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SHARKS!

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BEFORE THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

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SHARKS!

WEDNESDAY, JULY 18, 2018

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Committee met, pursuant to notice, at 10:24 a.m. in room SR–253, Russell Senate Office Building, Hon. John Thune, Chairman of the Committee, presiding.

Present: Senators Thune [presiding], Fischer, Sullivan, Heller, Gardner, Capito, Young, Nelson, Cantwell, Blumenthal, Baldwin, and Hassan.

OPENING STATEMENT OF HON. JOHN THUNE, U.S. SENATOR FROM SOUTH DAKOTA

The CHAIRMAN. Good morning. Welcome.

Today we are here to discuss innovations in shark research and technology.

What many of you may not know is that my home state of South Dakota has a long history with sharks. We have a connection that scientists date back 70 million years, from a time when South Dakota was covered by shallow seas. My State was once home of relatives of the great white shark, and we can still find their fossilized teeth today. So these are teeth that come from South Dakota. The Ginsu shark, whose tooth I have here, was named after its teeth—teeth that were sharp enough to take down the occasional dinosaur. And in fact, relatives of the Megalodon also swam in those seas. If anyone has seen the trailer for the soon-to-be-released movie “The Meg,” you will know not to turn your back on our South Dakota sharks. This is a tooth of the Megalodon right there. That could do some serious chomping.

But even before the movie “Jaws” was released in the 1970s, Americans have been fascinated by sharks. Aquariums and other educational programs have helped to demystify sharks, and our initial fear is turned into fandom.

Now, “Shark Week” is watched by millions of viewers every year and is celebrating its 30th anniversary.

But because they often live deep in the oceans, learning about many species of sharks is extremely difficult. Increasing our understanding of sharks has required innovation from shark scientists and engineers using everything from medical X-rays to satellites in outer space. These scientific efforts inform the management of shark stocks through the Magnuson-Stevens Fishery Conservation and Management Act. Under this Act, U.S. fisheries, including shark fisheries, are the best managed in the world.

To improve management of sharks, this Committee has passed both the Sustainable Shark Fisheries and Trade Act and the Shark Fin Trade Elimination Act. Among other things, these bills would protect sharks by regulating trade in shark fins.

Today, we are going to hear from four scientists from across the United States who are pushing the boundaries of what we know about sharks. This shark research is being used to improve American lives by increasing our understanding of oceans and fisheries and creating new innovations in engineering and even searching for medical breakthroughs.

For example, research on the aerodynamics of shark skin is being used to improve the design of airplanes, and shark cartilage is helping burn victims heal faster. Sharks were one of the first fish to carry satellite tags, leading to much better management of other highly migratory species in American fisheries, such as tuna and swordfish.

As it turns out, our fascination with sharks is more than justified, and I look forward to hearing from our expert witnesses today.

I am going to turn now to our Ranking Member, Senator Nelson, for his opening statement. Senator Nelson.

STATEMENT OF HON. BILL NELSON, U.S. SENATOR FROM FLORIDA

Senator NELSON. Well, Mr. Chairman, you definitely taught me something. I did not know that South Dakota had sharks.

But let me tell you what we have in Florida.

[Laughter.]

Senator NELSON. And Dr. Hueter is going to show you a video of the tagged sharks and how they are swimming ominously around the shores of the peninsula of Florida. You will see how we track those.

But we have another person that is well noted with regard to commentary on sharks, and that is Jimmy Buffet because as he introduces one song, he says, fins to the left, fins to the right. I bet you do not have that in South Dakota.

[Laughter.]

Senator NELSON. And I want to welcome Dr. Hueter from Mote Marine Laboratory in Sarasota. He is the Director of their Center for Shark Research, which is the only congressionally designated center for shark research in the country. He also serves as the Chief Science Advisor for OCEARCH, and that is a nonprofit that does shark tagging and research and provides free, open-source data and education.

Now, this Global Shark Tracker app that I looked at this morning is going to be explained by Dr. Hueter in just a minute.

Our other three witnesses have Florida connections as well.

Dr. Dove oversees the Georgia Aquarium Center. It is the conservation field station, which is located, lo and behold, in Flagler County, Florida.

Dr. Wilga received her Ph.D. from the University of South Florida in Tampa.

And Ms. Kukulya used the remote environmental monitor unit off the coast of Panama City as part of the Autonomous Underwater Vehicle Fest.

And I am delighted by the Florida representation here today.

We are trying to lead the way in shark research. We have one of the longest coastlines in the U.S. and are home to many types of sharks. We have some of the world's top experts, including those right here on the panel. We have some of the world's best research centers for shark research not only at Mote, but also Florida, Miami, Nova Southeastern, FAU, and FIT, and even more. And earlier this year, Florida researchers even discovered a new species of shark, the Atlantic sixgill shark.

Sharks are important to Florida's economy, supporting commercial and recreational fishing and ecotourism shark diving adventures. You know, I took you on an airboat in the Everglades to see alligators and Burmese pythons. Let us go shark fishing.

[Laughter.]

Senator NELSON. Believe it or not, some people pay money to swim with sharks.

Sharks also help keep the ecosystem in balance and are important for the health of Florida's coral reefs, which are already suffering from a disease outbreak and warming water temperatures.

Now, there is some reason to fear sharks also, and just last week, there was a rare double shark encounter at Fernandina Beach in northern Florida with two men being bitten within the same hour. Fortunately, those are non-life-threatening.

I want to thank the local fire department for quickly responding to the situation, immediately closing the beach until it was safe to reopen. But the reality is that the chances of an encounter with a shark are very low. Of millions of tourists visiting the beaches and getting in the water, there are just a handful of encounters.

There is a lot that we can learn from sharks. Sharks have been used to produce potential cancer-fighting and antibacterial medicines, smarter and more energy efficient designs, faster swimsuits used by the Olympic athletes. I did not know about them being used on airplane skin. I look forward to the hearing about these developments and others.

And given the long list of shark researchers around the country, I suspect that we are going to hear from some of them with more information on sharks. So thank you. And I ask for unanimous consent that any such comments that may be sent to us be included in the record, Mr. Chairman.

The CHAIRMAN. Yes, without objection. Thank you, Senator Nelson.

And I would say that in South Dakota I am not worried about—after having visited the Everglades with you and seen pythons, I am not worried about getting bit or swallowed by a python in South Dakota because I discovered the one thing they cannot tolerate is cold weather. And I am also not worried about shark bites in South Dakota. But at least it sounds like at some point in our State's history, we had that issue.

But I want to recognize now Senator Sullivan. I understand there is a distinguished Alaskan that you would like to introduce.

STATEMENT OF HON. DAN SULLIVAN, U.S. SENATOR FROM ALASKA

Senator SULLIVAN. Yes, sir, Mr. Chairman, and thank you very much.

I am pleased to introduce one of the panelists today, Dr. Cheryl Wilga, who is the Director of Biological Sciences at the University of Alaska, Anchorage, UAA, as we call it back home, a great institution that produces world-class scientists like Dr. Wilga. She is a leader in Alaska's university system. She has conducted incredibly important work on biological research and functional morphology. I have no idea what that is.

[Laughter.]

Senator SULLIVAN. But I am looking forward to hearing about it, which she will share with us today.

She also works tirelessly with students across Alaska as part of the Alaska Native Science and Engineering Program called ANSEP, and we are certainly proud of her work.

Dr. Wilga is a proud Athabaskan Alaska Native like my wife and my daughters. She got her start in academia at Kodiak College in Kodiak, Alaska, studying on our country's second largest island, which is in the Gulf of Alaska, which surely had an impact on her. Some of you know Kodiak is a magical place in many ways. The sea is essential to Kodiak. It is home to one of the largest fishing ports in the country, the largest Coast Guard station in the country, and it also has the biggest brown bears in the world, Kodiak bears. So, Mr. Chairman, maybe we can do a later hearing in the Commerce Committee just called "Bears."

[Laughter.]

Senator SULLIVAN. So we could do both.

As an undergraduate, she began to do study and research on boney skeletons of pollock, cod, and halibut. She said that the undergraduate research she did at Kodiak College and as the distinguished member from Florida, Senator Nelson, mentioned her later Ph.D. from the University of South Florida allowed her to develop a strong interest in all of the issues we are going to be talking about today. She did do her Ph.D. in Florida and then came back to Alaska.

She is going to discuss shark fossils biomechanics and how research is being applied to medical technologies. So really, really cutting-edge issues. And, Dr. Wilga, I look forward to your testimony.

I have to preside at 11 that is the only thing that will keep me from participating more in this hearing.

So thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Senator Sullivan.

And I do not think the Committee has jurisdiction over bears.

[Laughter.]

The CHAIRMAN. We have the rest of our panel today: Dr. Alistair Dove, who is Vice President of Research and Conservation at the Georgia Aquarium; Ms. Amy Kukulya, who is Principal Investigator and Senior AUV Operations Engineer at Woods Hole Oceanographic Institution; and Dr. Robert Hueter, who is the Director of the Center for Shark Research at Mote Marine Laboratory. So a great panel. We look forward to hearing from you.

I will start on my left and your right with you, Dr. Dove, and would ask you, if you can, to confine your oral remarks as closely to 5 minutes as possible. We will make sure that your entire statement is included as part of the permanent hearing record. And that will give us an opportunity to ask some questions. Dr. Dove, please proceed.

STATEMENT OF DR. ALISTAIR DOVE, VICE PRESIDENT, RESEARCH AND CONSERVATION, GEORGIA AQUARIUM

Dr. DOVE. Thank you, and good morning, Senators.

It is in the national interest for us to have healthy and abundant oceans to provide us with ecosystem services like food, transport, mineral resources, and recreation. Globally, these ocean assets have been valued at more than $24 trillion, delivering $500 billion worth—that is with a B—of benefit to humankind annually.

And to have those abundant oceans, we need healthy shark populations to play their roles as regulators in the marine food web. But this need is under threat because about a quarter of shark species populations are at risk of extinction primarily through the removal of roughly 100 million sharks per year by fisheries, both legal and illegal.

Improved shark conservation is also expected increasingly by a public as sharks have transitioned from being a widely vilified and feared group to their current status as a more iconic and widely admired group. You only need to look at the success of Discovery's "Shark Week" to see what I am talking about, or perhaps even this very hearing.

Public aquariums have a very important role to play in increasing public understanding and appreciation of sharks. The 55 AZA accredited aquariums across the country inspire millions of guests every year through live animal exhibitry, allowing them to create personal connections with these mysterious and ancient animals and motivating them to protect sharks for future generations. Many aquariums have their own in-house research and conservation programs that work hand in hand with academia and the NGO sector to advance shark science and conservation. At Georgia Aquarium, which is a 501(c)(3) nonprofit in Atlanta, we have a long track record studying whale sharks and manta rays, and we are beginning to diversify more into studying more quintessentially toothy sharks as we work on a major expansion project focusing on a shark exhibit, which will open in 2020.

Successful research on sharks is no mean feat because many sharks are highly migratory, which means they traverse large areas of the ocean and frequently cross many different jurisdictions and borders in the process. Advances in technology have made it possible for us to follow along with what sharks are doing when we are not able to follow them. And in particular, different types of satellite tags, which I believe Dr. Hueter is going to show you a couple of those in a moment—these tag devices have allowed us to answer and ask more sophisticated questions about the biology of sharks. These devices frequently contain sensors like you would find in a smart phone, and they relay information back to the scientists via satellite every time that iconic dorsal fin breaks the surface of the ocean. These studies have shown, for example, that even a single whale shark can cross the entire Pacific Ocean from the Gulf of California to the Mariana Islands. So these animals truly are global citizens.

But there are some significant challenges that face scientists who are trying to understand the biology of sharks. One really simple but really vexing problem is that we have very limited options when it comes to the different types of satellite assets that scientists can have access to. Almost all satellite tagging with sharks and most other animals as well is done through the French-based ARGOS satellite system, which was developed in the late 1970s. This legacy system forms a de facto monopoly that is ripe for disruption especially by open source initiatives. One such initiative called the Next Generation Animal Telemetry Project is currently being considered by the Bureau of Ocean Energy Management and NASA, and it would utilize the revolution in small open platform satellites, often called cube sats, to massively expand the coverage and available bandwidth.

Congress has an opportunity to help advance research and conservation for sharks greatly in three ways.

First, by encouraging and supporting strategic regulatory changes and funding initiatives that would open up the satellite sector, encouraging open source initiatives in particular, and increasing scientists' access to a wider array of satellite assets. I encourage the Committee to support exactly the kinds of initiatives represented by the BOEM and NASA cube sat project.

Second, Congress should institute and fund programs to support accredited aquariums in their efforts to promote shark research and conservation to the public. As non-traditional research facilities, it can be difficult for AZA facilities to tap into the National Science Foundation and other Federal funding sources. And right now, the Institute for Museum and Library Services is perhaps the only other Federal agency that is offering explicit support for zoos and aquariums, and that tends to be focused more on education.

Third, Congress should encourage and support multilateral management initiatives that aim to protect sharks as they cross international borders. The best example I can give you is the whale sharks. There is presently no regional agreement between the United States, Cuba, Mexico, Belize, and Honduras to manage the whale shark population that is shared by these countries, and one is sorely needed.

The evolution of public perception of sharks from vilified predators to cherished icons is welcome and overdue in my opinion. But there is still a tremendous amount that we need to do if we are going to promote the recovery of their populations to a point where they can ensure the healthy and abundant oceans that we all benefit from. And I thank you for the opportunity to speak on their behalf today.

[The prepared statement of Dr. Dove follows:]

PREPARED STATEMENT OF DR. ALISTAIR DOVE, VICE PRESIDENT, RESEARCH AND CONSERVATION, GEORGIA AQUARIUM

Good morning. It is in the national interest for us to have healthy and abundant oceans to provide us with ecosystem services like food, transport, mineral resources and recreation. Globally, ocean assets have been valued at 24 trillion dollars, delivering more than half a trillion dollars' worth of benefit to humankind annually. To have abundant oceans, we need healthy shark populations to play their important role as regulators of the marine food web. This need is under threat because 25 percent of shark species are at risk of extinction, largely due to the extraction of over 100 million sharks by fisheries every year. Improved shark conservation is increasingly expected by the public as sharks have transitioned from being widely vilified to their current status as an iconic and widely admired and respected group. You only need to look at the success of Discovery's Shark Week to see what I mean, or perhaps this very hearing.

Public aquariums play an important role in increasing public understanding and appreciation of sharks. The 55 AZA Accredited aquariums across the country inspire million guests per year through live animal exhibitry, allowing them to create personal connections to these extraordinary and ancient animals and motivating them to protect sharks for future generations. Many aquariums have their own in-house research programs that work with partners in academia and the NGO sector to advance the science and conservation of sharks. At Georgia Aquarium, which is a 501c3 non-profit aquarium in Atlanta, we have a long track record studying the ecology of whale sharks and manta rays, and we're expanding to study and conserve more quintessentially "toothy" sharks as we prepare for a major expansion project focusing on sharks, which is set to open in 2020.

Successful research on sharks is no mean feat because many sharks are highly migratory, traversing huge expanses of ocean and crossing through many different jurisdictions and borders in the process. Advances in technology have improved our ability to understand what sharks are doing when they go beyond our ability to follow in person. In particular, different types of electronic tag devices allow us to answer increasingly sophisticated questions about shark biology. Many of these tags incorporate sensors like you might find in a smart phone, and they connect the sharks to the scientist through satellite link-ups whenever that iconic dorsal fin breaks the surface. These studies have shown, for example, that a single whale shark can cross the entire Pacific ocean from the Gulf of California to the Mariana Island; these animals truly are global citizens.

There are some significant challenges that face scientists trying to understand the biology of sharks. One simple but particularly vexing problem is that we have very limited options regarding the satellite systems that scientists can access. Almost all satellite tagging with sharks uses the French-based CLS–ARGOS satellite system developed in collaboration with NASA and NOAA in the late 1970s. This legacy system forms a de facto monopoly that is ripe for disruption by open source initiatives. One such initiative called the Next Generation Animal Telemetry Project is currently being considered by the Bureau of Ocean Energy Management and NASA and would utilize the revolution in small open platform satellites, often called "cube sats", to massively expand the coverage and available bandwidth.

Congress can help shark research and conservation greatly in three ways. First, by encouraging and supporting strategic regulatory changes and funding initiatives that open up the satellite sector, encouraging open-source initiatives in particular, and increasing scientists' access to a wider array of satellite assets. I encourage the committee to support exactly the kinds of initiatives represented by the BOEM/NASA cube sat approach. Second, Congress should institute and fund programs to support accredited aquariums in their efforts to promote shark research and conservation. As non-traditional research facilities, it can be difficult for AZA facilities to tap into NSF and other Federal funding sources; right now the Institute for Museum and Library Services is perhaps the only Federal agency offering explicit support to zoos and aquariums. Third, Congress should encourage and support multilateral management initiatives that aim to protect sharks across international borders. For example, there is presently no regional plan with Mexico, Cuba, Belize and Honduras to manage the whale shark population shared by these countries, and one is sorely needed.

The evolution of public perception of sharks from vilified predator to cherished charismatic icon is welcome and overdue. But there's still a tremendous amount we need to learn if we are to promote the recovery of their populations to a point where they can ensure the healthy and abundant oceans that we all benefit from. Thank you for the opportunity to speak on their behalf here today.

The CHAIRMAN. Thank you, Dr. Dove.

Mrs. Kukulya.

STATEMENT OF AMY KUKULYA, PRINCIPAL INVESTIGATOR, SENIOR AUV OPERATIONS ENGINEER, WOODS HOLE OCEANOGRAPHIC INSTITUTION

Ms. KUKULYA. Chair and members of the Committee, I am Amy Kukulya, Principal Investigator and ocean robotics engineer at the Woods Hole Oceanographic Institution, which is the world's leading independent, nonprofit organization dedicated to ocean research, exploration, and education.

Thank you for inviting me today to testify.

My introduction to sharks came like many people, through the movie "Jaws." That movie is now more than 40 years old, but I believe it remains the primary reason why, when people think about sharks at all, they imagine ferocious eating machines that hunt humans. Thankfully, the entertainment industry has also helped advance innovative shark research and technology to help correct and broaden that perspective.

Privately funded programs like Discovery Channel's "Shark Week," a perennial ratings winner that has lasted 30 years, have also helped raise awareness of the importance of the sharks in our ocean's ecosystem.

One effort that I lead, *Project SharkCam,* has received $2 million over the past 6 years from Discovery Channel. It has had a significant impact on our understanding of the ocean's top predators. We now know they are not your average fish, that they help regulate ocean food webs, including many commercially important fisheries. Perhaps even more importantly, it has also had a side benefit of inspiring future scientists, engineers, and stewards of the sea.

My colleagues and I at WHOI's oceanographic systems lab developed SharkCam by leveraging REMUS, the autonomous underwater vehicle. REMUS was developed at WHOI thanks to strategic government investment from the Office of Naval Research and the Naval Oceanographic Office over the past 2 decades and is now the world's most widely used underwater robot. Thanks to this early and continuing government investment, the next generation of ocean-going robots are now accessible to scientists and researchers around the world from a number of companies, and a new industry has grown up around autonomous underwater technology.

SharkCam combines this innovative platform with underwater acoustic or sound communications in order to create a system to track, follow, and film a tagged animal. With it, scientists can now investigate the behavior, habitat use, and feeding ecology of sharks when they move out of sight and into their own environment.

In 2012, we successfully tagged and filmed our first shark in the waters of Cape Cod, revealing that great white sharks were hunting in shallower water than researchers had previously known. They hugged the ocean floor, swimming in turbid water as shallow as 6 feet, heavily relying on their sense of smell to hunt mostly seals.

