech shark tag technology to quantify the nature and frequency of white shark feeding events on seals.

In the meantime, towns across Cape Cod and the South Shore, the Cape Cod National Seashore, the AWSC, and MA DMF have been working to raise awareness through community engagement and outreach. Research information is shared with safety officials, residents, and visitors so that decisions can be made using the best available data. See AWSC's public safety page for more info: https://www.atlanticwhiteshark.org/public-safety

Local officials are also working to increase the frequency of medical stations along Cape Cod beaches, since the biggest risk to shark bite victims is blood loss following the incident. Most fatalities happen once the victim has reached the beach but before they can receive expert medical aid to stop the bleeding. This may not appeal to residents who are looking for a "solution" to human-shark interactions, but it is likely the quickest, most effective way to minimize loss of life.

Although extensive shark research is ongoing, the best near-term solution is to focus on educating and changing the attitudes of humans who use the ocean. The Cape Cod National Seashore is a National Park and should be thought of like other prominent National Parks such as Yellowstone or Yosemite where humans can also encounter predators. These are national treasures where people can enjoy the sights and the wildlife, but where personal safety is not guaranteed and visitors must take proper precautions.

What can be done?

The increased risk of shark bites around Cape Cod has elicited an understandable desire for a "solution" to the problem from the local community and their representatives. Shark bite mitigation is an emotionally-charged issue that has produced multiple responses in various parts of the world.

Some of the earliest human responses to attacks in the 20th century were "shark hunts"—disorganized efforts to fish for and catch the culprit shark in the days immediately following an incident (Curtis et al. 2012). Such efforts were based on the now debunked assumptions that sharks were territorial and could develop a preference for hunting humans and that a culprit shark could and should be caught after an incident.

From 1959 through the early 1970's, the State of Hawai'i funded a number of large-scale shark culling programs in response to a series of bites including a high-profile fatality. Over 4000 sharks were caught and killed using baited longlines in these programs, but only ~12% of these were tiger sharks, the species responsible for nearly all shark attacks in Hawai'i state waters (Wetherbee et al. 1994). Inconsistency in the sampling methodology and seasonality make it difficult to determine whether these programs significantly reduced shark populations in the state, and they were found to have no effect in reducing the number of shark bites (Wetherbee et al. 1994).

For decades, some countries have utilized shark control programs involving the permanent deployment of nets or other fishing gear to catch and kill sharks that approach swimming beaches (reviewed by Curtis et al. 2012). The largest of these programs are based around discrete beaches in New South Whales and Queensland, Australia and off the KwaZulu-Natal province of South Africa. Nets and baited lines in these areas are not deployed to repel sharks but with the intent to reduce the population of large sharks in the area and thereby reduce the likelihood of shark-human interactions. These programs have been successful in substantially reducing the number of shark bites on humans in these areas, but they do not eliminate the risk completely (Curtis et al. 2012). Such programs are also expensive to maintain and have a high ecological cost since the nets kill large numbers of sharks as well as other marine life such as large fishes, sea turtles and marine mammals. For this reason, recently introduced shark culling programs off the coast of Western Australia have been highly controversial and met with public outcry.

Physical barriers to prevent sharks from entering beaches have been utilized in some parts of the world but are expensive to maintain and often logistically impossible due to the broad area that must be protected, and the constant threat of structural damage from wind, waves, and corrosion.

The costs associated with shark control fishing and physical barriers has led other communities to turn to increased beach surveillance, with the most notable example being

the Shark Spotters program in Cape Town, South Africa. Here a small staff of human spotters are employed at strategic locations overlooking the beach and send warnings when a shark is sighted, allowing lifeguards to clear swimmers from the water. This program is accompanied by a beach flag notification system and an extensive public outreach campaign to educate ocean users about the presence of sharks and best practices for avoiding shark incidents (Engelbrecht et al. 2017).

Public outreach and biological research

The implementation of public outreach and education programs, in conjunction with basic scientific research, is likely the most effective way to ameliorate the impact of shark-human conflict. For instance, shark hunts or state-funded culling have not been implemented in Hawai'i since research showed that the main species responsible for these bites, tiger sharks, are wide-ranging and often move between islands within a 24-hour period (Holland et al. 1999). This work demonstrated that trying to catch a "culprit shark" after a bite was a fruitless endeavor. A more recent study there has shown that tiger shark reproductive patterns and use of habitat around human recreational sites is responsible for an increased likelihood of incidents around the island of Maui compared to Oahu (Meyer et al. 2018).

Published and ongoing research on white sharks in Cape Cod waters using electronic tags and photo-identification has elucidated the seasonal movements of this species (Skomal et al. 2017). Further work is underway using high-tech accelerometer (Whitney et al. 2018) and camera (Papastamatiou et al. 2018) tags to quantify their feeding behavior on seals. Such information will be shared directly with the public in collaboration with the AWSC and the New England Aquarium.

To that end, the AWSC's "Sharktivity" smartphone app is a powerful example of using technology to integrate basic research with public outreach. This app provides up-to-date information on the group's work tagging and tracking white sharks in the area while also allowing members of the public to submit their own shark sightings via photographs and videos. This technology disseminates research findings and encourages users to get to know individual sharks through their movements, demystifying them while also raising awareness of their presence. Shark tracking websites and apps from other institutions—most notably the non-profit group Ocearch—are also proving effective at engaging the public on these issues.

Research provides crucial information about the biology and behavior of these species that, when effectively communicated to the public, can reduce the fear factor and allow people to make informed decisions about their own use of the ocean.

Importance of innovation in discovery-driven research

The New England Aquarium has a long and robust history of conducting discovery-based scientific research that informs decision-making in support of responsible management of ocean resources. Our scientific research is cutting edge and relies on emerging technologies, big data, and predictive modeling to understand marine species that are inherently difficult to study from the surface. Studying these species is critically important to managing human impacts on the ocean and to working towards balancing human needs with ecosystem needs.

Like other scientific institutions across the United States, federal funding provides critical support to The New England Aquarium's research programs. In recent years, challenges and prizes have gained in popularity as an instrument for encouraging innovation and, if administered effectively, have the potential to accelerate technology development and increase the diversity of participants (individuals, teams, or organizations) addressing a given challenge.

While technology and innovation have an important role in enabling scientists to develop a greater understanding of predators, prey, and how they are interlinked, they have also enabled humans to become more effective predators ourselves.

Scientific research underpins our understanding of the natural world. It can also inform best practices to minimize the impacts that humans have on the planet and to achieve balance between human activities and the ecosystems that sustain life on Earth. The recent U.N. biodiversity study found that one in four species is at risk of extinction and further asserts that human activities are the cause (IPBES 2019). As the most intelligent and deadliest predator the world has ever known, the responsibility to prevent the majority of these conflicts lies with us.

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