Shark Tracks

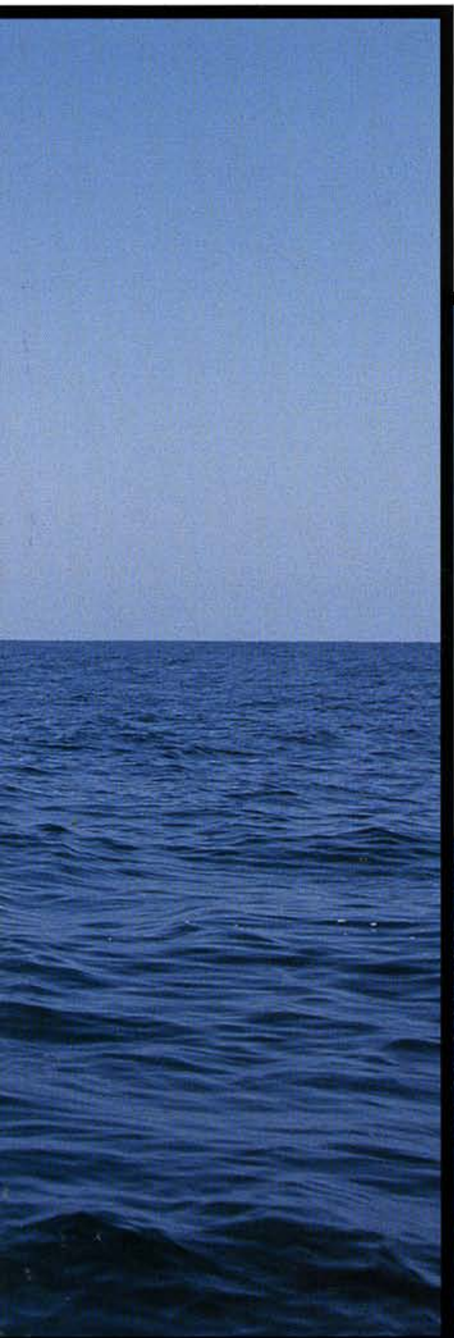
Above, *Chugey Sepulveda (left), Nick Wegner (middle), and Dan Cartamil set out to sea in search of sharks.*

CHUGEY SEPULVEDA WAITED. With patience and perseverance, he waited for the sharks.

Sepulveda, a fourth-year graduate student at Scripps Institution of Oceanography, has spent several hundred hours battling cold, fatigue, and uncertainty sitting in a tiny boat, endlessly bobbing up and down on the open ocean waters off San Diego, hoping for the sharks to appear. Enduring these less-than-ideal conditions is testimony to his dedication to a groundbreaking scientific project. Sepulveda's pioneering research into the activities and swimming behavior of southern California mako sharks will lay the groundwork for new conservation efforts that will help protect this overfished and vulnerable species.

Finally, the sharks arrived, and the scene changed in a heartbeat. Fueled by adrenaline, Sepulveda's first piece of business was to "feed" the sharks a high-tech tracking device. Once the device was in the shark's stomach, a chase began. Sepulveda was the predator, tracking the shark's every movement across the ocean.

The stakes in the chase were high. If Sepulveda followed the shark too closely, he ran the risk of disturbing its natural swimming behavior. If he didn't follow closely enough, he ran the risk of distanc-



BY MARIO C. AGUILERA

Technology, Innovation Help Researchers Understand These Elusive Creatures

Above, *Chugey Sepulveda makes detailed notes during tracking trips.* **Right,** *Dan Cartamil helps harness a thresher shark that will become part of a tracking study.*

Above, *Southern California's waters are one of the few nursery habitats in the North Pacific Ocean for mako sharks.* **Right,** *Chugey Sepulveda (left) and Jeffrey Graham have adapted high-tech instrumentation to track sharks in their natural environment.*

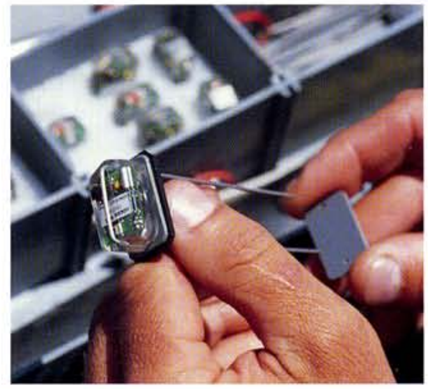
ing himself from the animal and losing the vital tracking signal emitted from the high-tech device. If the shark regurgitated it, the chase, tracking device, and many hours leading up to this moment could all go down the proverbial drain. And if this wasn't enough pressure, Sepulveda was a novice tracker using newly adopted technology.