Since then, we have filmed more species of sharks, including basking, bull, and great hammerheads, all in a very different habitat at depths down to nearly 1,000 feet. At every step of the way, we have discovered more about these incredible animals, including never before seen hunting, territorial, and sleeping behavior. We have also adapted the technology to follow endangered leatherback sea turtles and are working on modifications to track even more marine animals. Further investment in this technology will be instrumental in providing visual data to help develop effective policies and management strategies around the globe.

In order to continue this important work, we need to expand our public-private partnerships which will require enhancing public investment in basic research.

In the administration's draft of "Science and Technology for America's Oceans: A Decadal Vision," there is a very telling statement that I think will stand the test of public comment. It reads: "The ocean science and technology enterprise can provide the foundational knowledge needed to address many complex ocean-related challenges and inform decisionmaking that will ultimately strengthen our Nation and its communities." That is what we are after, foundational knowledge to address complex challenges and inform decisionmaking to strengthen our Nation and its leadership in understanding and managing our global interconnected ocean.

I want to thank the Discovery Channel and the many foundation and individual donors for their foresight and commitment in helping advance our national interests and the sharks themselves because they also contribute. They help keep the ocean healthy, which has untold economic, environmental, and cultural and spiritual value. Without sharks and the technology to understand them, our ocean and our nation would be a much different, poorer place.

And that concludes my oral testimony. Thank you for the opportunity to testify before the Committee today, and I will be happy to answer any future questions.

[The prepared statement of Ms. Kukulya follows:]

PREPARED STATEMENT OF AMY KUKULYA, PRINCIPAL INVESTIGATOR, SENIOR AUV OPERATIONS ENGINEER, WOODS HOLE OCEANOGRAPHIC INSTITUTION

Chair and Members of the Committee, I am Amy Kukulya, Principal Investigator, senior autonomous underwater vehicle (AUV) operations engineer at the *Woods Hole Oceanographic Institution,* the world's leading, independent non-profit organization dedicated to ocean research, exploration, and education.

Thank you for inviting me to testify today on sharks and innovations in shark research.

My curiosity about the ocean started on my grandparents' dock in Barnegat Bay, N.J., where I first became fascinated with what lies beneath the surface. I spent my early academic years studying krill, the most abundant animal in the ocean and one that helps support marine food webs worldwide.

I have since dedicated myself to being a steward of the ocean, conveying my fascination with the ocean to people of all ages and acting as a liaison between the technology and science communities. In the process, I have also come to recognize and appreciate, on a very personal level, the many ways the ocean nurtures my own family and enriches my community.

The greatest takeaway from my years as an aspiring marine biologist was that without the right tools, advances in the science that explains how the ocean works and how it affects us on land is hindered. And without good science, effective policy and legislation cannot happen at the rate we need in order to keep pace with the changes we are seeing in the ocean today.

That realization led me to embark on a journey to develop new, innovative tools to help solve some of the problems that scientists and policy makers want to address. One effort I lead, *Project SharkCam,* has had a significant impact on our understanding of the ocean's top predators. Perhaps even more importantly, it has also had a side benefit of inspiring future scientists, engineers, and stewards of the sea. I will spend the remainder of my time discussing that technology and showing how it connects with other types of big fish research techniques. I'll also be showing video of what this technology looks like and the potential of what it can do after I finish my testimony.

My introduction to sharks came, like many people, through the movie “Jaws.” That movie is now more than 40 years old, but I believe it remains the primary reason why, when people think about sharks at all, they generally imagine ferocious eating machines that are a significant threat to humans. Thankfully, the entertainment industry has also supported advancement of innovative shark research and technology to help correct and broaden that perspective. Privately funded programs, like The Discovery Channel’s “Shark Week”—a perennial ratings winner that has lasted 30 seasons—have helped raise awareness of the importance of sharks to the ocean’s ecosystem. They have also contributed to our efforts to better understand sharks in their native habitat. Our research and engineering team at WHOI has received nearly $2 million over the past six years from Discovery Channel for our work developing and improving *SharkCam technology*. That investment alone accounts for the vast portion of funded shark research at WHOI over that same period, a trend we have seen growing over the years, in which private support far outstrips Federal funding for shark research.

In the ocean, it is very difficult to directly observe the behavior of large, wide-ranging animals. This is particularly true for feeding behavior because predation events are rarely documented. Indeed, much of what is known about the foraging behavior of sharks comes from a limited number of direct observations in shallow water (*Tricas, 1985*), from submersibles (*Nelson et al., 1986*) and from animal-borne imaging (*Marshall, 1998*). Given the lack of such observations, the feeding ecology of large oceanic animals has been inferred from tagging and tracking data (*Skomal & Benz, 2004*), stomach contents (*Cortés, 1997*) and fatty-acid and stable-isotope analyses (*Iverson et al., 2004; Estrada et al., 2006; Hussey et al., 2012*). While such information can be useful for identifying critical habitat and food web relationships, these studies reveal little about animal behavior (*Skomal & Kukulya, 2015*), a key motivation behind the development of SharkCam.

My colleagues and I at WHOI’s Oceanographic Systems Lab (OSL) developed SharkCam by leveraging the REMUS autonomous underwater vehicle, which was developed at WHOI thanks to strategic government investment from the Office of Naval Research (ONR) and the Naval Oceanographic Office (NAVOCEANO) and is now the world’s most widely used underwater robot. REMUS is known primarily for its role in enabling undersea mine countermeasure and deep-ocean search and survey work and is changing the way we explore and map the ocean. Thanks to this early government investment, a new generation of ocean-going robots are now accessible to scientists and researchers around the world and a new industry has grown up around autonomous underwater technology. With SharkCam, our goal was to leverage this innovative platform, as well as underwater acoustic or sound communications, which I will describe shortly, to create a system to track, follow, and film a tagged animal in the wild so that scientists could investigate the behavior, habitat use, and feeding ecology of sharks when they move out of sight and into their own environment.

There are more than 500 species of sharks, all of which have their own distinct behaviors and many of which are threatened, largely due to overfishing and shark-finning. As apex predators at the top of the food chain, sharks play a key role in ensuring the health and diversity of marine ecosystems, including many commercial fisheries, by maintaining balance in the food webs below them. Despite their importance, we still don’t know where most sharks go for much of the year or why, where they mate, or where they give birth. We do know, however, that shark populations cannot sustain the level of human impact we see around the world, but without a basic knowledge of their behavior and life cycle, it’s impossible to properly develop effective management strategies that adequately protect sharks.

In 2012, we successfully tagged and filmed our first shark in the waters of Cape Cod, revealing that white sharks were hunting in shallower water than researchers had previously known. They hugged the ocean floor, swimming in turbid water as shallow as 6 feet, heavily relying on their sense of smell to hunt mostly seals.

Since then, we’ve filmed more species of sharks, including basking, bull, and great hammerheads, all in very different habitats and at depths down to 300 meters (nearly 1000 feet). At every step of the way, we’ve discovered more about these incredible animals. We have documented subsurface behaviors never before seen such as sleep-gliding, deep-water ambush attacks, steep vertical dives, territorial behavior, and detailed sequences that document the methodical process before, during and after an attack. We’ve also adapted the technology to follow endangered leatherback sea turtles and are working on modifications to track even more marine animals. This technology will be instrumental in providing visual data to help develop effective policies and establish management around the globe.

Researchers have been tracking sharks using acoustic and satellite tags for more than half a century. In the 1960s WHOI researcher Frank Carey led development of implanted tags, which eventually led to sound-emitting acoustic tags, a baseline of technology that is still in wide use.

Today, animal-borne tags come in many forms, some of which have been commercialized, and can be categorized into those that communicate via sound underwater, such as SharkCam, and those that communicate via radio waves through the air to satellites (radio waves cannot penetrate seawater). Both types send small bursts of data packets back to a central location to record such things as water temperature and the depth the animal has swum through, as well as an estimate of its position. In the case of low-power tags that are on a shark for long periods of time, this only occurs when the animal is at the surface or near a relay station capable of downloading and transmitting data back to shore. These data crumbs provide researchers with a view of where animals are going and the conditions of the water they pass through, but they don't tell us their behavior and habitat use or feeding and mating information. The datasets they create, which can span months to years, help us better understand sharks and their role as the ocean's top predator. The sharks themselves also act as scouts that provide insights into the nature of the places they favor and offer the additional benefit of return data from parts of the ocean where they routinely travel, but we can't. They have already revealed a previously unknown connection between the upper ocean and the twilight zone (*Gaube et al., 2018*), a relatively unknown part of the ocean that is the recent focus of *researchers at WHOI* fueled by an Audacious Award made possible by the TED organization and a group of visionary donors. The tagged sharks have also become social media stars with thousands of followers who muse online about what a shark is doing as data comes back in near-real-time. Like SharkCam, much of the animal-borne tag funding at WHOI in recent years has come from non-governmental entities, including corporations and hundreds of small, individual donations.

As a result of my work with SharkCam, I have logged more direct, subsurface shark observations than most people. I understand that in order to continue this important work, we need to expand our public-private partnerships by first enhancing greater public investment in basic research. This fuels innovation and invites greater private investment of the type we've seen in recent years, but we can't rely on the private sector alone. In the draft of "*Science and Technology for America's Oceans: A Decadal Vision,*" there is a very telling statement that I think will stand the test of public comment. It reads: "The ocean science and technology enterprise can provide the foundational knowledge needed to address many complex ocean-related challenges and inform decision-making that will ultimately strengthen our Nation and its communities."

That's what we're after—foundational knowledge to address complex challenges and inform decision-making to strengthen our Nation and our global, interconnected ocean. I want to thank the Discovery Channel, many foundation and individual donors, and the sharks themselves, for their foresight and commitment in our national interest. Because sharks do contribute. They help keep the ocean healthy, which has untold economic, environmental and even cultural and spiritual value. Without sharks and the technology to understand them, our ocean, and our Nation would be a much different, poorer place.

The investments we make toward understanding the behavioral ecology of top ocean predators today will affect conservation efforts in the coming decades and will help ensure the ecological health of marine ecosystems, which are significant contributors to the economic prosperity of our Nation and many coastal communities.

The CHAIRMAN. Thank you, Ms. Kukulya.

And I think each of our panelists had a video that they wanted to show at the conclusion of their remarks. Can we kind of scroll up Dr. Dove's video first, Lyle, and then go to Ms. Kukulya's? OK. This is Dr. Dove.

[Video shown.]

Dr. DOVE. So there is no sound to this video. It illustrates a couple of field activities, research activities.

This first one is in the UK Overseas Territory Island of St. Helena, which is in the far south Atlantic. It is the place where Napoleon was exiled. And they have a whale shark population. We think it might be the only place in the world that has so been documented where whale sharks go to mate.

And you can see a tag there attached to the dorsal fin of the animal. It is one of the other engineering challenges that we face. It is impossible to send high bandwidth signals, radio signals through sea water. So you really do rely on the animal to break the surface so that you can get that message to the satellite, or you have to program the tag to come off.

This is Chris Schreiber. He is one of our curators at the aquarium. We developed a technique for taking blood from whale sharks in the aquarium environment. We are the first people to do that. And that was necessary for the veterinary care of the animals that we have in the collection. But it also provided us with a test bed for developing methods that we could then take to the field to advance shark research in their natural setting. So that whale shark is being fed right now, and he is taking blood from the pectoral fin as they swim alongside. As you can imagine, it is pretty tricky. It is like juggling and riding a bike.

And here we are taking the same technique to Indonesia where there is a fishery where whale sharks get captured in fishing nets, and while they are stuck in those nets, we have an opportunity to do a bunch of science with them, including taking blood and attaching tags properly, and getting measurements before we send those animals on their way. And we have three animals right now that are swimming around in Indonesia with tags that we applied during that sort of application.

So the ability to develop those techniques in the aquarium environment and then take those techniques to the field we consider one of the great advantages of the public aquarium environment.

But the story does not end with the research. We then need to bring all that information back to Georgia and share it with our 2.3 million guests that we have visiting every year. We are the most popular tourist attraction in the State of Georgia and one of the largest public aquariums in the world. So we really have a terrific opportunity to put shark science and conservation in front of a lot of people and to really change attitudes about shark science.

Thank you.

The CHAIRMAN. Thank you, Dr. Dove.

And Ms. Kukulya.

[Video shown.]

Ms. KUKULYA. Yes, thank you.

So I will just give you an overview of some of the discovery the SharkCam has brought back.

First we attach the transponder to the shark and then we launch the REMUS SharkCam. Here you see the tag put on the shark and the REMUS following behind. We tell the vehicle the position of the tagged shark, and then it goes to a predetermined position that is programmed in the vehicle. The vehicle emits a ping every few seconds. The tag responds with distance, sparing, and depth in an advanced game of Marco Polo.

Here is Cape Cod, our first deployment in 2012. We found a great white shark as it hunted in murky, shallow water, which is an incredibly difficult environment to navigate. The vehicle's onboard computer is constantly forward predicting where the shark is going to be because it is not enough to go where it is. You have to know where it is going.

Here are six camera views, as seen in our most recent deployment in the Bahamas. We followed bull and great hammerhead sharks here at night. Here very close to the sea floor. Here in increasingly rugged terrain. And here as it interacted with another bull shark, and another as it traveled from shallow water into deep water and into the night offshore.

In Guadalupe Island, Mexico, we recorded this shark swimming shallow at the surface, mostly warming itself. And then we followed the same shark at night as it swam into a 2-knot current, its mouth agape, and more than 600 feet below the surface in a sort of catatonic sleep-like state.

In Guadalupe, sharks appear to be highly visual predators and took a special interest in REMUS. Here this tagged shark got behind the vehicle and used its senses, including vision, smell, hearing, touch, and electro-reception to assess it. It seems the electromagnetic signature of the vehicle might have fooled the shark into thinking it was prey.

We also experienced several ambush attacks below by untagged sharks, I might add. This one drove the vehicle up nearly 6 stories. That also prompted us to aim the camera pointed down so we could watch as these deep ambush attacks developed. You might notice some teeth falling out along with those paint chips.

So that gives you a quick glimpse as to some of the innovative new shark technology coming out of Woods Hole Oceanographic. Thanks for the opportunity to share that.

The CHAIRMAN. Thanks, Ms. Kukulya.

Dr. Wilga.

STATEMENT OF DR. CHERYL ANN DENESHA WILGA, PROFESSOR AND DIRECTOR, BIOLOGICAL SCIENCES DEPARTMENT, UNIVERSITY OF ALASKA ANCHORAGE

Dr. WILGA. Thank you. So thank you for the opportunity to talk about how technological innovations have helped us understand shark behavior.

[Slides shown.]

Dr. WILGA. And so the next thing I am going to talk about—next slide—is fossils. So fossils like this—this is a shark tooth with many cusps—have been found for many, many years in many different states in the Midwest, not quite in the Dakotas yet, but close. But the jaws and the head have not ever been found with these yet. And so people have tried to figure out where this went, and this led to a lot of creative reconstructions of where they might go, including on the tail and the fins, which is kind of crazy.

So some paleontologists from Idaho contacted me, including Ray Troll, who drew some of these pictures.

Next slide, please.

They found boulders with the fossils inside. And on the top of that slide to the left shows the Helicaprion spiral tooth whirl in a boulder that has been opened, and on the right are Edestus tooth whirls. They are partial whirls. They are not full whirls. But what we did was we CT-scanned an entire boulder, got rid of the nonfossil parts, and that left the jaws, which had never been found before with these teeth. And the green part is the upper jaw. The blue part is the lower jaw. And you can see where the big tooth whirl sits into the lower jaw, and it moves like this. This is a 3-D print. So it moves like this, and the lower jaw acts sort of like a chop saw, and it eats soft prey.

The Edestus on the other side has a small tooth whirl on each side of the jaws, the upper and the lower jaws, and it sort of opened in a rotating manner like this. You see there is an extra articulation in there, sort of like snakes. And it looks like it might have sliced prey in a little bit different way than Helicaprion did. Those were actually found in the Dakotas. So you have those Edestus.

And this is the artist reconstruction of what they might have looked like, which is a little more in line with reality. You do not put teeth on fins and tails, at least not proper vertebrates.

So the next slide shows a new technology. Well, engineers have been using it for a long time. Biologists have just started adapting it for studying organisms in flow. You see that the shark on the left is actually suction feeding. Not all sharks bite, and the shark on the left is suction feeding in the water column. The shark on the right is suction feeding on a substrate. And you will notice that the red, which is the amount of water being sucked into the shark's mouth, is much bigger on the substrate. Well, these sharks are using ground effects to be able to reach prey further away. So sharks around coral reefs actually put their heads around the crevices and use those crevices like straws to suck in food. And you do pretty much the same thing as well when you suck through a straw.

The next slide. It is really hard to see sharks—the inside of their mouth when they are feeding. So we used X-ray technology. This new technology called XROMM allows us to use X-rays, which you are looking at right now. Now, the sharks have the cartilage skeleton, so you cannot really see it in X-rays that well. So we implant metal markers. And we use those metal markers to track and animate CT-scans. So if you play that movie again, you will see the CT-scan moving. You will see the cranium on top in white and the upper jaw and the lower jaw opening as they are suction feeding, hopefully. It is not going to play now.

So basically this technique—you can see it here. Here is the upper jaw and the lower jaw opening. And do you see that element than swung back and down? That really expands the throat and creates the suction. The pectoral girdle in the back swings back to help expand the throat for suction. And you do this too when you sip through a straw. So if you imagine yourself sipping through a straw, your throat expands as well. So this technique actually allows us to use CT-scans and X-rays to be able to see what is going on inside the mouth of sharks and other animals as they are feeding.

So in the next slide, my current research is understanding shark cartilage. As you know, they have skeletons made out of cartilage, and yet they eat sea lions and bite metal things. And so how do they do that with jaws made out of cartilage?

So we have looked at this, and other people have discovered that they actually have an armor around the cartilage. So the blue part on the slide is the hyaline cartilage, which is like the stuff in your nose and your ears. It is flexible. But then outside, there are these tessellated or mineralized blocks in gray, and they are interconnected by ligaments in red. And that allows the cartilage to remain flexible but strong. So this allows sharks bite things that are harder than the jaws but also remain flexible so maybe their jaws are bending just a little bit about prey that is harder than their jaws are.

Thank you, and we will take questions.

[The prepared statement of Dr. Wilga follows:]

PREPARED STATEMENT OF DR. CHERYL ANN DENESHA WILGA, BIOLOGICAL SCIENCES DEPARTMENT, UNIVERSITY OF ALASKA ANCHORAGE

Introduction

Good morning Mr. Chairman and members of the Committee. I am honored to testify today about recent advances in our understanding of sharks and the technology that has enabled my biomechanics research. The results of these studies have benefited society and show strong promise for biomedical applications. My name is Cheryl Wilga and I am a professor and director of the Biological Sciences department at the University of Alaska Anchorage, Program Coordinator for the University of Alaska's National Institutes of Health—Idea Networks for Biomedical Research Excellence (NIH-INBRE), Research Associate at the Museum of Comparative Zoology at Harvard University, and faculty mentor for the Alaska Native Science and Engineering program (ANSEP). I am Dena'ina Athabascan from Kenai Alaska. My husband, who retired after 20 years in the U.S. Coast Guard, was stationed in Kodiak Alaska, where my academic career started. I received an A.A. degree from the University of Alaska's Kodiak Campus, a Ph.D. in Biological Sciences from the University of South Florida in Tampa, and conducted postdoctoral research at the University of California Irvine and Harvard University. I was a professor at the University of Rhode Island before coming back home to Alaska and the University of Alaska in Anchorage.

Biological sciences is by its very nature interdisciplinary and so is my research. I study musculoskeletal systems and determine how they function using biomechanical methods. My graduate research focused on the mechanisms of how the jaws protrude from the head when sharks feed; yet maintain a streamlined profile when swimming. My postdoctoral research focused on testing the classical theory how sharks swim, which was based on how airplanes fly. I collaborate widely with colleagues at my own and at other institutions using a variety of new technologies. An important part of this research is the training of biological, mathematics, and engineering undergraduate and graduate students in these projects. Currently, my research on how sharks, which have jaws made of cartilage, can feed on prey that have body parts that are harder than the jaws. Bony fish and seals have skeletons made of bone, and sea turtles also have a bony shell. This project has led to a discovery that has potential biomedical applications. I have been fortunate to be funded by The CIRI Foundation for my undergraduate studies, the Ford Foundation for my graduate studies, and the National Science Foundation for my postdoctoral and professorial studies.

Why sharks don't swim like airplanes fly

Sharks weigh more than water, and to swim steadily forward, they must also create lift to remain in the water column (see ppt figure pg 2). Most bony fishes have a gas bladder that makes them near neutrally buoyant and so they can hover in the water. Sharks have an inclined edge to the tail, called heterocercal, which thrusts water backward and downward as they swim. The backward-downward water thrust causes an equal and opposite forward-upward reaction around the center of mass that pushes the head downward. Try this with a pencil: hold a pencil in the center of mass; push one end of the pencil upward and forward; as a result, the other end of the pencil is moved downward and backward. The classical theory of heterocercal tail locomotion predicted that the pectoral fins of sharks created lift, much like an airplane does, which keeps the head end of the shark up in the water and the shark can swims forward. The wings of an airplane are angled upward, which creates faster flow over the top of the wing than below the wing, generating lift. Try this with a piece of paper: blow over the top of the paper; the paper will be lifted upwards.

I tested the classical theory using digital particle image velocimetry (DPIV) with Dr. George Lauder at the University of California Irvine and Harvard University. Engineers had used this technique for years, and Dr. Laude was one of the first to use it to answer biological questions. The technique involves seeding the water with neutrally buoyant reflective particles that move with the water (see ppt figure pg 3). A low power laser sheet aimed through the water illuminates the particles so their movement can be visualized and measured. The particles in the water look like a snowstorm. Computer software measures the magnitude and direction of particle movement and returns velocity vectors, just like what you see in weather reports on TV. Video recordings are used to not only visualize water flow but to measure it as well and this DPIV technique has been used to understand how organisms manipulate water for swimming, feeding, and breathing. DPIV results showed that the tail of sharks do indeed push water downward and backwards at an average angle of 30 degrees (see video clip ppt figure 4), but the pectoral fins do not provide lift to keep the head up in the water during steady forward swimming (see ppt figure pg 4+5). The pectoral fins do create upward and downward lift when moving up and down in the water column (see ppt figure pg 5). The lift that keeps the head upwards during steady forward swimming comes from the body. Water moves faster over the top of the body than the bottom creating lift. More lift is generated as the shark swims faster and body posture becomes more horizontal with increased speed (see ppt figure pg 6). We found that the pectoral fins of sharks function like delta wing fighter jets in being very maneuverable and able to turn rapidly (negative dihedral—wings angled downward) (see ppt figure pg 7). This is very different from a passenger airplane where the wings function to generate lift but also self-stabilize the fuselage (positive dihedral—wings are angled upward), which is a very good thing for passenger planes (see ppt figure pg 7). Using DPIV, one of my graduate students, now Dr. Anabela Maia, found that the first dorsal fin of high speed sharks that live in the open ocean functions as a stabilizer, like the keel of a boat. In contrast, the first dorsal fin of sharks that living in complicated environments, like coral reefs, functions as a thruster and helps them maneuver. She found that the second dorsal fins of both function as a thruster. The National Science Foundation funded this research.

Fossil Shark Mysteries Resolved

Palaeobiologists had long puzzled over how the teeth of *Helicoprion* and *Edestus* functioned in the absence of other fossilized body parts. These extinct species are relatives of modern sharks, but their teeth look nothing like modern shark teeth (see ppt figure pg 9). Numerous creative reconstructions were presented on where these tooth whorls were located on the body (see ppt figure pg 10). This collaboration on the function of fossil shark teeth is with Dr. Leif Tapanila from Idaho State University. A boulder containing the jaws and teeth of a *Helicoprion* specimen was CT scanned and the non—fossil parts were removed by software. This was the first time that a complete set of jaws was found with a tooth whorl in place. We were able to reconstruct how the jaws articulated with each other and with the tooth whorl from the processes on the jaws, which were similar to well known extinct species and modern sharks (see ppt figures pg 11+12). The lack of scratches and nicks on fossil *Helicoprion* tooth whorls indicated that they fed primarily by cutting off the soft parts of prey like ammonites and nautiloids, which were numerous at the time (see ppt figure pg 13). Only a single tooth whorl was present in *Helicoprion* and was located on the lower jaw, which pushed the prey into the mouth as it closed like a saw blade. In contrast, CT scans of *Edestus* fossils revealed that a short tooth whorl was present on the lower and upper jaw. Reconstruction of *Edestus* jaws and tooth whorls suggest that once the prey was captured between the jaws, the lower tooth whorl rotated back and forth against the prey held by the upper tooth whorl (see ppt figure pg 14). Artist reconstruction by Ray Troll shows what these extinct shark relatives might have looked like (see ppt figure pg 15).

Suction Feeding Sharks!

Not all sharks feed by biting directly onto their prey. Some sharks use suction to bring the prey to the mouth. In collaboration with Dr. Lauder again at Harvard University, with my postdoc Dr. Nauwelaerts, we used DPIV to see the water moved by a suction feeding shark specialist, Bamboo sharks *Chiloscyllium plagiosum.* When bamboo sharks capture food using suction in the water column, water is moved into the mouth from a distance of one mouth width away (see ppt figure pg 16). However, when the same sharks captured food using suction when sitting on the bottom, water is drawn into the mouth from twice as far away. Bamboo sharks use ground effects to extend the distance that suction is effective. Sharks that feed around coral reefs, used ground effects, to suction food from crevices like a straw (see ppt figure pg 17).

It is difficult to see what is happening inside the mouth of sharks when they feed. In collaboration with Dr. Beth Brainerd at Brown University, my grad student, Brad Scott, and my postdoc, Dr. Ariel Camp, we used CT scans and X-ray videos to study what the skeletal elements are doing during suction feeding in a technique called XROMM (X-ray reconstruction of moving morphology). Tiny surgical metal beads are implanted in the skeleton of the parts of interest with the shark under anesthesia. The shark is fed using two video X-ray machines to visualize the 3-dimensional motion of the metal beads. The beads in the X-ray videos are tracked and the motion is applied to the 3D-CT scans of the skeletal elements (with beads). The video (see ppt pg 18) shows the moving 3D CT scan superimposed over the X-ray video of a suction feeding bamboo shark. Note the element in pink (hyoid) that rapidly expands the throat to create the suction to move the food into the mouth. Also note that the cartilaginous skeleton of the shark does not show up well in the X-ray videos (looks like a ghost), but the metal beads are readily apparent. We also implanted the food with a bead and included the pectoral girdle in another study. The results revealed that the pectoral girdle is moved backward to help expand the throat when bamboo sharks suction feed (see ppt figure pg 19). The National Science Foundation funded this research.

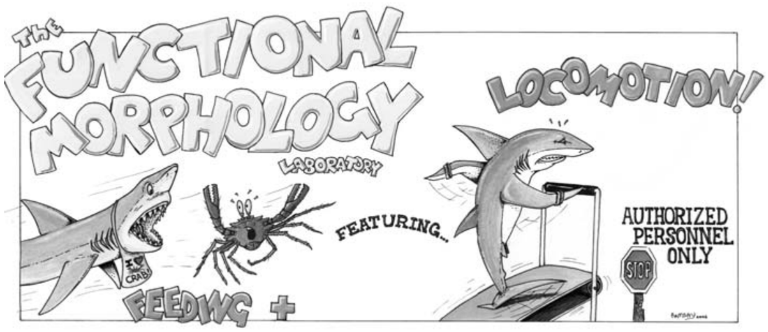
How do Sharks Feed on Bony Prey with Jaws of Cartilage?

The focus of my current National Science Foundation funded research, with my postdoc Dr. Petra Ditsche and several undergraduate biology and engineering students, is how do sharks, with jaws made of cartilage, feed on prey that have bone and other hard parts. Bony fish and seals have skeletons made of bone, and sea turtles also have a bony shell. Shark cartilage (called tessellated cartilage) has a core of hyaline cartilage, much like that in your ears and nose, that is surrounded by an armor of mineralized tiles interconnected by ligaments (see ppt figure pg 20). The surface looks like kitchen tiles and the thickness of the mineralized tiles varies among species. Not surprisingly, the thicker the mineralized tiles, the stiffer the cartilage (see ppt figure pg 21). It has been predicted that tessellated materials (alternating stiff and soft substances) become stiffer with increased compressive force but not in tension (see ppt figure pg 22). Our results support this phenomenon (see ppt figure pg 23). The National Science Foundation funded this research.

Biomedical Applications Inspired by Shark Cartilage

Current total disc replacement (TDR) devices are composed of metal alloy plates sandwiching a plastic core and, very recently, a titanium mesh cage that replaces an intervertebral disc (IVD), both of which can leach metal particles into the body, prevent flexion at the joint, and cause degeneration of adjacent bone (Salzmann *et al.,* 2017; Jacksons, 2018). There is a need to fill this gap in available IVD implants with a non—metallic material that will conserve flexibility of joint motion and reduce bone erosion. The cartilage of sharks possess exactly this desired properties, it is relatively stiff under compression, but flexible in tension. Our long term goal is to produce artificial tessellated human joint cartilage that can be 3D printed in the form of a patient's own healthy intervertebral disc or knee meniscus to replace their damaged cartilage. This material can also be used in prostheses, where strength and comfort is key. The rationale is based on the uncommon combination of high stiffness and flexibility, making tessellated cartilage an ideal model material for a new replacement biological implants that will cause less degeneration of adjacent bone than metal implants. We expect the outcome to be the development of an artificial tessellated implants or prosthetic linings inspired by shark tessellated cartilage that is capable of withstanding repeated bending and torsional stress incurred during normal human joint motion. This artificial tessellated human IVD implant has the potential to transform the surgical treatment of joint damage by allowing flexion rather than fusion at the joint. Equally important, the outcome will have a positive impact on society with economic benefits. We are currently looking for funding support for this project.

Thank you Mr. Chairman and members of the Committee for the opportunity to testify before you today. I am happy to answer any questions you may have, or to provide additional information to the members and committee staff at any time.

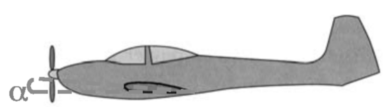


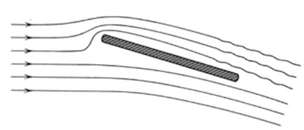
Biomechanics of Shark Behavior

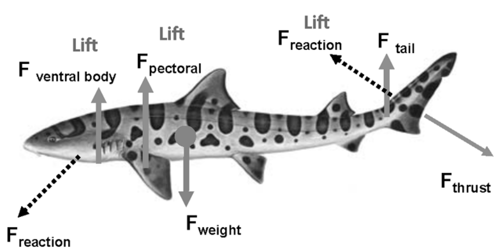
Dr. Cheryl Wilga
University of Alaska Anchorage

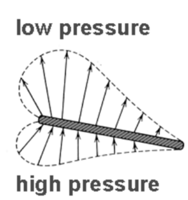
1

Lift and the Classical Theory of Swimming in Sharks

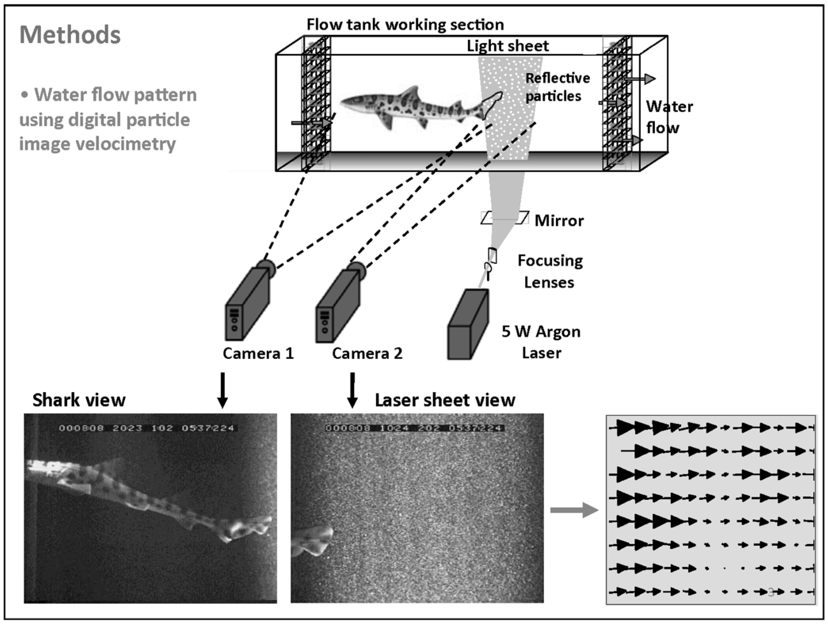








2


Methods
• Water flow pattern using digital particle image velocimetry
Flow tank working section
Light sheet
Reflective particles
Water flow
Mirror
Focusing Lenses
5 W Argon Laser
Camera 1
Camera 2
Shark view
Laser sheet view
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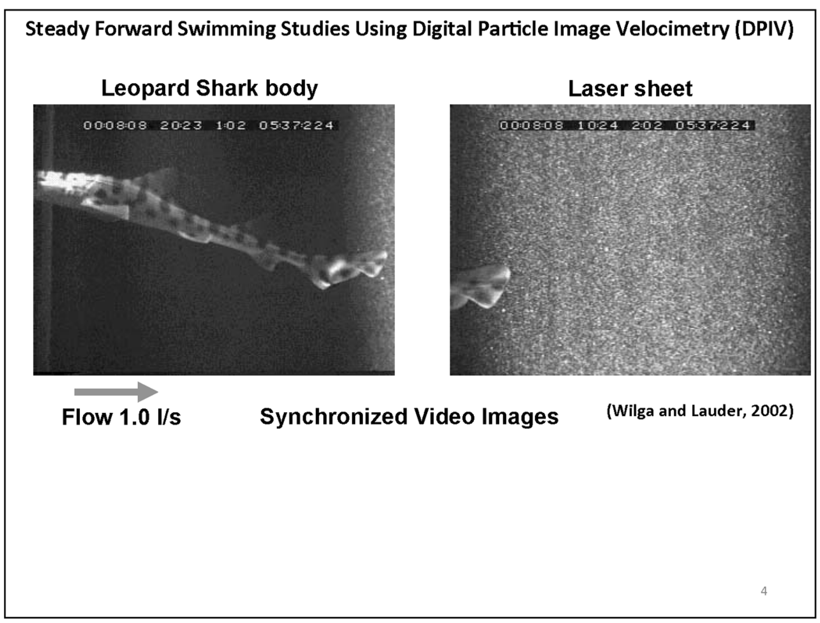
Steady Forward Swimming Studies Using Digital Particle Image Velocimetry (DPIV)
Leopard Shark body
Laser sheet
000808 2023 102 0537224
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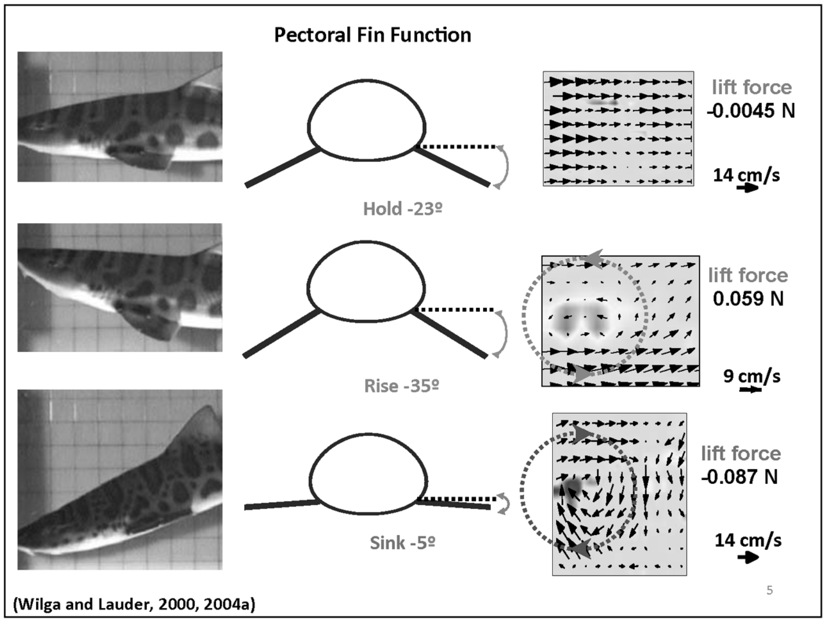
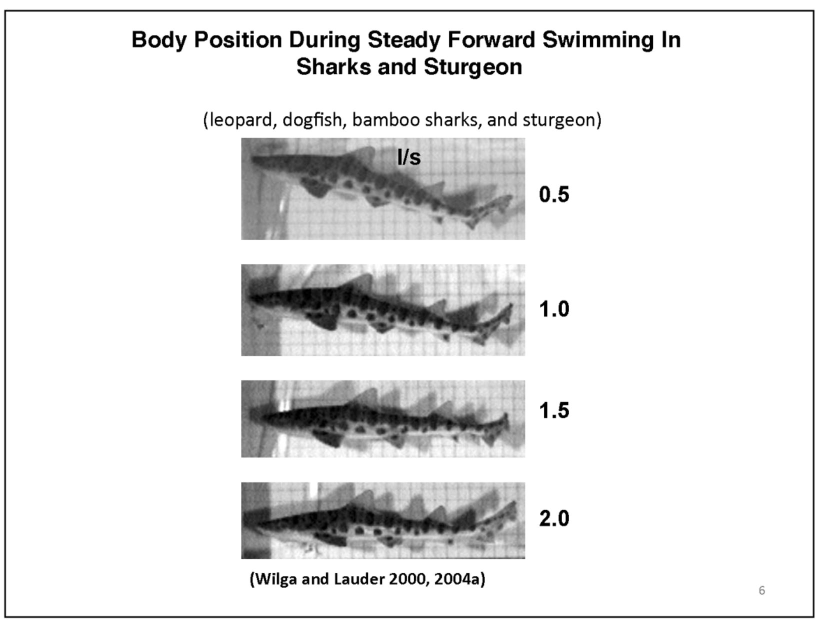
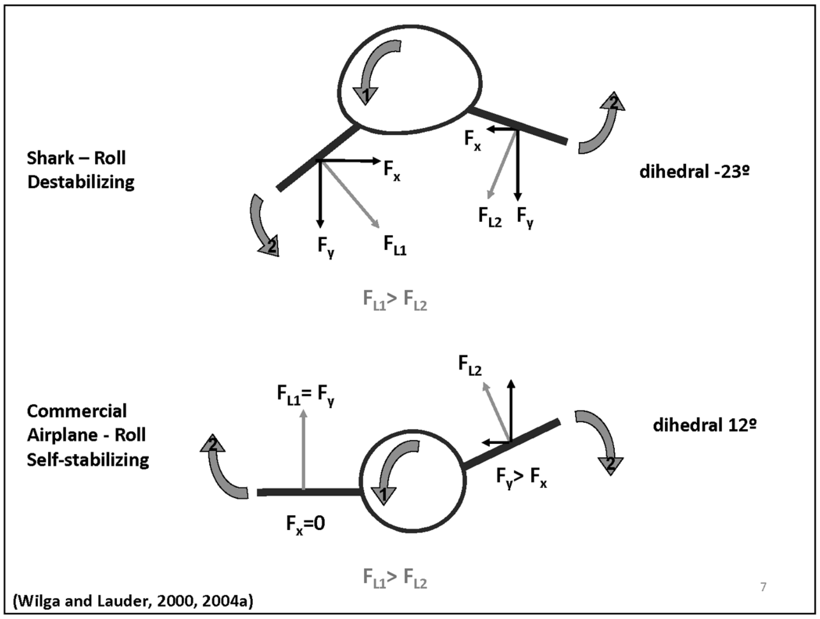
Flow 1.0 l/s
Synchronized Video Images
(Wilga and Lauder, 2002)
4