"Everything in the ocean is overfished, but the problem with sharks is that they don't have the ability to recover as effectively as a lot of other animals," said Scripps marine biologist Jeffrey Graham, Sepulveda's advisor and a member of the Center for Marine Biotechnology and Biomedicine at Scripps. "They have low rates of reproduction and are subject to high fishing mortality. I saw the timing of this project as very right to help establish a greater public awareness of shark conservation problems. We needed to learn more about these animals in their natural habitat."

IN THE BEGINNING

Sepulveda fondly remembers these same waters as a childhood setting for many family fishing expeditions. A native of Orange, California, the skills and interests Sepulveda developed in those formative years eventually led to studies at California State University, Fullerton. There he earned a master's degree studying tuna and mackerel swimming energetics (the study of how an animal partitions its metabolic fuel).

His master's thesis advisor, Kathy Dickson, was Graham's first graduate student at Scripps. This link eventually led to Sepulveda's arrival at Scripps, in 2000, where he first volunteered on a project headed by Diego Bernal, a recent Ph.D.



graduate of Graham's laboratory.

During this time, the seeds of Sepulveda's research were sown. It also was a time when many changes were occurring in the way sharks and other marine life were fished in California waters. Regulations were put into place to protect leatherback turtle populations by ending gill netting off California north of Point Conception, near Santa Barbara. This has led to increased gill net activity in southern California waters. Also, in an effort to protect marine mammals swimming near the ocean's surface, gill nets are required to be set at levels deeper than 11 meters (36 feet).

Mako sharks are not the primary target of the California gill net fishery, which is aimed at catching swordfish and thresher sharks. However, makos (predominantly juveniles) make up a significant component of the gill net catch. Mako and thresher sharks are important catches for the commercial sportfishing industry and recreational anglers in southern California.

"Our society is so technologically advanced now that our fishing methods are incredibly productive. We are very, very efficient at removing organisms from the ocean," Sepulveda said.

Little information is known about how these sharks move and spend their time in the Southern California Bight, which extends from Point Conception into Baja California, and is one of the few documented nursery habitats in the North Pacific Ocean for makos.

With all of that in mind, Sepulveda began to put together his first tracking excursion.

"Understanding mako physiology and how it relates to their movements in the wild may pro-

Top left and right, *Chugey Sepulveda prepares an "archival" tag, a device that he uses to continuously record movements of thresher sharks.* **Above,** *Long, thin identification devices, nicknamed "spaghetti tags," provide valuable shark identification information.*

From left to right, this page, *Chugey Sepulveda prepares a bait, or "chum" bucket; he deploys the bucket to attract sharks to his boat; he readies a hollowed-out fish embedded with an acoustical tracking device; the fish is ready to be placed in the water; a hydrophone is placed in the water to help locate the device inside a shark's stomach.*

vide information that can lead to better management strategies," Sepulveda said.

MONITORING THE MAKO

As Sepulveda set out to track makos, he decided to focus on juveniles because of their essential role in maintaining the population and their importance as top-level predators in the Southern California Bight.

There were many questions to try to answer: Where do makos spend most of their time? In deep water or shallow? In northern regions or southern? How far offshore? Do they move in predictable patterns?

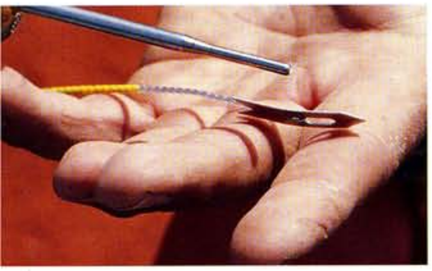
To help answer these questions, Sepulveda adapted a high-tech acoustic tracking device and a tracking system provided by Dave Holts of the National Marine Fisheries Service (NMFS). When it came time to use the novel system, Sepulveda went to sea with fishing and tracking equipment, chopped bait (known as "chum") to attract sharks, plenty of determination and patience, and food to sustain him and other researchers who went along, including UCSD student Corey Chan and NMFS researcher Suzy Kohin.

When the chum finally attracted a mako to his boat, Sepulveda fed the shark a hollowed-out mackerel implanted with the acoustic device. Unbeknownst to the shark, the device inside its stomach sent out an acoustic pulse detected by Sepulveda's onboard hydrophone.

For the next 24 hours—and 56 hours on a subsequent trip—one Sepulveda team member concentrated on charting the complex movements of the animal, logging every liquid step of the way. Sleep and rest breaks were alternated between researchers. If both felt sleepy, neither would get any sleep as there was a possibility of losing the tracking signal.