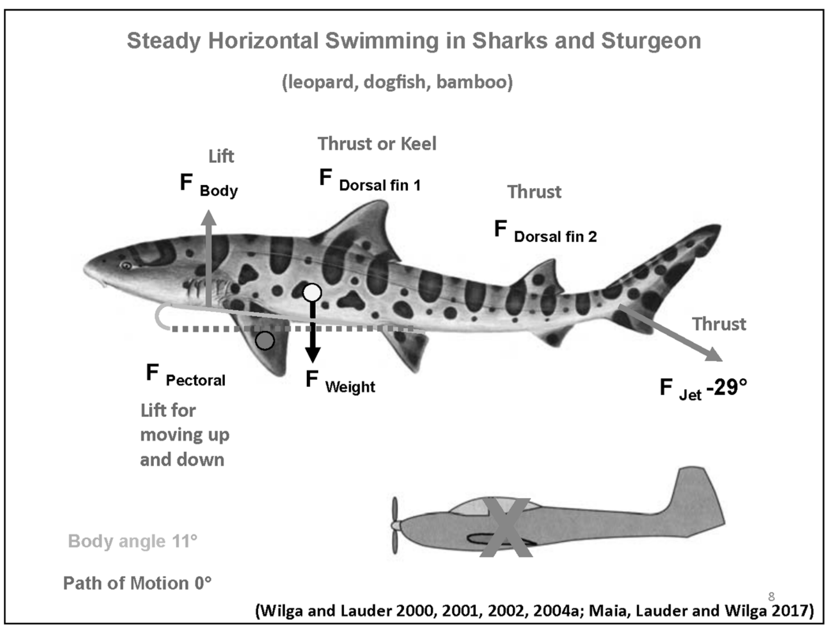


Pectoral Fin Function
lift force
-0.0045 N
14 cm/s
Hold -23º
lift force
0.059 N
9 cm/s
Rise -35º
lift force
-0.087 N
14 cm/s
Sink -5º
(Wilga and Lauder, 2000, 2004a)
5



Body Position During Steady Forward Swimming In Sharks and Sturgeon
(leopard, dogfish, bamboo sharks, and sturgeon)
l/s
0.5
1.0
1.5
2.0
(Wilga and Lauder 2000, 2004a)
6

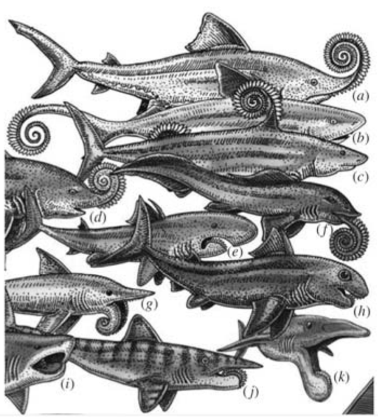

Shark – Roll
Destabilizing
dihedral -23º
F_x
F_x
F_y
F_{L1}
F_{L2}
F_y
$F_{L1} > F_{L2}$
Commercial
Airplane - Roll
Self-stabilizing
$F_{L1} = F_y$
F_{L2}
dihedral 12º
$F_y > F_x$
$F_x = 0$
$F_{L1} > F_{L2}$
(Wilga and Lauder, 2000, 2004a)
7


Steady Horizontal Swimming in Sharks and Sturgeon
(leopard, dogfish, bamboo)
Lift
F Body
Thrust or Keel
F Dorsal fin 1
Thrust
F Dorsal fin 2
Thrust
F Jet -29°
F Pectoral
Lift for
moving up
and down
F Weight
Body angle 11°
Path of Motion 0°
8
(Wilga and Lauder 2000, 2001, 2002, 2004a; Maia, Lauder and Wilga 2017)

Palaeobiologists long puzzled over how these fossil teeth, which are nothing like modern day shark teeth, functioned in the absence of fossilized cranial or postcranial elements.

9

Numerous creative reconstructions were presented.

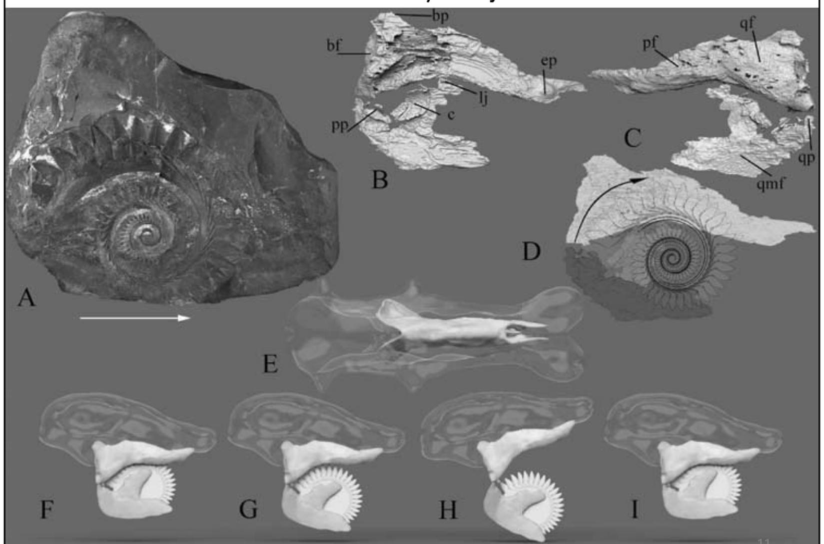


(reviewed in Tapanila, Pruitt, Pradel, Wilga, Ramsay, Schlader, Didier 2013)

(Ray Troll)

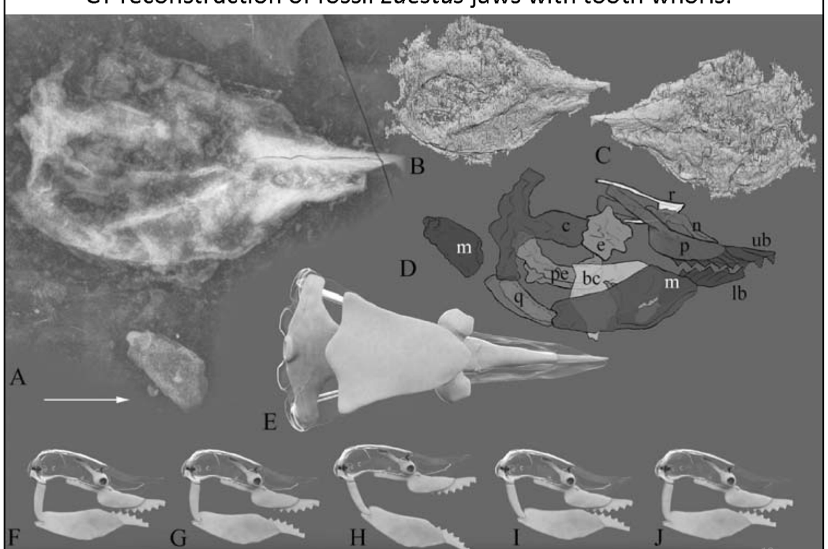
10

CT reconstruction of fossil *Helicoprion* jaws with tooth whorls.



(Tapanila, Pruitt, Wilga, and Pradel, In Press)

CT reconstruction of fossil *Edestus* jaws with tooth whorls.



(Tapanila, Pruitt, Wilga, and Pradel, In Press)

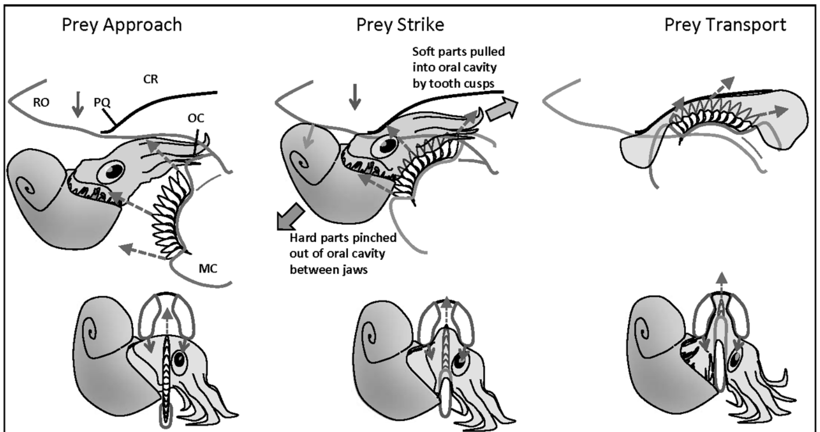


Figure X. Proposed prey capture behavior in *Helicoprion* sp. Prey is approached with the head raised and the lower jaw fully depressed with teeth aligned to catch the soft parts. The strike occurs when the soft parts of the prey is impaled on the tooth cusps and pulled into the oral cavity by elevation of the lower jaw and depression of the head. The hard parts are pinched out of the oral cavity between the jaws. Transport of the prey occurs when the lower jaw continues to elevate, pushing the prey further into the oral cavity where suction is then used to move the prey to the esophagus. CR, cranium; MC, Meckels cartilage (lower jaw); OC, oral cavity; PQ, palatoquadrate (upper jaw); RO, rostrum. Blue arrows show direction of jaw movement. Purple dashed arrows show direction of force of individual tooth cusps.

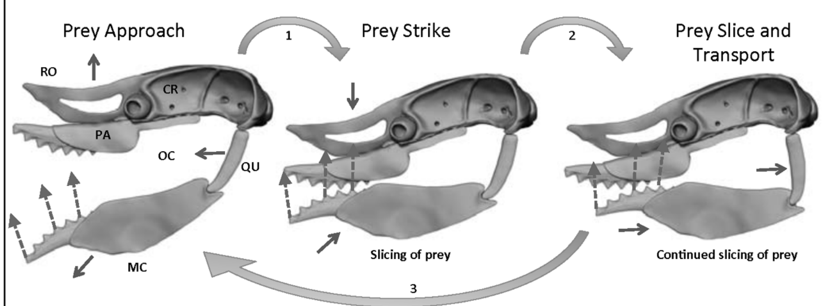
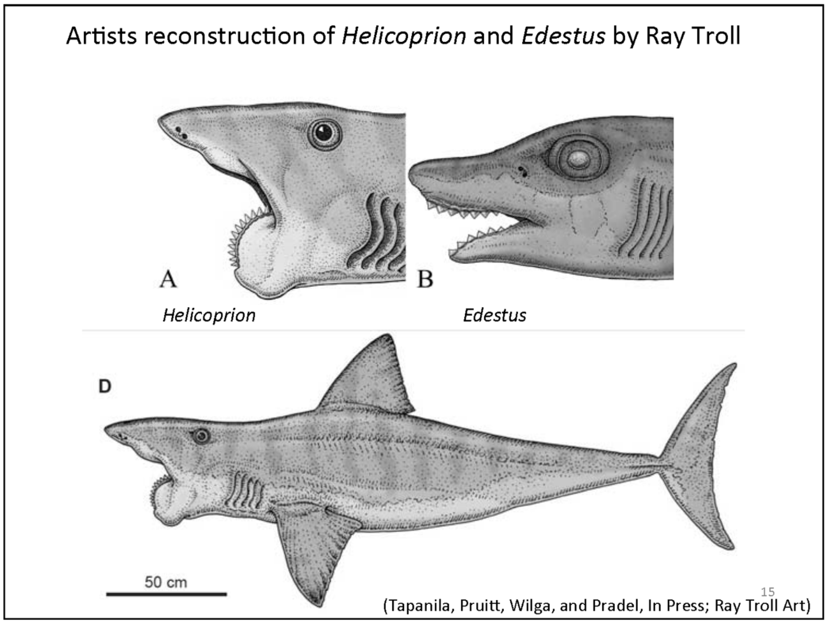
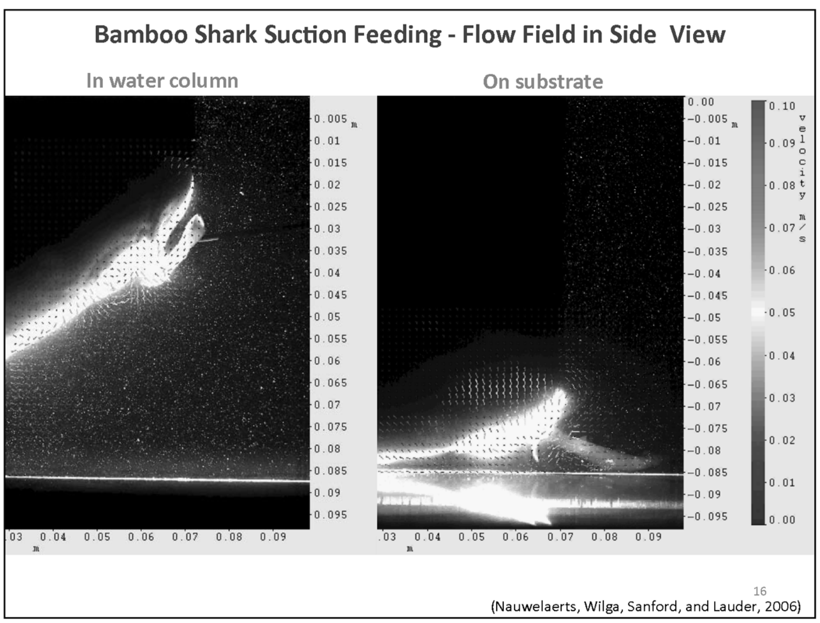


Figure X. Proposed prey capture behavior in *Edestus* sp. The prey is approached with the head raised and the lower jaw fully depressed and protracted forward by the quadrate with teeth aligned to catch the soft parts. The strike occurs when the head is depressed and the lower jaw retracted and elevated by the quadrate and jaw adductor muscles (not shown). This causes the lower tooth whorl to slice through the prey that is held against the stationary upper tooth whorl. Transport of the prey occurs when the lower jaw continues to retract, while continuing to slice the prey to pull it further into the oral cavity. This cycle of protruding and retracting the lower jaw to slice through the prey while held against the stationary upper jaw could be repeated to disable and reduce the prey (blue arrow sequence). Suction is then used to transport the prey to the esophagus. CR, cranium; MC, Meckels cartilage (lower jaw); OC, oral cavity; PA, palatine (anterior part of upper jaw); QU, quadrate (posterior part of upper jaw with modified function for jaw suspension); RO, rostrum. Blue arrows show direction of jaw movement. Purple dashed arrows show the direction of force of individual tooth cusps.


Artists reconstruction of *Helicoprion* and *Edestus* by Ray Troll
A
B
Helicoprion
Edestus
D
50 cm
15
(Tapanila, Pruitt, Wilga, and Pradel, In Press; Ray Troll Art)

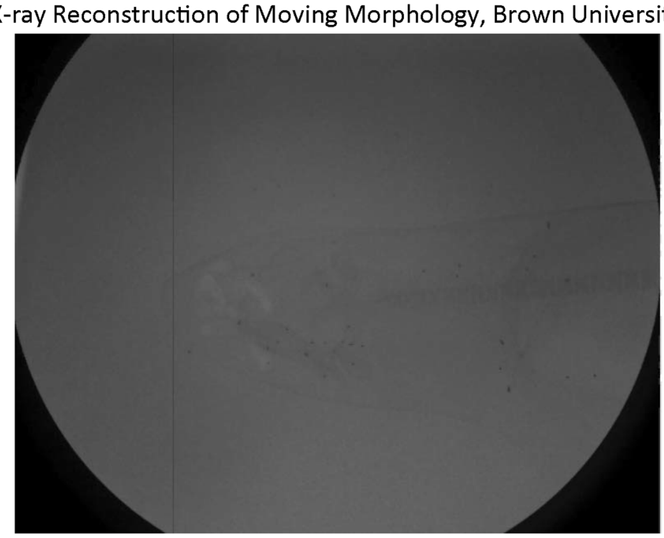

Bamboo Shark Suction Feeding - Flow Field in Side View
In water column
On substrate
velocity m/s
16
(Nauwelaerts, Wilga, Sanford, and Lauder, 2006)

Nurse Shark Foraging in a Crevice

17

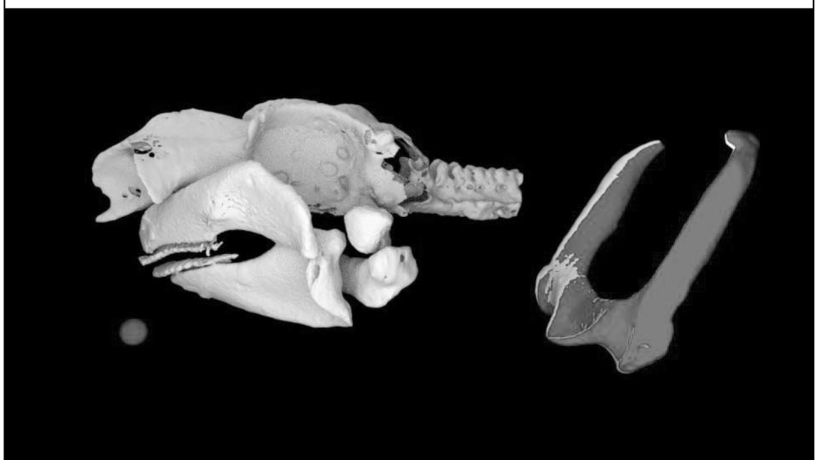
(C. Church)

XROMM Reconstruction of Bamboo Shark Suction Feeding
(X-ray Reconstruction of Moving Morphology, Brown University)



(Scott, Wilga and Brainerd, in Preparation) 18

XROMM Reconstruction of Bamboo Shark Suction Feeding
(X-ray Reconstruction of Moving Morphology, Brown University)

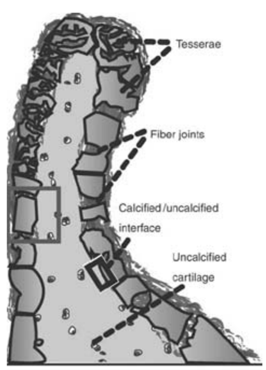


(Camp, Scott, Brainerd and Wilga, 2017)

19

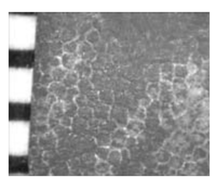
Shark Tessellated Cartilage

Cross-Section of Jaw

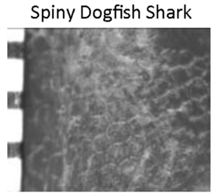


(Dean and Summers, 2006)

Cartilage Surface



Spiny Dogfish Shark



Little Skate

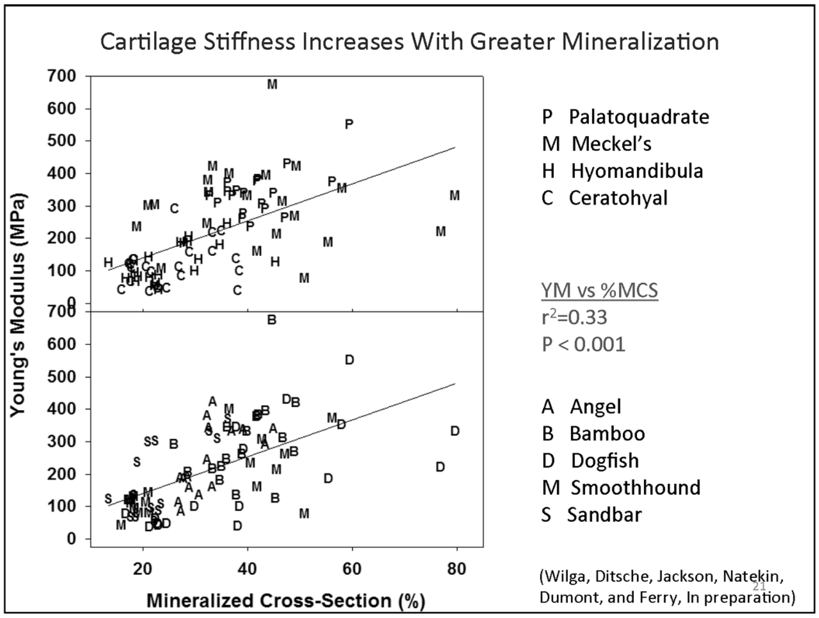
Scale – mm ruler

Cross-Sections of Jaw

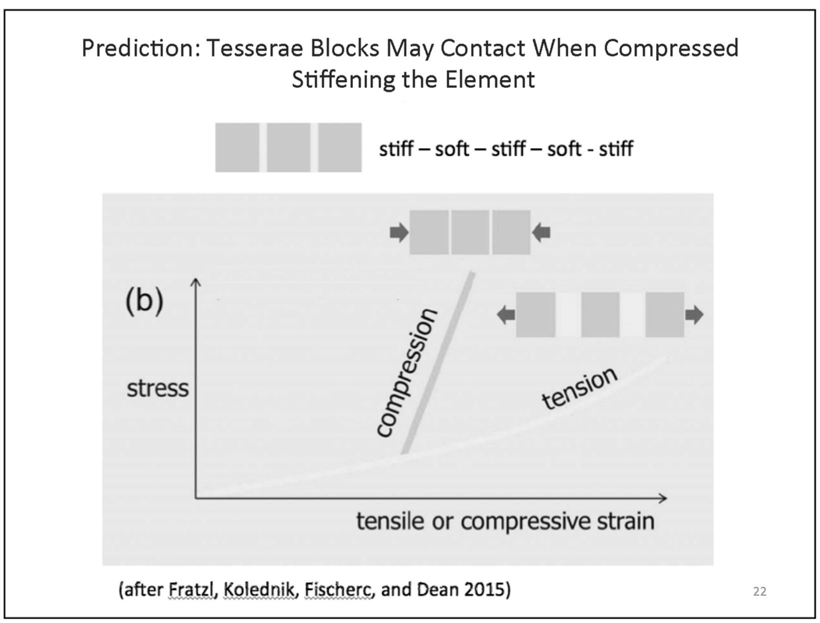
Angel Shark **Sandbar Shark**

(Wilga, Ditsche, Jackson, Natekin, Dumont, and Ferry, In preparation)

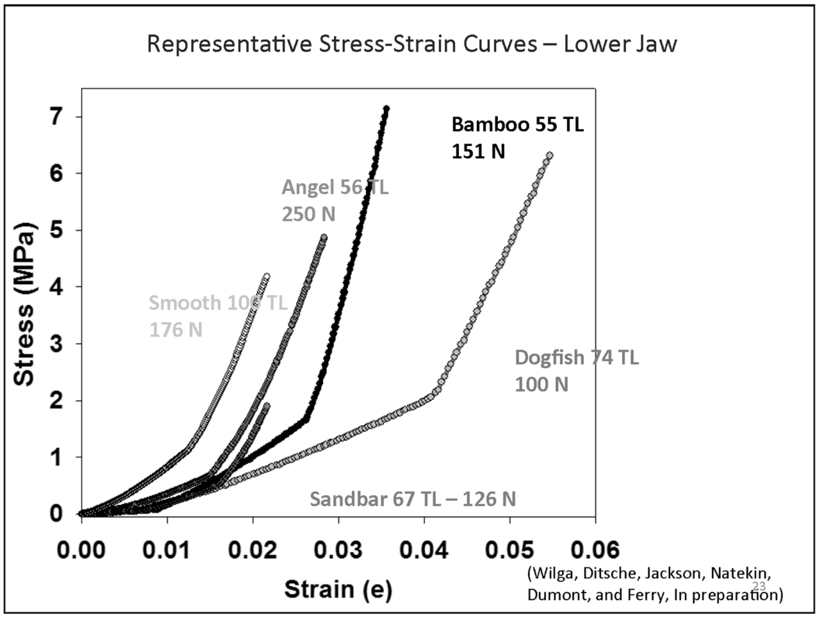
20



Cartilage Stiffness Increases With Greater Mineralization
Young's Modulus (MPa)
Mineralized Cross-Section (%)
P Palatoquadrate
M Meckel's
H Hyomandibula
C Ceratohyal
YM vs %MCS
r2=0.33
P < 0.001
A Angel
B Bamboo
D Dogfish
M Smoothhound
S Sandbar
(Wilga, Ditsche, Jackson, Natekin, Dumont, and Ferry, In preparation)
21



Prediction: Tesserae Blocks May Contact When Compressed Stiffening the Element
stiff – soft – stiff – soft - stiff
(b)
stress
compression
tension
tensile or compressive strain
(after Fratzl, Kolednik, Fischerc, and Dean 2015)
22



The CHAIRMAN. Thank you, Dr. Wilga.
Dr. Hueter.

STATEMENT OF ROBERT E. HUETER, PH.D., DIRECTOR AND SENIOR SCIENTIST, CENTER FOR SHARK RESEARCH, MOTE MARINE LABORATORY

Dr. HUETER. Mr. Chairman, my name is Dr. Bob Hueter, and I guess I am the Ranking Member of this panel because I have been studying sharks for more than 40 years, the last 30 years at Mote Marine Laboratory and more recently as Chief Science Advisor for the nonprofit organization, OCEARCH.

When I started studying sharks 40 years ago, the technology for working on these animals, especially at sea, was very limited. For example, if you wanted to figure out where a shark went in its life and tag them, we used these plastic tags that were put underneath the shark's skin with a unique number or this kind of a tag that is put in the fin. And you let the shark go and you hope that somebody caught the shark sometime later and reported that number back to you. So you got a little bit of information sort of from point A to point B, but not a whole lot in between.

Well, I am pleased to report to you today that now, 40 years later, we have the technology to do much more. You have heard about some of it here already on the panel this morning.

We can electronically track sharks in real time from space using satellite-linked tags like has been mentioned that started out with kind of crude models like this that went on shark's fin and today look a little bit more like this that are miniaturized and can track a shark when it comes to the surface for 5 years or more.

We also have satellite tags like this that started out as fairly big models, sort of the Ford pickup size model. And these record data on the animals and then pop off later. Now they look like this, much more compact but also quite expensive. And as Mr. Nelson mentioned, OCEARCH has tagged a lot of sharks, hundreds of sharks, with this type tag and you can follow those sharks yourself on the global shark tracker, an app on your smart phone.

As Amy mentioned, we now conduct underwater surveys with HD cameras. Her glider—it is very sophisticated. Her robot is sophisticated. We also have underwater camera systems that can document the presence of animals without having to catch them and kill them.

A new technique, environmental DNA, where we can grab a water sample and evaluate, analyze that water sample and tell who has been swimming by there recently. And so detect things like endangered species in certain habitats.

We now have the technology to do very sophisticated exams of sharks at sea using vessels like the OCEARCH vessel and release the animals unharmed. As Al mentioned, we can house sharks in excellent condition now in various facilities, aquariums and research facilities.

And most interestingly, we now have people working on, in detail, the disease-fighting properties that sharks have, their resistance to cancer and other serious diseases and their natural remarkable wound-healing abilities.

So this work has been funded a lot by Federal agencies, but even more, I would say, by private foundations and philanthropy. And through this we have discovered that sharks are more sophisticated than we once thought, able to navigate the oceans and go to very precise parts of their lifecycle. They do play an important role in ocean ecology as the top predators, kind of like the bears of the sea. Mr. Sullivan left, but I would throw that out there.

They are highly vulnerable to fishing pressure. We can over-fish them. But they are also vulnerable to such problems as ocean pollution, habitat alteration, and climate change.

They provide an incredibly important laboratory model for fighting human disease in that sharks produce substances that stop the growth of human tumors—cancer cells in culture and do not affect the normal cells.

The shark attack, as Mr. Nelson mentioned, is a real thing, but we now know it is not a major threat to human swimmers and we can educate people how to minimize the risk.

And sharks have become a valuable basis for the economies of many local communities through fishing and diving tourism.

So there are many things that Congress can do to help continue to push this field and help us advance this field.

You can promote the U.S. investment in technology development for tags and devices like this to get them even smaller and longer-lasting.

You can provide funding to NOAA for an extramural competitive program to fund specific research on sharks and other highly migratory species.

The international collaboration issue, as Al mentioned, is very important.

And finally, encourage Federal agencies to fund biomedical research on these non-traditional models because they hold such great potential.

I thank the Committee for this opportunity, and I do have a short video clip from OCEARCH.

[The prepared statement of Dr. Hueter follows:]

PREPARED STATEMENT OF ROBERT E. HUETER, PH.D., DIRECTOR AND SENIOR SCIENTIST, CENTER FOR SHARK RESEARCH, MOTE MARINE LABORATORY

Introduction

My name is Dr. Robert Hueter and I am a Senior Scientist at Mote Marine Laboratory, an independent, nonprofit research and education institution based in Sarasota, Florida. Over its 63-year history, Mote has grown from a one-room laboratory to a world-class marine research and science education enterprise that now has five campuses stretching from Sarasota Bay to the Florida Keys, 24 research programs, 200 staff, 35 Ph.D.-level researchers, more than 1,600 volunteers and more than 11,000 members. Our research has evolved from a primary focus on sharks to now conducting diverse studies of our oceans, with an emphasis on conservation, sustainable use and environmental health of marine and coastal biodiversity, habitats and resources. We also have significant education, public outreach and public policy programs that are integrated with our research.

At Mote, I am the Director of Mote's Center for Shark Research, which was established by the U.S. Congress in 1991, in recognition of Mote's leadership in research and conservation of sharks and their relatives, the skates and rays. I also serve as the Chief Science Advisor for another nonprofit research and education organization, OCEARCH, which is headquartered in Park City, Utah. This organization operates a research vessel specialized for shark research, the *M/V OCEARCH,* which currently is based on the U.S. east coast for studies of white sharks and other species.

My research on sharks spans more than 40 years and has taken me to every continent except Antarctica. From this research I have published about 200 scientific papers and reports and have edited six volumes on shark biology. For the past 21 years, I have served on NOAA's Advisory Panel for Highly Migratory Species (sharks, tunas, swordfish, billfishes) and also have served on the Shark Specialist Group of the United Nations' International Union for the Conservation of Nature (IUCN) for about 20 years. I am a Past-President, and currently serve on the Board of Directors, of the American Elasmobranch Society (AES), the largest professional organization in the world comprising scientists, students, and other experts studying sharks, skates and rays, collectively known as the elasmobranch fishes.

Background and progress

Sharks represent one of the oldest living groups of vertebrate animals (animals with backbones, like us), appearing in the fossil record about 400 million years ago. Today this group comprises about 500 living species distributed in every ocean, the deep sea, and even in freshwater in some places. They range in size from small species that grow to less than one foot long to the largest fish in the sea, the whale shark, which can attain a length of about 45 feet. These 500 or so species of sharks are as different from each other as are the various bird species from one another, so we must always keep in mind the diversity in shark species when we describe what sharks do, where they are found, and how they interact with humans.

Sharks are supremely adapted to their environments. In many ways, they figured out, evolutionarily speaking, how to meet life's challenges tens or hundreds of millions of years ago, and have been successful survivors ever since. Among the adaptations that make sharks special are their big brains and highly attuned sensory systems, their reproduction which in most cases is more similar to that of mammals like us than to the other fishes, and their ability to resist infection and serious disease, such as cancer.

When I began as a student in shark research at the University of Miami more than 40 years ago, the technology available for our research was limited, particularly for studies of sharks at sea. In the 1970s, exciting advances in understanding "what makes sharks tick" were made in the laboratory, funded by organizations such as the Office of Naval Research.[1] Most of this work focused on why sharks at-

[1] Resulting scientific publications include the 1978 landmark volume *Sensory Biology of Sharks, Skates, and Rays,* edited by ES Hodgson and RF Mathewson and published by ONR.

tack humans, which at that time was perceived to be a significant threat. But research at sea—what we scientists call "field work"—consisted then almost entirely of killing sharks for samples, documenting shark catches in fisheries, basic tagging studies to understand shark migration, or scuba diving observations of shark behavior. Tagging sharks to track their movements back then meant putting a plastic tag on a shark and hoping that someone would recapture that animal some time later and report the catch back to you. The technique was inexpensive and yielded a lot of "Point A to Point B" movement data, but details of the animals' life cycles and other critical information were missing. These "conventional tags" did not reveal enough about the sharks' daily, monthly, or multi-year patterns, or anything about their three-dimensional movements in the sea, that is, their depth preferences.

I am pleased to report that now, 40 years later, we have the technology to:

- Electronically track shark migration in real time from space, collect data on sharks' minute-by-minute movements and behavior for periods of years, and share this information with policy makers and the public online;
- Conduct underwater surveys with HD camera systems and remotely operated vehicles, and use advanced methods of detecting DNA in the environment, to determine shark distribution and abundance without having to catch the animals;
- Conduct sophisticated examinations of sharks at sea and release the animals unharmed;
- House sharks in excellent health in state-of-the-art research and aquarium facilities for study and public education; and
- Investigate in detail the disease-fighting properties of sharks, including their natural resistance to cancer and their remarkable wound-healing abilities.

Most of these innovations have occurred in the last decade or two. Some of this work has been supported by NOAA, the National Science Foundation (NSF), the Department of Defense (DoD), and the National Institutes of Health (NIH), but a great deal of it has been funded by private foundations and philanthropy.

Through this innovative research, we've learned many things about sharks, including:

- Sharks are more sophisticated than once thought, conducting extensive migrations that involve ocean navigation and returning to specific areas important for their life cycles.[2]
- Sharks play an important role in ocean ecology and maintaining the healthy balance of life in the sea, with most sharks functioning as top predators in marine environments—sort of the lions, tigers and wolves of the sea.
- Sharks are highly vulnerable to fishing pressure and can be overfished and wiped out of an area very quickly through intensive fishing activity, from both targeted fishing and unintentional bycatch.
- Sharks also are vulnerable to ocean pollution and environmental contaminants, to habitat alterations and onshore development, and to climate change.
- Sharks provide an incredibly important laboratory model for fighting human disease, including the development of new cancer therapies for people, accelerated wound-healing treatments for military and other applications, and novel antibiotics to fight drug-resistant pathogens.
- Shark "attack" is not a major threat to human swimmers and we can educate people how to minimize whatever risk exists.
- Sharks have become a valuable basis for the economy in communities supported by diving eco-tourism and by sustainable shark fishing, including catch-and-release recreational fishing.

With this new knowledge, we have turned the tables from treating sharks as man-eating monsters—a remnant of the World War II experience and the *Jaws* era of the mid-1970s—to viewing these animals with admiration, respect, and appreciation for their important role in the sea and their value in contemporary research. We've used this information to improve the status of shark stocks in U.S. waters, where, through responsible fisheries management, we've rebuilt most of our shark

[2] Hueter RE, MR Heupel, EJ Heist and DB Keeney. 2005. Evidence of philopatry in sharks and implications for the management of shark fisheries. *J. Northw. Atl. Fish. Sci.* 35:239–247.

populations from an overfished state back to sustainability.[3,4] We still have some species to work on here, such as the endangered sawfish (a type of ray) and depleted dusky sharks and shortfin makos. And in other places around the world the status of sharks is not so encouraging, with about one-quarter of shark and ray species threatened with extinction.[5] But by and large, innovative research has generated a time of enlightenment about sharks over the past 30 years, creating the first-ever era of shark conservation activism worldwide.

How we got here

Technological development played a major role in making these advances. Many new tools made their way into the shark research community, and entire chapters and books are now written on these various tools and techniques. I will highlight just a few here as examples of the innovative approaches available to us as shark researchers only over the past couple of decades.

Advanced tracking using satellite telemetry: The ability to track animal movements from space has revolutionized our understanding of shark migration. We can attach electronic sensors with a miniature computer, transmitter and battery pack, housed in a relatively compact device, to a shark and communicate with that device via satellite without having to recapture the animal or recover the device. These "satellite-linked tags" come in a variety of forms, but most work either by transmitting near-real-time data when a tagged shark is at the surface (which not all sharks will do) or by recording and archiving data for transmission later when the tag has separated from the shark and floated to the surface. Types of data we can obtain with these tags include geolocation, temperature and depth, and post-release survivorship, giving us the detailed, three-dimensional records of shark movements that the old-style, conventional tags lacked. With satellite tags we are getting a picture of how sharks move in time and space over periods exceeding five years, providing a true breakthrough in shark field research. These tags are a wonderful innovation for our research, but they have their limitations. First, attaching the tags to the sharks can be a challenge, and not all shark species are able to be fitted with these tags. Second, geolocation in the case of archival tags that don't surface on the shark is estimated by algorithms that use light levels, because telemetry with satellites doesn't work underwater, so these position tracks can be imprecise. And third, the tags are expensive, ranging from around $500 to $5,000 each, with only a few manufacturers in the U.S.[6] and abroad[7] able to supply them to researchers. Most of these tags communicate via the Argos satellite system, a 40 year-old, French-based system that has its own limitations. The cost of satellite time on Argos can add up to become an expensive research cost as well.

Miniaturized sensors, transmitters and long-lived batteries: Tiny sensors that can be incorporated into telemetry tags are now available to measure light, temperature, conductivity (salinity), pressure (depth), acceleration, oxygen, magnetic field, heart rate and other key variables. Acoustic "pingers" and their batteries have been miniaturized down to a scale that can be safely implanted inside sharks, allowing for the detection of animals swimming into range where an acoustic listening station is operating. This provides useful information on fine-scale movements of sharks and connectivity between acoustically monitored regions, and is even being used as a warning system for beach swimmers. Batteries powering these sensors and transmitters now are capable of lasting five years or more, depending on the application.

Underwater, miniature high-resolution video cameras: The advent of versatile, small, relatively low-cost, high-definition underwater cameras such as the GoPro (*www.gopro.com*) has provided a critical tool to advance shark field research. These cameras are incorporated into underwater stations known as BRUVs (Baited Remote Underwater Video) that attract sharks and allow for animals to be identified and counted, without having to hook the sharks. Miniaturized video cameras are also the basis of animal-borne systems that record a shark's point-of-view for periods up to several hours and then release from the shark for retrieval at the surface.

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[3] NOAA. 2018. 2017 Stock assessment and fishery evaluation (SAFE) report for Atlantic highly migratory species. NOAA Atlantic Highly Migratory Species Management Division, Silver Spring, MD. 216 pp.

[4] Simpfendorfer CA and NK Dulvy. 2017. Bright spots of sustainable shark fishing. *Current Biology* 27: R83–R102.

[5] Dulvy NK *et al.,* 2014. Extinction risk and conservation of the world's sharks and rays. eLife 2014;3:e00590 DOI: 10.7554/eLife.00590.

[6] Includes: Wildlife Computers, Redmond, WA; Microwave Telemetry, Columbia, MD; Desert Star Systems, Marina, CA

[7] Includes: Lotek, Newmarket, Ontario, Canada; Star-Oddi, Garoabaer, Iceland (in development phase).