"The first time we did this we were thinking it was too good to be true. We thought the shark would regurgitate the device at any second," Sepulveda said. "But in the end, the device was there in the shark's stomach 24 hours later."

After the first tracking expedition, the project was considered a success. Sepulveda's feeding-and-tracking technique eventually resulted in seven successful tracking excursions, each carefully depicting the mako's free, natural swimming patterns. Other investigators who have tracked makos by attaching tags would first catch the sharks using traditional hook-and-line methods. This method would



Clockwise from top left, this page, *A spaghetti identification apparatus; an archival data tag; data from tags are downloaded onto computers; notes correspond to each tag attachment; Sepulveda and Cartamil attach the tag to the dorsal fin of a thresher shark.* **Center,** *The shark is released into the ocean.*

typically produce tracks that probably reflected unnatural behavior because sharks often struggle violently when they are caught and restrained for tag attachment. After being released, they exhibited unnatural, high-stress behavior such as immediately swimming to greater depths as a defense tactic, a trait not observed in any of Sepulveda's tracks.

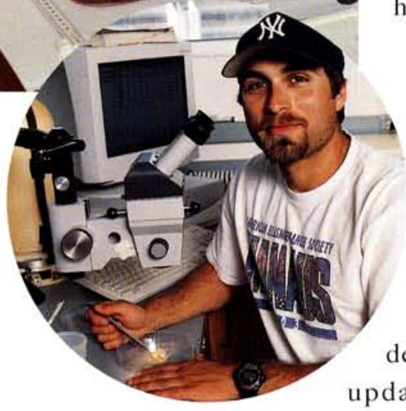
"I think Chugey was extremely clever to take advantage of the mako's willingness to ingest the pinger-stuffed mackerel," Graham said. "That boosted the scientific merit of the study because he could follow a shark that had not been spooked."

The project resulted in a research paper recently published in the journal *Marine Biology*. In the paper, Sepulveda, Graham, and coauthors Chan, Kohin, and Russ Vetter (NMFS) meticulously detail movement patterns, depth preferences, and other data never previously obtained in shark studies. The results show that makos collectively spent the majority of their time, 80 percent, in the shallow upper 12 meters (39 feet) of the ocean. One shark stayed there 99 percent of the time. Only five percent of sharks' time was spent at depths greater than 24 meters (78 feet). This is of great importance considering that the current mandates for protecting marine mammals on the gill net fishery require that nets be placed below 11 meters (36 feet). Thus, these mandates may be inadvertently providing protection for juvenile makos in that they spend most of their time above this depth.

The tracking also revealed that the animals exhibited most of their movement up and down the water column during daylight hours. This, the scientists say, may be due to, the sharks' reliance on vision for locating prey, and is reflected in their greater depth penetration during daylight hours.

All of this information, they hope, will provide scientists with a better understanding of the mako's fine-scale movements and will provide fishery managers with data that accurately depict how habitat areas are used by the animals. In the end, Sepulveda hopes this will eventually translate to reduced juvenile mako bycatch.

"This is the first time that this



Left, *Nick Wegner examines a cross-section of shark muscle.* **Below,** *Dan Cartamil employs a dissecting microscope to investigate the interior properties of a thresher shark.*

has ever been done so everything is new and interesting," said Dickson, Sepulveda's former advisor. "These new data generate more ideas because now you have something to really base your hypothesis on."

The project's success has led to a follow-up study on thresher sharks, which, like the previous study, is funded by the California Sea Grant College Program. Sepulveda and new Scripps graduate student Dan Cartamil are updating their methods by employing "archival" tags that record a long-term series of movement information.

The square, paper-clip-sized electronic recording tags attached on the thresher's dorsal fin stay with the animal and record data for months at a time. Larger threshers are likely to be caught offshore by commercial fishers while smaller fish will most likely be landed by sport fishermen. Recovered tags are returned to the laboratory where the information is downloaded onto computers.

The information is so valuable that the researchers are offering fishermen a $50 reward for each returned tag. Sepulveda and Cartamil believe the cost is well worth it, as the data will significantly broaden their knowledge about the activities of southern California sharks.

The expanded database will be important for predicting shark movement patterns and identifying possible areas or depths that can be considered thresher "hot spots." Ultimately, Graham and Sepulveda hope it will factor into future protection of the animals.

"Both of Chugey's projects are giving us new scientific information," Graham said. "A Ph.D. student needs to demonstrate that he or she can apply scientific methods and acquire data through research, and this gives them the potential to discover something important. Chugey Sepulveda has done this."

Above, *Researchers (left to right) Jeanine Donley, Diego Bernal, Doug Syme, and Robert Shadwick aboard fishing vessel* Legend.