Genomic techniques to detect species presence: The analysis of environmental DNA (eDNA) collected from seawater samples is a relatively new innovation to detect the presence of shark species in a specific area.[8] The power of this technique is in its ability to signal critical locations of threatened or endangered species, so that action plans to restore those species can be formulated. For example, the smalltooth sawfish was once a fairly common shark relative along the southeast U.S. coast, but over the past 50 years has been reduced to such low numbers that it is now listed for the U.S. Endangered Species Act. In other countries, this sawfish has all but completely disappeared. Finding the individuals left, therefore, can be a very difficult process through traditional surveys. Enter eDNA, which can be used to assay simple water samples from habitats and regions with potential for supporting sawfish, and identify those places that sawfish might still occur, by finding evidence of their DNA in the sampled water.

Advanced at-sea research platforms specialized for working on large sharks: Catching and handling large sharks for examination and tag attachment is difficult and can be a risky affair, both for the sharks and the researchers. Having access to a stable platform at sea, where the sharks can be temporarily restrained in excellent condition and the scientists can perform their procedures, is a rare asset for research. Fortunately, new innovations in research vessel design have helped to overcome this challenge. One such vessel is the *M/V OCEARCH,* a privately owned 130-foot ship outfitted with a hydraulic platform that can lift up to 75,000 pounds. This provides a stable platform for a team of researchers to conduct about a dozen procedures on large sharks in a period of 15 minutes, after which the sharks are released unharmed. OCEARCH has been around the world creating new opportunities in shark research in North and South America, Africa and Australia. Hundreds of sharks have been studied and the tracks of tagged animals are available online for the public to see via the OCEARCH website (*www.ocearch.org*) and the Global Shark Tracker, a free app for smartphones. Shiptime is provided at no cost to researchers—representing a donation of about $25,000 per day to the scientific community—and resulting data on dozens of topics are made available through open access to fellow scientists and policy makers. The ship is currently based on the U.S. east coast, where the OCEARCH program is affiliated with Jacksonville University in northeast Florida. The ship contains lab space for researchers to analyze blood, read ultrasound images, configure satellite tags, and much more. A proposal is pending with the National Science Foundation to upgrade the science infrastructure on the ship, and her next research cruise is scheduled for mid-September to study the white sharks off Nova Scotia and Newfoundland, Canada.

Major developments in aquarium design and life support for research and public display: Steadily over the past 20–30 years, the design and operation of aquaria to house sharks have advanced to where many species can be maintained for long periods in excellent health. The largest of these aquaria are at public facilities such as the Georgia Aquarium, which houses whale sharks, something that was unthinkable in the U.S. 25 years ago. This provides unparalleled access for researchers and veterinarians to study shark health, nutrition and behavior under controlled conditions. Some marine research laboratories also have built large facilities for housing and studying sharks in captivity. Mote Marine Laboratory is one such location for this work, where we have large tanks for housing sharks for experimental research. Our Marine Experimental Research Facility (MERF) was built with funding from NSF and in partnership with the Georgia Aquarium. Researchers from many institutions have used our MERF facility to conduct innovative studies on a number of shark species over the past decade.

Sophisticated laboratories for microbiological, cell and tissue culture to study disease resistance in sharks: The mystique concerning sharks and their relatively low susceptibility to disease has existed since the early 1900s. Of particular fascination has been the very low incidence of tumors found in sharks and their relatives in the wild, which has led several laboratories to focus on sharks' natural resistance to cancer. With the explosion of information since the early 1990s on the importance of the immune system in combating human disease, cell culture in the laboratory has rapidly become one of the major tools used in these studies of sharks. To understand the role of the immune system to fight disease in sharks, Mote Marine Laboratory scientists have developed the precise conditions necessary to keep shark immune cells alive in the laboratory, resulting in living cultures of these shark cells. During their initial 3–4 days in culture, shark immune cells produce compounds that possess remarkable abilities to kill human cancer cells with little or no adverse effects toward normal cells, an extremely desirable property for any compound with

[8] Bakker J *et al.,* 2017. Environmental DNA reveals tropical shark diversity in contrasting levels of anthropogenic impact. *Scientific reports* 7(1):16886.

the potential for development into a novel cancer therapeutic drug. In studies funded by DoD with the goal of identifying potentially novel antibiotics effective against wound infection pathogens, furthermore, Mote scientists and their collaborators have purified more than 300 marine microbes found in the mucus on sharks' skin. These microbes show effectiveness against pathogenic bacteria and 57 produce either broad-spectrum antibiotics or targeted activities against MRSA (Methicillin-resistant *Staphylococcus aureus*) or VRE (Vancomycin-resistant *Enterococcus*).

Use of social media to increase citizen science and promote research, public education and shark conservation: Not to be left out is the significant technological impact the rise of social media has had on shark research. By reaching a huge public audience in real time, shark researchers can engage the participation of citizen scientists to report tag recaptures, send images of individually identifiable animals, and document rare sightings of sharks. This has contributed in major ways to our understanding of sharks [9] and has engaged the public on a scale never before attainable. For example, the use of social media by OCEARCH reaches more than 91,000 followers on Twitter and 470,000 followers on Facebook. The public educational and conservation value of such a large online classroom participating in real time research activities is revolutionary.

Recommendations to Congress

The U.S. Congress plays an important role in promoting further developments in shark research and technology. In my capacity as an expert scientist specializing in the study and conservation of sharks, I recommend that Congress take the following measures:

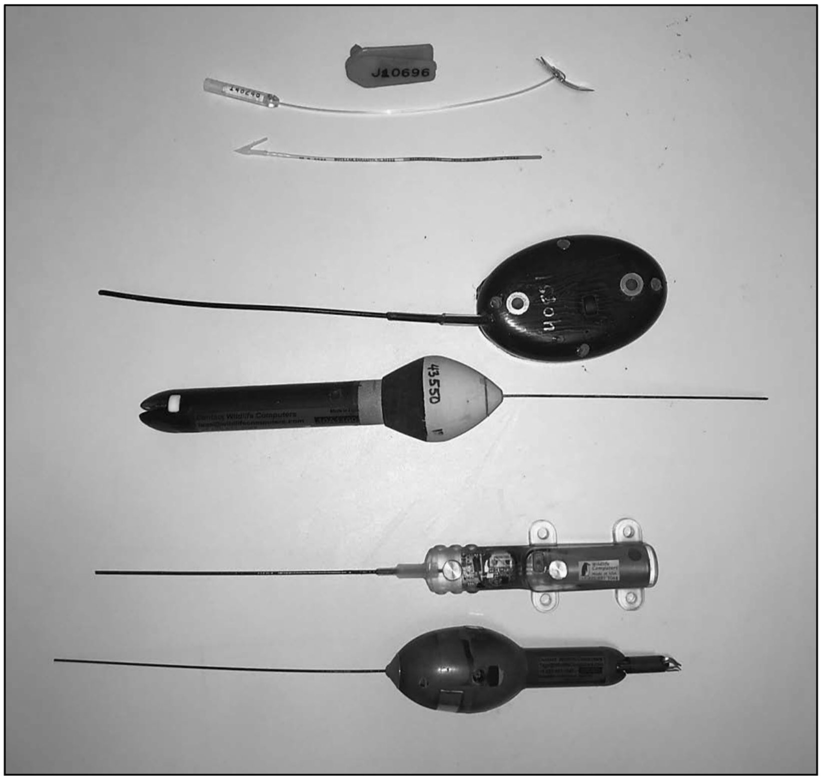
- Promote U.S. investment in technology development to continue to diversify, miniaturize and lengthen the deployment times of satellite tags and other devices used in shark field research. The European Space Agency (ESA) has invested more USD $1 million into the development of a new-generation satellite tag to compete with U.S. and Canadian models, with the potential for this ESA tag to record data for decades on the sharks and cost less than USD $500 per tag. ESA engineers are field-testing their prototype now.
- Provide funding to the NOAA/NMFS/Fisheries Science and Management FY19 budget for a competitive extramural research program exclusively for sharks and other highly migratory species of fishes (tunas, swordfish, billfishes). This request will solve a critical shortfall in funding field research on these species, help drive technology development, address agency priorities, and promote public-private partnerships in marine fisheries research. We ask for an appropriation of $4 million for this purpose.
- Promote international collaborations in shark research, fisheries management and conservation, as these animals know no political boundaries and routinely move back and forth among the jurisdictions of multiple countries. Such "shared stocks" cannot be managed effectively by one nation alone. Those nations that have not adopted acceptable standards for sustainable shark fishing, such as the prohibition of shark "finning"—the cutting off of a shark's fins and discarding the rest of the animal at sea—should be prohibited from importing their shark products into the U.S. For this reason, the Senate should support S. 2764, the Sustainable Shark Fisheries and Trade Act of 2018, introduced by Sen. Rubio and favorably reported without amendment on May 22, 2018, by the Committee on Commerce, Science, and Transportation.
- Encourage Federal agencies to fund biomedical research on non-traditional animal models, such as sharks, that show demonstrated, scientific potential for clinical applications to fight human disease, including cancer.

I thank the Committee for this opportunity to provide my testimony on this important topic.

Robert E. Hueter, Ph.D.
Director and Senior Scientist, Center for Shark Research
Perry W. Gilbert Chair in Shark Research
Mote Marine Laboratory
Chief Science Advisor, OCEARCH

[9] Norman BM *et al.,* 2017. Undersea constellations: the global biology of an endangered marine megavertebrate further informed through citizen science. *BioScience* 67.12: 1029–1043.

SUPPLEMENTARY FIGURES



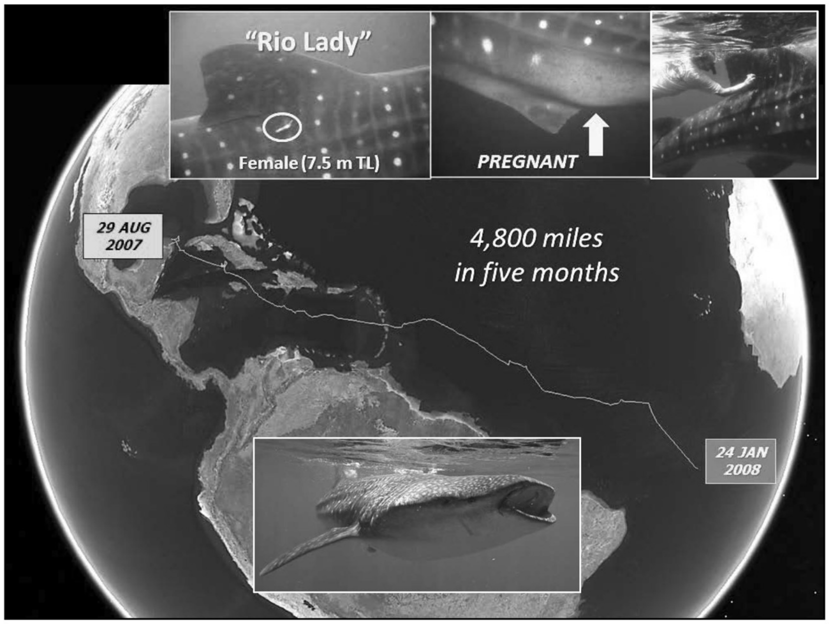
Evolution of shark tags from conventional, external tags (top) to early generation satellite tags (middle) to miniaturized, long-life satellite tags (bottom).

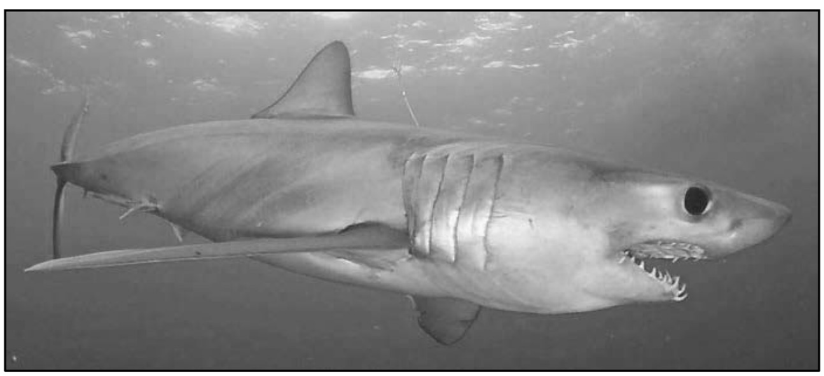
M/V OCEARCH, a specialized 130-foot research vessel designed to study large sharks. The hydraulic platform deployable off the starboard side of the ship can lift up to 75,000 pounds.

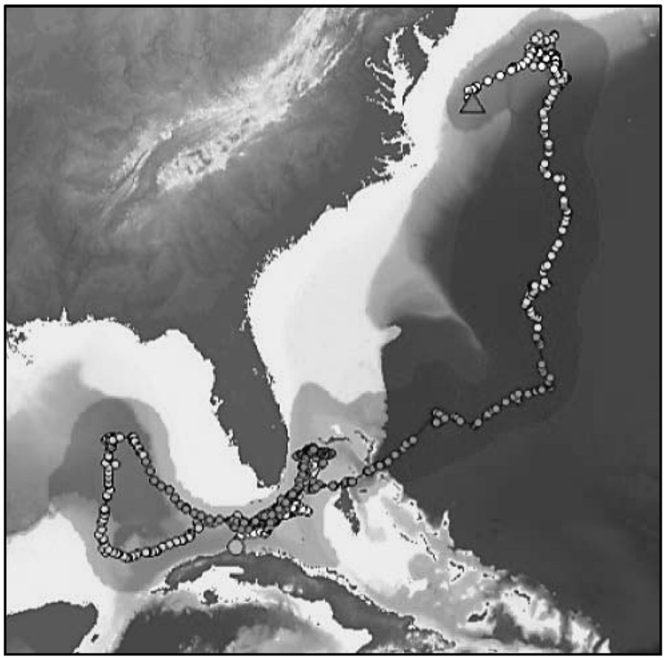
A large white shark being sampled and tagged on the platform of the *OCEARCH* (left) and then being released (right).

Female white shark "Miss Costa" (above) was not quite a mature adult when we tagged her on *OCEARCH* in September 2016 off Nantucket, but nearly two years later in July 2018 she is looping offshore, indicating she might be pregnant with her first litter of pups.

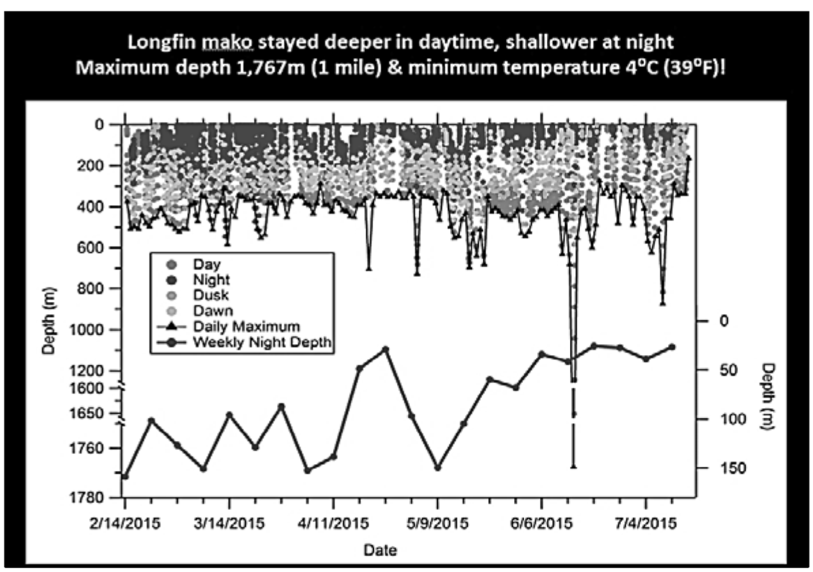
"Lydia," a 14.5-foot, 2,000-pound female white shark when we tagged her on *OCEARCH* off Jacksonville, FL in March 2013, has since covered more than 46,000 miles in the northwest Atlantic Ocean (above). "Rio Lady," a pregnant 25-foot whale shark that Dr. Hueter tagged off Isla Mujeres, Mexico in August 2007 (below) covered 4,800 miles in five months, showing us where she likely gave birth to her approximately 300 pups in the middle of the Atlantic Ocean, just south of the Equator.

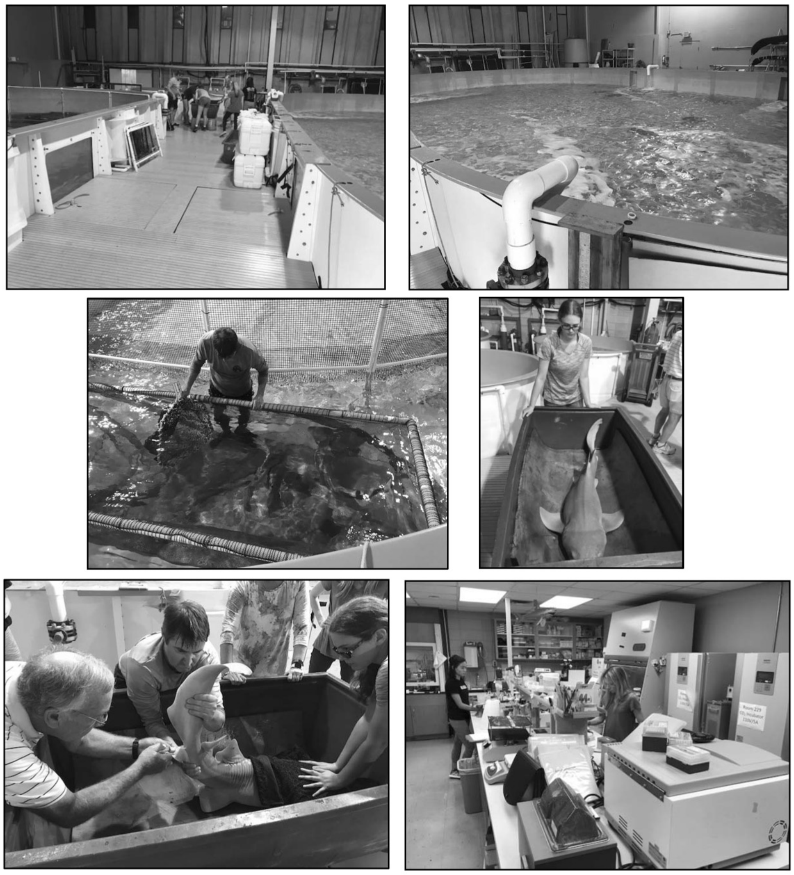

"Rio Lady"
Female (7.5 m TL)
PREGNANT
29 AUG 2007
4,800 miles in five months
24 JAN 2008





A rare longfin mako (above) was satellite-tagged by Mote Marine Laboratory scientists and collaborators from the University of Havana off the north coast of Cuba in February 2015. The mature male shark passed through territorial waters of Cuba, Mexico, Bahamas and the U.S. before its tag popped up five months later off the mid-Atlantic coast (left, red triangle), demonstrating the multi-national nature of these migratory animals. Its depth data (below) showed daily dives to about a quarter-mile deep, with occasional extreme dives to more than one mile deep and near-freezing temperatures.





Biomedical research on sharks at Mote Marine Laboratory is conducted at the Center for Shark Research's Marine Experimental Research Facility (MERF), a specialized facility for holding large sharks. Nurse sharks (above) are used to study the disease resistance of sharks, including to cancer. Blood is drawn from experimental animals (bottom left) and immune cells are grown in culture in Mote's Marine Biomedical Laboratory (bottom right), where studies show the sharks' cells produce chemicals that kill human cancer cells while leaving normal, noncancerous cells alone.

The CHAIRMAN. OK. We will put that up, Lyle.

[Video shown.]

Dr. HUETER. There is a little background sound on this.

So this was an expedition off of Nantucket a few years ago. It shows our crew, our fishing crew, going out to capture a white shark so that we can bring the shark up onto the ship. That is Chris Fisher, the head of OCEARCH. He is a remarkable guy. And that is Captain Bret McBride.

And you see this platform that goes off the side of the ship. That then raises up. We have the animal supplied with water, and we can work on it. We give ourselves 15 minutes like a NASCAR pit crew collecting samples, taking blood, and tagging the animals with a variety of tags, and then finally letting the animal go.

You can go on the OCEARCH website and see the amazing tracks of animals like this, tracks of as much as 50,000 miles after release.

The CHAIRMAN. Thank you, Dr. Hueter.

Let me just, if I might, direct a question to everybody. First up, Dr. Dove, did you say that fishermen harvest 100 million? Did you say that?

Dr. DOVE. That is the global estimate. It is somewhere between 100 million and 200 million sharks a year. It is very hard to know. And so oftentimes sharks are caught in bycatch, and oftentimes those bycatch numbers are not recorded. They may just say they caught a certain weight of sharks in bycatch. So it is difficult to enumerate, but it is certainly in that ball park. And compared to the six humans that are attacked in a fatally unprovoked attack globally each year, it is a very big disparity, but it is a huge number.

The CHAIRMAN. So six fatalities each year.

Dr. DOVE. Roughly globally, yes.

The CHAIRMAN. For the whole panel, could you speak about the role of partnerships between public and private funding sources to support the development of new technologies and innovations for studying marine species? Dr. Hueter?

Dr. HUETER. Yes. As I mentioned, there has been funding for this kind of research from agencies like NOAA, NIH, NSF, the Department of Defense, but much of the pushing the frontiers of shark research, including the biomedical work in the laboratory, has been privately funded through foundations and philanthropy. And it is very powerful when a scientific group can both qualify for Federal funding and also have a private donor, especially to help through the times when the Federal grants or other government grants are not there.

So the group OCEARCH is a perfect example of a public-private partnership in that this is a private, independent nonprofit research and education organization. And we have actually a proposal pending with the National Science Foundation to improve the infrastructure on the ship for our science, and we are hoping to hear positively from that soon.

So this is a very important and powerful way that the field can be moved forward, through public-private partnership.

Ms. KUKULYA. Thank you. So I think it is important to note that the advanced technology that I presented today was funded through the Office of Naval Research, NAVO, and the Federal Government. And without that investment, I would not be here talking about the science that we are able to do with this technology. So it is the government investment that puts the technology in the hands of scientists to enable science.

That said, all the money that we receive for shark research has been also privately funded or by hundreds of individual donors through crowd funding. With the exception of endangered turtle research, which we have received one grant to date for endangered leatherback behavior ecology research. I think collaborations amongst the people on the panel and really spending more time to strategize how to get more funding our way is important.

The CHAIRMAN. Anybody else?

Dr. Wilga, the research that you talked about has some really promising applications. Could you talk about how you made the connection to medical applications of your work on sharks and how other scientists can look for unexpected ways to connect their work to other types of applications?

Dr. WILGA. Sure. So the focus of my current grant, which is funded by the National Science Foundation, was to try to understand how do sharks fish with cartilaginous jaws, eat things like sea lions and metal UAVs and things like that when their jaws are made out of cartilage. And so when we discovered—we did not discover the tessellations, but in our material and mechanical property tests of the cartilage, we discovered that they actually get stiffer with increased force. The more force you put on the cartilage, the stiffer they get, but they remain flexible.

So this seems to be like a really promising material for things for intervertebral disks, knee meniscus, prosthetic coverings, and things like that. So we have a grant into the National Institutes of Health and we are also going to go to the National Science Foundation to see if we can get funding to develop this. So we are at the end of this part of the project, but now we need funding to develop the synthetic part.

So we are not going to use cartilage to make these parts. We are actually going to synthesize out of current, I guess, applications or current devices that are put inside the body for implants and mimic that increasing stiffness with more force but maintain the flexibility because this seems to be the ideal material that you would want to put in a replacement intervertebral disk or replacement knee meniscus or, say, the lining of a prosthetic. Right now, they are all metal, and metal degrades the adjacent vertebrae, and so we are working on something that is non-metallic that will retain flexibility but also strength. And so we are currently looking for funding for that. But we did not know at the beginning when we started this project that there could be biomedical applications for it.

But that is one of things my lab does. I have a post doc who know has two patents and she is working on this one with me as well. So hopefully this will get funded and you will see this in the future.

The CHAIRMAN. How does shark cartilage help burn victims heal faster?

Dr. WILGA. Oh, so I did not do that one. I actually do not know about that. I do know that synthetic glucosamine and synthetic chondroitin helps joints and helps arthritis and things like that, but I am not sure about the burn part. I do not know about that part.

The CHAIRMAN. Ms. Kukulya, we have heard the management of sharks is hampered by a lack of good data on their distribution and abundance. Could you describe some of the ways in which new technologies can help better inform fisheries managers about data-poor species?

Ms. KUKULYA. Absolutely. Thank you for the question.

So it is important to know since the 1800s, up until about 10 years ago, if you would look at data of all the observations of sharks on the eastern seaboard, it would be about 600 data points.

But in the last 10 years with private funding and OCEARCH and organizations like that, there are a lot of different tag technologies that we have seen today that are put on animals. And what those tags allow is to see where animals are going and getting really broad scale resolution.

And so that is where the advanced technology that I have, which is still pretty unique to the playing field, where it is not enough to know where the animals are going. What our technology enables is a lens into the ocean. Scientists can, if we are studying a land animal like an elephant, look out their window and see a great distance. The ocean is an opaque lens. And so the visual capabilities of this technology that can follow along and observe animals interacting in their own natural environment just enables you to see what they are doing and gives information and data sets to policymakers to make informed decisions on how to actually conserve the species but the ocean ecosystem as a whole.

So another example would be in relation to endangered leatherback turtles and our study that was funded by NOAA. Turtle scientists are being asked by fishermen how do I modify my technology to be more turtle friendly. The answer was we do not know because we have not been funded to do that.

So now we do have an ongoing study that allows us to swim along with turtles in a high density fishing area around Cape Cod and actually put eyes on the animals and see what is happening because otherwise we are just guessing. And so with more funding to further develop this technology so you can go longer and deeper and track more animals is going to be critical to be able to get the data in the hands of the people that make informed decisions.

The CHAIRMAN. Thank you.

Senator Nelson.

Senator NELSON. Dr. Kukulya, what is it about that underwater vehicle that attracted the shark?

Ms. KUKULYA. Another great question, and that is what is really fun about this is that we have a lot of data but it is still a sparse data set. When we first did this, you saw that clip of 2012 in Cape Cod, we asked the scientists. OK, what do you expect the shark to do? Because we need to tell the computers a little bit of information to give it a little help. And they are like, we have no idea. That is why you are doing this.

And so when we followed the great white sharks, they had zero interest whatsoever in SharkCam, and they were hunting in murky water. And in retrospect, we learned later because of what happened in Guadalupe, the sharks in Cape Cod were using the sense of smell. They were hunting out seals in large seal colonies off of Mono Island and Cape Cod. And we went to Guadalupe Island. I honestly did not think we were going to be attacked, we could have adverse interactions with any sharks. And we did not know until we pulled the vehicle out of the water and saw these massive bite marks all over it.

The scientists we were working with from the Department of Marine Fisheries in Massachusetts, Dr. Gregory Skomal—you know, that is where we learned where having a unique perspective of making these direct observations and having this tool that can go under the water that in the past people were just making hypotheses as to how these sharks hunt.

And so we think what you are seeing, because at times we put cameras on the tags on the sharks, so you can actually get a perspective of what the animal is seeing. And you see a SharkCam silhouette. It could be 100 meters below. The water is crystal clear and you can see a SharkCam above, you know, silhouetted. And so they were using visual—highly visual predators in deep clear water and they were swimming below and spotting SharkCam. And some of the untagged sharks who were immature were making these 4- to 6-knot dashes to grab it and ambush it from below. Some of the tagged sharks were then coming up forward, head-butting SharkCam, and that was more of a territorial behavior. That lovely sequence where you see all the senses of the shark with sniffing and sensing the electromagnetic poles—it is really trying to figure out if this is a big yellowfin tuna or a seal. And it made a mistake. And oftentimes the same shark does not attack again. Sometimes it does, and we usually see those in immature sharks who might be learning how to hunt.

Senator NELSON. Dr. Hueter, how critical is the shark research to finding a cure for cancer?

Dr. HUETER. Well, the fact is that we know for sure, after decades of work at Mote and other places—at Mote, we have a scientist, Dr. Carl Luer, who heads up this work—that sharks—when you expose them to cancer-causing chemicals, they do not develop the disease unlike just about any other vertebrate animal out there. And the group is focusing now on the immune system of sharks and how they are able to essentially neutralize cancer within their own bodies by creating substances from those immune cells that stop the growth and division of cancer cells, which is what a tumor is all about. It is uncontrolled growth. And they have tested now those substances. They are identifying them and testing those substances in the laboratory against human breast cancer cells and showing that they stopped the growth and division of the human breast cancer cells in the lab and do not affect the normal cells. So it has tremendous potential.

The problem has been that sharks are what we call a non-traditional model. They are not a mouse or a rat that typically organizations like NCI funds. So it has been slow going to identify what these substances are, and most of that has depended on private funding.

Senator NELSON. As you know, we are having discharges of nutrient-laden water that in our fresh water is causing algae blooms, and those algae blooms are going on out to salt water. Have you seen an impact that these algae blooms have had on sharks?

Dr. HUETER. Well, it is a horrible situation that is going on in Florida, and I thank you, Mr. Nelson, for all your engagement on this. We need to do something.

The fortunate thing is that in Florida so far, most of this impact has been in fresh water, but we do have some shark species and a relative of the shark, the sawfish, which is an endangered species on the ESA list, that uses the Caloosahatchee River for critical parts of its life history. Bull sharks use the Caloosahatchee as a place to give birth to their young and where their young grow up.

It is a nursery area. And sawfish range pretty far up there. As you know, that river is being very seriously impacted not only this year but in previous years, but this year particularly bad by these algal blooms.

So, yes, eventually this is going to have very serious ramifications for these shark populations that we are trying to rebuild through good fisheries management.

Senator NELSON. And the phenomenon out in the Gulf of red tide—is that affecting sharks?

Dr. HUETER. Well, we know that red tide kills sharks. They, most of them being fairly large and mobile animals, seem to avoid it. The little ones that get caught up in big blooms that cannot swim fast enough do get killed, and we get small sharks washing up on the beach all the time in a serious red tide bloom.

The problem, though, is that when you displace an animal because of some kind of environmental disturbance like that, they might survive that event, but you may have pushed them away from parts of their range that they should have been for feeding or for reproduction. Those impacts are the hardest to measure, but they are real.

It is very similar to when *Deepwater Horizon* was happening and we were out studying the effect of the spreading oil on shark populations. We found in the middle of the Gulf that a lot of these sharks avoided where the oil was. A lot of the coastal ones, though, were killed. But the ones that avoided it were thrown off their natural migratory cycle. So these things have very serious ramifications for the health of our shark populations.

Senator NELSON. And you all pointed out that the shark attacks are rare. Can you attribute any of these attacks that are close to shore of which sharks are swimming there because of a change of the environment that you mentioned?

Dr. HUETER. Most of the incidents that we have in Florida are because of smaller sharks that are feeding fairly close to shore where there are swimmers—a shark called the blacktip shark, for example. So in Florida, I cannot say that we have noticed that yet.

But I can say that it has been documented now that there are shifts happening in some of these shark populations that they are moving farther north up the East Coast. Sharks that normally would stay more in the Florida area are moving up in the Carolinas through temperature change in the oceans and warmer temperatures up north, leading to the possibility of the exposure of the swimmers up there to more of these kind of biter sharks near the beach.

But as far as red tide algal blooms, thankfully not yet. They have not caused sharks to go crazy and start attacking us. They may yet have had enough and start playing it out on us.

Senator NELSON. Dr. Dove, do you agree with that, that rising ocean temperature is causing the sharks to migrate north?

Dr. DOVE. Yes. So changes in our climate are affecting the oceans in myriad ways. One of the biggest ways that we see that is in the changes in distribution of animals, and it starts at the lowest levels with plankton and it works its way all the way up to sharks, which can change their distribution. These highly mobile animals can adapt to that very quickly by moving to different places if they have a preferred temperature envelope, as we like to say. If they have a preferred temperature envelope they like to be in, they can swim to wherever the conditions are those temperatures.

But one of the things about the impacts of climate change on the oceans is it is not necessarily the problems that we know and can characterize. It is the problems that we have not even thought of yet and some of the unexpected and chaotic outcomes that you get when you perturb a bigger global and complex system like that. So we should not be surprised to see sharks changing their distributions in response to changes in the environment. What follow-on effects that has for people who interact with sharks at the beach or anywhere else I think is yet to be seen. But it is a fairly regular call these days that we start to get a lot of calls in the springtime as the sharks are moving along the coast to go south, that people are seeing a lot more sharks and having shark interactions at the beach.

But as Senator Thune said in his opening comments, the chances of a negative interaction with a shark is still less than the chances of being struck by lightening. So we are still talking about vanishingly uncommon occurrences.

The CHAIRMAN. Thank you, Senator Nelson.

Senator Cantwell.

STATEMENT OF HON. MARIA CANTWELL, U.S. SENATOR FROM WASHINGTON

Senator CANTWELL. Thank you, Mr. Chairman.

I would like to, Dr. Dove, I think talk a little bit about plastics and pollutions in the oceans. I know the subject here is sharks, but I could make the same point about orcas which have been found with plastic—a dead orca I think in South Africa two years ago. And toxins in general are one of the big threats to our southern resident orca population.

So just recently in Seattle, we became one of the first major cities to ban plastic straws and utensils. And a number of companies, including Starbucks, are working to minimize this waste.

Do you think this is an issue which sharks are impacted by, and what else can we do to minimize this?

Dr. DOVE. Thank you for the question.

It absolutely is an issue for sharks. There was a viral video last week out of Australia of a tiger shark having plastic bag after plastic bag pulled out of its stomach. It was an emaciated animal that had become entangled in some equipment and its stomach was completely impacted with plastics. It is very similar to what we see in other apex predatory animals that you mentioned like orcas and dolphins. So we should not be surprised to see the ocean plastic crisis expressing itself in sharks, and indeed, that appears to be the case. And that is something we at Georgia Aquarium would like to study more in the coming years.

It really comes down to some important consumer decisions. So right here on the table in front of me, I have got one good decision and one maybe not as good decision about how I am going to take my water today. So really, plastic has become so invisible to us because it is completely ubiquitous. And making those decisions—and I applaud Starbucks for making the decision that they did—is difficult. It requires behavior change, and it is going to be hard for all of us to begin to evaluate where single-use plastics, which is the problem, not plastic that is designed to be reused multiple times—it is the single-use plastics where there is a big disjunct between how long I am going to be drinking out of that bottle of water and how long it is going to live in the environment, if it ever makes it way into the ocean.

And we have seen it everywhere we go, into the Galapagos, into St. Helena, one of the most remote inhabited places in the world that was shown in my video. We did the first island-wide assessment of plastic impacts to that island this year. And they have a terrible problem with plastic, but it is not their plastic. It is plastic that is washing up on the their shores from the activities of everybody else. And so this really is a global problem because there is one ocean that connects us all, and it impacts the sharks and it ultimately impacts us as well. So we should not underestimate the size and scale of the plastic pollution problem in the ocean.

Senator CANTWELL. Well, I was not going to digress but since you brought this up, I have consulted with a lot of people about this as it relates to water. And my understanding is that some companies actually, as they are making the bottle, rinse it out and some do not. If you do not rinse it out, then you have plastic residue that we are all drinking. So I would love it if this Committee would look more into that issue.

But on the subject as it relates to pollution, what can we do to get more statistics as it relates to this? Or what kind of efforts do you think it would take to get more action in reducing this pollution? Because, obviously, we have populations of fish that we want to retain. We are having a discussion about temperature, but this is as big a threat. Is that your understanding?

Dr. DOVE. I consider it one of the greatest threats to the health of ocean ecosystems, and because it is so large and complex and wide-ranging, it is going to require solutions that are both top down and bottom up. So the consumer choice is a bottom-up control where we decide not to buy those products anymore. But there is a role for regulatory mechanisms that encourage companies or literally outlaw certain types of products that really are pointless or represent a particular risk. And the same thing can be said for ghost gear, which is abandoned fishing gear, which is significant part of the plastic pollution problem in the ocean. So it requires both top down and bottom up. Presumably the Committee has more control over the top down.

But there are places where we should encourage creative product designs so that people are making considerations about the fate of products while they are designing them and not assuming that once that is empty that we do not have to worry about it anymore. It goes in the trash and then it is gone. But as we have seen, there really is no "away." You cannot throw a plastic bottle away. It ends somewhere, and the ocean is downstream of everything.

Senator CANTWELL. And is there anything else on the toxin front that we should be looking at?

Dr. DOVE. So the toxin front is a really interesting one. So this is the idea of the poison pill or the one-two punch that you get from plastic where plastic in the ocean is a threat in and of itself for ingestion or choking on it or becoming entangled, but also it attracts pollutants while it is in the water and they stick to the plastic. And when the animal ingests the plastic, it also gets the toxic effects from all the chemical pollution that stuck to the plastic while it was floating around.

That is definitely a field of research that needs to be advanced. We know now how many species are impacted by plastic pollution in the ocean. It is pretty much all of them. The more we look, the more we see. What we have not really done yet—and this is what needs more research and more funding support—is to make that mechanism link between what happens when that tiger shark eats all those plastic bags and why did that tiger shark die. Was it physical obstruction? Was the animal poisoned? We do not know yet. And that is going to require a lot more sophisticated research.

Senator CANTWELL. Thank you.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Senator Cantwell.

Dr. Hueter, you have done some research on some shark species that are often perceived as dangerous by the public. How could your research help demystify sharks for the public and promote conservation of these apex predators?

Dr. HUETER. One of the technological developments that has not been mentioned but I mentioned in my written comments is the advent of social media to engage the public in sort of a mega-classroom, if you will, of people watching the research and understanding the value of it through the scientists' eyes.

When I started work in this field back in the "Jaws" era, the sharks were viewed as trash fish by fishermen, and they were viewed as man-eating monsters by everybody else. And that has changed now to a view of—I forgot how Al put it, but it was very eloquent—one of respect and admiration for the magnificent adaptations of these animals and their role in the sea.

And I am thrilled that after so many years of educating people—me and my peers—that we now see people on these coastal beaches that are watching sharks with tags like this that are coming up very close to the beach, a 14 to 16-foot great white shark. And they are not saying let us go out and kill it, but they are rooting the shark on. They are adopting the shark, and they understand that that shark is not really threatening them. They are not looking for people, that they are there trying to do their thing and they have been there for millions of years.

So I feel like we are winning that battle, especially in the United States. Across the rest of the world, this is an era of shark conservation activism. That is very exciting. But we still have lots of work to do in terms of turning the tide and getting people to understand that sharks are vulnerable resources and over-fishing and things like finning must be eliminated.

The CHAIRMAN. Dr. Dove, you spoke about your use of satellite technology to study the movement of sharks. Could you speak a little bit more about the challenges of using that type of technology for your research?

Dr. DOVE. Yes, thank you.

There are lots of crossovers between space technology, space engineering challenges and ocean engineering challenges. Increasingly as we use the space technologies to monitor the ocean, those come to the fore more and more and nowhere more than animal telemetry which really took off and really became a useful tool for us once we were able to incorporate satellites in that data flow.