IN THE FRIGID WATERS OFF ALASKA late last spring, a group of scientists spent several weeks searching for the large, powerful salmon shark. In a series of investigations headed by Scripps marine biologist Robert Shadwick, these scientists are studying the "extreme" biomechanics of these extraordinary animals.

Salmon sharks, like their great white and mako cousins, belong to a group called "lamnid sharks," animals with a high-performance locomotion system and muscle design that allow them to ply the oceans with fast, continuous motion.

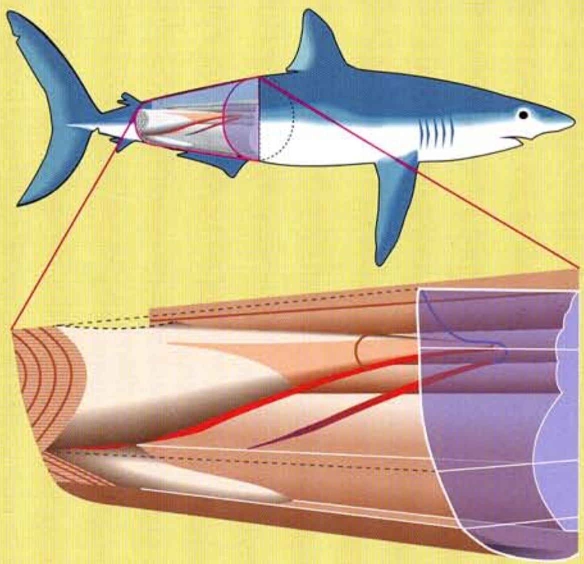
Scientists have been intrigued by these powerful swimmers for years. Of the more than 25,000 fish species in the ocean, only a select few, including lamnid sharks, are able to elevate their internal core body temperature for high-speed swimming. Most fish have a body temperature close to the outside water temperature.

"These sharks' interior [red] muscle, which powers steady swimming, acts at high temperature, just like a mammal's, but the rest of the muscle in the body operates at lower temperatures, like that of an ordinary fish," Shadwick said. "Even their closest non-lamnid shark relatives keep a cooler body temperature like most fish, but these animals have elevated internal temperatures, many degrees warmer than the water surrounding them—which should give them a power boost."

Shadwick and Scripps marine biologist Jeff Graham began investigating these issues more than a decade ago, first concentrating on the high-performance design of tunas.

Recent research at Scripps by Shadwick and Scripps graduate student Jeanine Donley revealed the similarities between the lamnid shark's muscle system and that of the tuna, which is a bony fish not widely thought to have much in common with sharks. This

Left, *In Alaska, the researchers studied salmon sharks in near-freezing temperatures.* **Inset,** *Robert Shadwick (top) and Doug Syme plot shark muscle data for analysis.* **Center,** *The interior architecture of the shortfin mako shark reveals how red muscles (pink area), which propel continuous swimming, coordinate with tendons (red) to transfer power to the animal's tail region.*



amazing parallel has prompted questions about these creatures' mutual ancestry and evolution.

"Sharks and bony fishes have been separated for over 400 million years, and yet we see one group of sharks and one group of bony fish that share a remarkable host of similarities in body form and function. It's interesting to understand how mechanical design principles influence the evolution of locomotion in these animals," said Donley, lead author of the study, which was published in the journal *Nature*.

To help Shadwick and Donley probe deeper into lamnid shark muscle dynamics, they employed an array of equipment and instrumentation—from tiny devices that precisely record muscle movement to video analysis of the animals in an ingenious swim tunnel that functions like a treadmill for fish. The research has shed new light on lamnid sharks' thrust-producing swimming, which provides necessary bursts of speed for targeting prey.

The success of the lamnid shark research set the groundwork for the new study in Alaska where the scientists hoped to unravel the mystery of shark swimming even further. Lamnid sharks living in southern California waters can keep their temperatures elevated, but what about similar sharks living in much colder conditions, closer to freezing? Indeed, salmon sharks, which typically weigh several hundred pounds, live in an environment in which their internal temperatures differ from the outside water temperature by as much as 20°Celsius (35°Fahrenheit).

A group that includes Shadwick, Donley, Scripps alumnus Diego Bernal, who is now on the faculty at Weber State University in Utah, and Doug Syme of the University of Calgary studied these fish in unprecedented detail while in Alaska and are now analyzing the data they collected.

"This research is risky in that it's really hard to get access to the salmon sharks, and at the end of the day we might go home empty handed," Shadwick said. "But hopefully we will contribute to the knowledge of how muscles function by studying something that's an extreme—a fish that seems to have fish muscle in most of its body and warm, mammalian-like muscle stuck in there right in the middle to enhance its swimming performance. We shall see."