So that is hampered by a couple of things. I mentioned during the video that we have this problem where radio signals, electromagnetic signals of most bandwidths do not travel through sea water. And this is a problem that vexes the Navy on a daily basis, that they cannot send high bandwidth data under water. And so we really are relying on tags that can come to the surface by themselves or the shark comes to the surface for you and breaks the surface and relays that information by satellite.

But even if that happens, the ARGOS satellites that these tags work with—there are only six of those. They have been up there since—well, they started putting them up there, I guess, in the 1970s. They are getting very long in the tooth. We have very few other alternatives. Coverage is not uniform. So when we work in the tropics or close to the equator or in the southern hemisphere, the coverage is not nearly as good as it is in the higher latitudes of the northern hemisphere. And that means you get less information, which means that your expensive tag—and some of the tags—the MiniPAT tag there on the end that you are talking about, that is a $4,500 piece of equipment. So you are tying an expensive piece of equipment to a highly mobile animal swimming around in a viscous, corrosive liquid, and you are hoping that animal is going to go away and tell you some useful science. And that is very, very difficult.

So the tags right now are probably not the limiting step, although they are expensive. The problems that we are having is we just do not have options where we can adapt which satellites we are able to use to where we are tagging, who we are tagging, and what that animal's behavior is. So it really would help us a lot if we could massively expand what access scientists have to satellites.

And I think that BOEM and NASA cube sat approach is really, really creative. It uses a different radio bandwidth. It uses a completely different approach where the tag talks to one satellite, and then the message bounces around among the cube sats until it finds a node to come back to earth. That is quite different from the way the ARGOS satellite system works. And we need all of those creative boffins at NASA and BOEM and other places, the Office of Naval Research of the Air Force even, to look at these solutions. And that is really how we are going to advance animal telemetry into the next century.

The CHAIRMAN. And this would just be maybe to the entire panel too. Would you like to highlight any particular challenges that scientists face while doing shark research? Anybody on that?

Dr. WILGA. Funding. It takes people to do things. It takes money for equipment. It takes money to go find the sharks to see what they are doing, to bring them into the lab. I bring sharks into the lab. So I have big tanks. Just like aquariums, it takes some money to filter those tanks and keep the water the way the sharks like it. So funding is probably the biggest issue.

They are challenging to work with, but once you understand them and once you understand how to do the things that they like to work for you, then it works out pretty well.

But really, I guess funding is the biggest obstruction.

The CHAIRMAN. Yes, sir?

Dr. HUETER. You have to keep in mind these are not stripers in the Chesapeake Bay, that when you make a decision to work on sharks, you are pretty much deciding to work offshore in most cases. And you are working on animals that are large that move tens of thousands of miles, that cross over political boundaries. Sharks do not care about international boundaries out there. They move back and forth. So because of all those logistical realities, yes, it becomes expensive work. You need big vessels. You need expensive gear.

And then if you are going to look at the whole picture of a shark's life and understand its range both two dimensionally and three dimensionally in the water column, because they do move around so much, you have to work with other countries, and sometimes permitting and getting those collaborations is tough. I have been working in Cuba since 2005, and things have been up and down in that situation but we continue to do that work. And it is quite demanding to get the permission and the collaborations going. But you have to because these animals take you there. You cannot just work on them in your back yard and learn everything that is needed to know about them.

The CHAIRMAN. Given the fact that some of these sharks are incredibly difficult to find in the wild, can you talk a little bit about some of the ways research that is being done at aquariums provides the opportunities to the scientific community to conduct research on live animals that would otherwise be impossible to find in the wild?

Dr. DOVE. Yes, I would very much like to speak to that.

So we have 55 roughly accredited aquariums in the country. Most of them feature sharks. It is one of the things that our guests most enjoy when they come to learn about the oceans. And so there are a number of ways that can help.

Some of the learning happens organically as we conduct routine animal care procedures. We sometimes have to face unsolved problems that are unexpected. So, for example, in the video it showed one of our curators taking blood from a whale shark. That had not been done before. So just where do you put the needle is a very simple question. And the aquarium environment gives you a semi-controlled environment in which to do that. So in the course of animal care and taking veterinary care of the collection so that animal welfare standards are kept to the highest levels, we learn things, and then we can take that information out to the field.

So I really do love that idea of the aquarium as test bed and a really virtual cycle between what happens in the aquarium setting and what happens in nature. So we learn from the aquarium. We apply it in the field, but we also learn in the field and apply it in the aquarium. The way we feed the whale sharks at Georgia Aquarium is derived exactly from work that we did with Dr. Hueter about 10 years ago, understanding how whale sharks feed in the natural setting, the angle of their body, the way their filtration mechanism works. And we take that behavior that we observe in the field and use it for better husbandry in the aquarium setting.

So there is a terrific opportunity with the zoological collection-based institutions to advance science in ways that you cannot otherwise. I think Dr. Hueter would tell you that when he came to Georgia Aquarium and we were able to put him in a veterinary exam with a whale shark and he was able to see and touch and exam and measure the filter feeding apparatus of a whale shark for the first time up close, that that was something that would not have been possible otherwise without the aquarium.

The CHAIRMAN. Thank you.

Senator Blumenthal.

STATEMENT OF HON. RICHARD BLUMENTHAL, U.S. SENATOR FROM CONNECTICUT

Senator BLUMENTHAL. Thanks, Mr. Chairman.

Dr. Hueter—am I pronouncing your name correctly?

Dr. HUETER. It is Hueter like computer.

Senator BLUMENTHAL. Thank you, Dr. Hueter.

I have been reading with great interest your testimony and all of the work that you have done over 40 years and the encouraging news that we have replenished some of the stocks that were overfished. Which species do you regard at greatest risk of either endangerment or extinction?

Dr. HUETER. Thank you for the question, Senator.

Senator BLUMENTHAL. The sawfish I think is mentioned in your——

Dr. HUETER. The sawfish, which is a type of ray, which is a shark-like animal, a relative of the sharks, is the species group of greatest concern worldwide right now. In the United States, sawfish used to be abundant all along the Atlantic and Gulf coast and the Southeast up until about the 1930s or 1940s, but when gill nets were introduced in fisheries, this was an animal that was severely not adapted to encounter a gill net. So they have been reduced down to remnant populations of probably several thousand. Based on work at Mote, I am proud to say, they were listed on the ESA, the first marine fish to be listed on the ESA about 15 years ago or so.

They are coming back. There is excellent work happening with them. Of course, they are a prohibited species for any kind of fishing. But we have to really be concerned about some of the habitats that they need to come back.

Beyond that for the large coastal shark population as a whole, over 25 years of very difficult management evolution within this country, we have brought back most of these species to a sustainable level. There are, however, still some that are species of concern. One is the dusky shark, which still—it is debatable of what the status is of that animal, but some estimates show that it is going to take more than 100 years to grow them back to where they are a sustainable population.

And then out in the open sea, a species that we thought was doing fine was reassessed recently, the shortfin mako, which is a very popular game fish—it is a good shark to eat. And it is impacted by commercial fisheries, especially by foreign fleets. It turns out the mako is in trouble, and we are trying to take action now on the international stage to protect the mako.

So we still have work to do, but the great news is that the U.S. now is what has been called by others a "bright spot" for sustainable shark fishing. And we are doing a lot of things right in this country now through very hard work over the last 25 years.

Senator BLUMENTHAL. The work that has been done over these past years I assume has focused on better management. What other areas do you think are most important for us to emphasize in terms of making sure that our shark populations are preserved?

Dr. HUETER. Well, you cannot have better management without the best science, and the science has underpinned the management gains that we have made over the last 25 years. So if you go back 50 years in fisheries science, the scientific basis for making decisions was a little bit crude. And over time because of much better approaches to collecting good data and analyzing those data and looking at situations where the data are not particularly abundant, we have got much better techniques of estimating the status of the shark population.

You have to understand that these animals are very difficult to count. You cannot go out and do like a bird count and figure out how many sharks are in the sea. So we have to get that information through various ways. And those models that are being used have improved greatly. The types of science—as I mentioned, we even have underwater cameras that can detect the presence of sharks and possibly count them now without having to catch them. It is the science that has led the way and needs to continue to lead the way to carry out all the goals of shark conservation.

And when I say "conservation," I do not mean preservation. I mean sustainability, a fair and balanced use of the animals in fisheries, and preserving them where it is necessary to preserve the health of the ecosystem.

Senator BLUMENTHAL. And let me conclude with this question. You also make the point in your testimony that the public view of sharks has been largely shaped by the World War II experience and "Jaws" and similar kinds of public entertainment.

If you were talking to, let us say, the average American whose concept of sharks is that they are dangerous, they are attackers or predators, and we ought to be alarmed about them, and who should care about them, would you say that the danger of shark attack for most Americans is something that we ought to have top of mind when we go swimming in certain areas? Would you say the danger has increased at all? In other words, are sharks more of a threat now than they were at some point in the past? And what would you say to the average American about why we should care about sharks?

Dr. HUETER. Well, first of all, that conversation that you described with the average American would be a conversation that I would have had maybe 25 years ago where the person would say why should we care about sharks. You know, we should wipe them all out. I just do not get that kind of response anymore, except very rarely.

Senator BLUMENTHAL. Because people understand why we should care.

Dr. HUETER. We do some things wrong, but one of the things we have done right is use social media and wonderful places like the Georgia Aquarium and other major aquariums to educate people and get people to put things in perspective, give people the facts, which is something we scientists like to hold onto. And when it comes to the issue of shark attack, which I have written papers on—and actually we advocate not calling it an attack in a lot of cases because many of these incidents are simple mistaken identity type bites. They are not really attacks. The risk is so low that it should not be something that we elevate to the highest priority.

Having said that, every time a shark bites a person, it is not trivial. It is serious. So we are not sweeping it under the rug. We are putting it into perspective and getting people to understand that sharks have much more value to us in ecological ways, in ways for fisheries, and for the economy, for tourism, and also in science. I mean, all the things we are learning from sharks we have heard a little bit about today. Their natural resistance to cancer. We need these animals. We need them to be in a healthy state.

And, yes, we are rebuilding the shark population on the U.S. East Coast, but there may be some people concerned about that. But in fact, when you look at all the statistics over the past, the only thing that has tracked the number of shark bites or attacks on people have been the number of people in the water, not the number of sharks.

So we think with continuing great education and getting people to use common sense how they interact with these animals and watching some of these specific situations like the return of white sharks on the East Coast, that we can strike the balance that is needed to have the kind of ocean that we all want. I continually tell people when they report to me they have seen a shark, I said is that not wonderful. It is so much better than seeing garbage floating by or syringes or something like that. When you see a shark swimming out there, rejoice. That means it is a healthy ocean.

Senator BLUMENTHAL. My time has expired.

But this subject is fascinating. I would welcome any other comments that others have in response to those questions. I did not mean to single out Dr. Hueter.

Ms. KUKULYA. I would like to make two comments, if that is OK. Quick ones.

Greg Skomal has a reply. He is a scientist that I work with with the Massachusetts Department of Marine Fisheries. And his advice to the public goes like this. Drive safely. You are more likely to get hurt driving to and from the beach than getting bit by a shark, and make sure you wear your sunscreen. So that is his comment.

And I think another thing to tell the average American is, very simply put, the sharks are apex predators. They are at the top of the food chain. If they collapse, the fish underneath them collapse and so on and so on. It is a domino effect. And before that, you have a collapsed fishery and that has huge socioeconomic impacts on our economy and jobs.

Senator BLUMENTHAL. I am not sure I—they are at the top of the food chain.

Ms. KUKULYA. Yes.

Senator BLUMENTHAL. If they collapse, the fish under them collapse too.

Ms. KUKULYA. That is correct.

Senator BLUMENTHAL. Is that a causal chain or a symptomatic one, if you understand? In other words, they enable other fish to survive because they weed out populations or—explain that to me.

Ms. KUKULYA. Does the scientist actually want to answer that?

Dr. HUETER. We call this phenomenon trophic cascades, trophic meaning feeding. When you eliminate or greatly reduce one level, you have these effects that cascade down through the food web, through the ecosystem. So there are actually documented cases of when sharks were essentially eliminated from reef systems in the Pacific and the Caribbean, that it so disrupted the balance, it so disrupted the food web, that the things that they fed on became too numerous to be in balance. They ate the fish below them and wiped them out. And unfortunately, those fish were responsible for sort of mowing the lawn of the reef and keeping algae from growing over the reef. And the reef itself ended up dying by being overgrown with algae. Who would have predicted that would be an effect up here from when the sharks were removed?

But we have other examples of this. We used to talk about them theoretically. Now there are real world examples. The key is that when this happens, because of the slow reproductive potential of sharks to come back, you have to live with these problems for decades and perhaps even longer. So this is a very real thing.

Senator BLUMENTHAL. Similar to the big cats in the jungle.

Dr. HUETER. That is right or wolves. When wolves were hunted out in the West and parts of the West, then you see problems in the deer populations. Exactly the same principle.

Senator BLUMENTHAL. Now you are getting much closer to the Chairman's territory.

[Laughter.]

Dr. HUETER. I wanted to invite the Chairman to come with Mr. Nelson to Mote. We will be happy to take you out shark diving sometime.

[Laughter.]

The CHAIRMAN. That sounds very interesting.

[Laughter.]

Senator BLUMENTHAL. Thank you all for your excellent testimony.

The CHAIRMAN. Thank you, Senator Blumenthal. You were not here earlier, but I actually showed the teeth of sharks that roamed the high plains of South Dakota in a different era. And I do want to thank the South Dakota School of Mines and Technology for making those available to us for this hearing.

And I just say again thank you to our panelists. You know, there is a certain, with sharks I think, historically sort of fear and fascination, because most of us—our orientation with sharks was Roy Scheider and Police Chief Martin Brody and Richard Dreyfuss from the movie "Jaws." But at the same time, I think a lot, as you said, we have learned since then, and the amazing amount of research that is being done and some of the innovation that it is leading to is pretty remarkable. And we want to see, obviously, that continue in a way that improves the lives of Americans. And some of the things that are happening in the area of the medical space, health care, have, it seems to me, at least some very significant potential, in addition to the other aspects, commercial and economic aspects that have been mentioned as well today.

Senator BLUMENTHAL. Sharks have been victims of a lot of fake news.

[Laughter.]

The CHAIRMAN. OK.

[Laughter.]

The CHAIRMAN. But anyway, I want to thank you all. You will probably get some written questions for the record for members of the panel. I would ask if you could respond to those as quickly as possible. We will keep the record open for a couple of weeks to accommodate that. But, again, thank you for being here today. Thanks for your testimony and your responses to our questions.

This hearing is adjourned.

[Whereupon, at 11:53 a.m., the hearing was adjourned.]

A P P E N D I X

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. DAN SULLIVAN TO DR. CHERYL ANN DENESHA WILGA

Question 1. On the surface, the biomechanics of how sharks feed seems worlds away from the study of human biology, artificial implants or medical prosthetics. How is it that you came to realize your research might have such significant medical applications?

Answer. My current grant focuses on how sharks, which have cartilaginous jaws that are made of hyaline-like cartilage like what is in your nose and ears, are able to feed on prey that have bones and hard shells. We measured the stiffness of the jaw cartilages in different shark and ray species, and the resulting stress-strain curves showed an abrupt upwards inflection. This inflection revealed that shark cartilage becomes stiffer with increased force, much like squeezing a slinky toy. Other researchers theorized this inflection, and our research supported that. This unique combination of having a flexible inner core surrounded by stiff articulated mineralized blocks, allows shark jaws to bend slightly around objects that are harder than the jaws rather than breaking. A key property of shark jaws when feeding is that some regions are under compression while other areas are under tension. We realized that if we could reproduce and synthesize those properties, they could be used in applications that are subject to variable force but also need to be flexible, particularly in applications that are simultaneously under compression and tension like intervertebral discs, knee meniscus, and prosthetic lining.

Question 2. What do you see as the next critical stage in your research? Given the promising medical and commercial applications, what Federal support are you seeking?

Answer. We have nearly finished examining the mechanical properties of cartilage in many shark, skate, and ray species and are preparing our results for publication. The next step is to apply the properties of the three components of shark cartilage to 3D printed models made from CT-scans of healthy intervertebral discs, meniscus, or lining with the requisite mechanical properties for that part. We are seeking funding from the National Institutes of Health and the National Science Foundation.

Question 3. Education and workforce development are perhaps the most recognized and best understood aspects of our Nation's public university systems—and yet research like you presented here today is driving so much innovation and discovery. Can you talk a bit about the importance of your research on the University of Alaska's overall mission?

Answer. Part of the mission of the University of Alaska is to inspire learning and to advance knowledge while preparing students for jobs or professional schools after graduation. Active and experiential learning, like being involved in research, coupled with traditional foundational knowledge better prepares our students for the workforce and professional careers. Most of the faculty at UA involve students in research. There is cutting edge research in cancer biology, arctic biology, climate change, fish and wildlife populations, and microbiomes, to name just a few, with undergraduate students working with and being mentored by graduate students and postdoctoral researchers, who in turn are mentored by the faculty. These collaborations are key to the experiential learning process and our students are more marketable after graduation because of them. For example, biological science, natural science, civil and mechanical engineering, and mathematics students and postdocs have worked together on these projects in my lab. All of them have successfully entered the workforce or graduate programs.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MAGGIE HASSAN TO ROBERT E. HUETER, PH.D.

Global Warming. Scientists have proven that the ocean acts like a sponge and stores the majority of the Earth's surface heat.

Question 1. Given your background, how does global warming affect our oceans and the animals that make up these fragile ecosystems and what should we do to prevent further damage in that respect?

Answer. Whether they live on land, in the water, or in the air, animals are adapted to a certain range of temperature extremes. Their upper tolerance for warm temperatures is dictated by how their bodies physiologically perform in those higher temperatures, all the way to the body cells' enzyme systems that control metabolism. This is no less true in the sea, where many marine creatures live "on the edge" with respect to upper temperatures to sustain life. When those temperature maxima shift upward through climate change, animals that cannot readily adapt either die—as in the case of sedentary species like corals—or they move to where water temperatures are more tolerable. Being able to relocate, however, does not guarantee that a population can continue to thrive, for the geographic shift might not ensure success in finding food or producing offspring.

The world's societies should be doing everything possible to mitigate the effects of human-induced contributors to global warming. As I am not a climate change expert, I will demur on naming what those specific actions should be. But I will say that if we take no action, we must be prepared to live with a whole new set of environmental conditions that will include, but not be limited to, sea level rise, warmer and more acidic oceans, die-offs of marine and terrestrial natural communities, more intense hurricanes, major shifts in agriculture, and resulting disruption of human economies. And unlike some environmental challenges we face, these effects will not be fixable once the situation has progressed too far, creating a global crisis for our children and grandchildren.

Species Migration. Along the East Coast, we have shark and fish species that live in cold waters and, as I am sure you are aware, sharks can often help maintain ocean ecosystems. With water temperatures rising, all species—including the sharks—are forced to migrate north.

Question 2. How has this impacted fisheries in Northeast?

Answer. Most of what we currently know about this is only predictive, based on sophisticated modeling of everything from plankton dynamics to fisheries production. We do know through empirical evidence that some shark populations have begun shifting northward along the U.S. east coast. But because fisheries are affected by such a complex interaction of many factors, it's difficult to say how global warming has already affected fisheries in the Northeast. What is predicted is that fish population centers will shift to higher latitudes (north) and farther offshore to seek cooler waters and deal with changing prey availability, which will in turn mean that fisheries productivity at lower latitudes (south) and nearshore will decrease. This will seriously disrupt fishing communities and their economies and could increase the cost of fishing in many regions, threatening our food supply of protein from the sea.

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