Samuel H. 'doc' Gruber in the lab in 1963, microtome slicing shark eye for retina histology (right); The young Gruber spent his weekends diving and spear fishing on the schooner *Blue Goose* in 1957, when there were still big fish (below)

Doc Gruber

— *Pioneer of Shark Science, Part I*

Samuel H. 'doc' Gruber began studying sharks in 1961, perhaps before any other scientist had done full-time research on a living shark. During his long career, he founded the Bimini Biological Shark Lab, the Shark Specialist Group of the International Union for the Conservation of Nature, (IUCN), a United Nations organization based in Switzerland, and the American Elasmobranch Society. He has published over 200 scientific papers, and his work is still ongoing today. His ground breaking discoveries have given us an extraordinary glimpse beneath the veil of mystery surrounding these unusual marine animals that are so different from all other vertebrates. His decision to study sharks was as unplanned as it was final.

Text by Ila France Porcher
Photos courtesy of Dr Samuel Gruber
Additional shark photos by Peter Symes

As a young man growing up in Florida, he loved to dive, and often went off for weekends of scuba diving and spear fishing on a 30m schooner called the *Blue Goose*. The ship had belonged to Hermann Göring, commander-in-chief of the German Luftwaffe (Air Force) under the Nazis, and it had found its way to Miami when it was liberated at the end of World War II. A weekend of diving fun on the *Blue Goose* cost only seven dollars, and at that time, there were still big fish!

On one of these outings in 1958, Gruber had speared a grouper hiding in a submarine cave, and was emerging with it into open water when he saw a hammerhead shark approaching. It was the largest shark he had ever seen, and as it glided towards him, it seemed to be the size of a submarine!

Sure that he was about to die, he plunged back into the cave with his fish, and found himself in the same position that the grouper had just been in, as he looked out. Watching in awe as the momentous shark passed him, he was seized with the desire to know what sort of an animal it was.

When he returned to the university, he asked his professor what was known about sharks, and found that no one knew much at all. So he decided then and there to become a marine biologist and study them.

Research begins

With the idea of becoming a medical doctor, Gruber was attending Emory University at the time, and was majoring in pre-medical studies. He had been especially intrigued by the study of comparative anatomy in which he had dissected a shark, a giant salamander, and a cat.

That summer he was taking courses at the University of Miami, and had asked if he could assist the comparative anatomy laboratory dissecting the animals. Now, inspired by his riveting meeting with the hammerhead shark, he transferred to the University of Miami, earned his undergraduate degree in zoology and chemistry, and applied to graduate school to study sharks.

In 1960, the University of Miami's Marine School had hired Dr Warren Wisby as professor and researcher in marine animal behaviour, with an emphasis on sharks. As a student of the famous professor Arthur Davis Hasler, Wisby was best known for having discovered the actual mechanism of homing in salmon. By marking hatchling salmon, and going back to their streams when they returned to spawn, Wisby had found that they came back to the exact stream in which they had hatched.

So Gruber's timing was perfect. He was given a research assistantship, and didn't have to pay for tuition. In fact he was paid the huge sum of 103 dollars

shark tales

Gruber (left) and Wisby (right) collecting eyes from specimen during shark tournament, 1963

Collecting shark eyes at tournament in Bayshore, New York, 1962

a month as a graduate student there!

Wisby told him that the Navy had given them a grant to study shark senses. When aircraft went down at sea, it happened at times that sharks attacked the flyers in the water. In those days flyers wore two types of suits—high visibility suits called International Orange, and the standard khaki flying suits. According to a Navy report, the flyers wearing International Orange suits were attacked to a man, while the ones wearing khaki suits were left alone. As a result, the Navy had started calling those orange suits yum yum yellow.

Wisby directed Gruber to look at the literature and report back on the possibility that sharks have colour vision. So he examined all the old reports. They were mostly in German, and they concluded that sharks could not see colours because they lacked the cone-shaped photoreceptors in the eye's retina that permit colour vision in humans and other animals.

Duplexity Theory

The Duplexity Theory of vision was introduced in the 1860s by a German scientist named Max Schultze, and states that rods and cones in the retinas of an animal that possesses both, have two functions. Rods are used in night vision when there is little light, while the cones take over during the day, providing the ability to see colours, fine details, and to discern rapidly flashing lights.

Some animals, such as squirrels and iguanas, that are active in daytime, have no rods in their eyes, and nocturnal animals or those adapted to the darkness of caves or the deep sea, have no cones. Therefore, the lack of cones found by early researchers in the retinas of sharks, suggested that they were unable to distinguish colours.

But Wisby questioned the old conclusions. He asked Gruber to go out and actually collect sharks' eyes, and see what he could find. So Gruber went to shark tournaments and collected the eyes of every species of large shark caught off the of the eastern seaboard of the United States. He put a catheter into their hearts while they were still beating—the animals were brain-dead—and perfused gluteraldehyde, a preservative chemical, through their arteries, to fix their eyes for future study under the electron microscope.

On one occasion, he was notified that a young great white shark was caught and was being held for him. This was the chance of a lifetime for the young graduate student, as white sharks were very rare. He ran out in a boat to where the fisherman was waiting with a barely living 54 lb specimen, successfully perfused the shark, and collected the eyes.

Can sharks see colour?

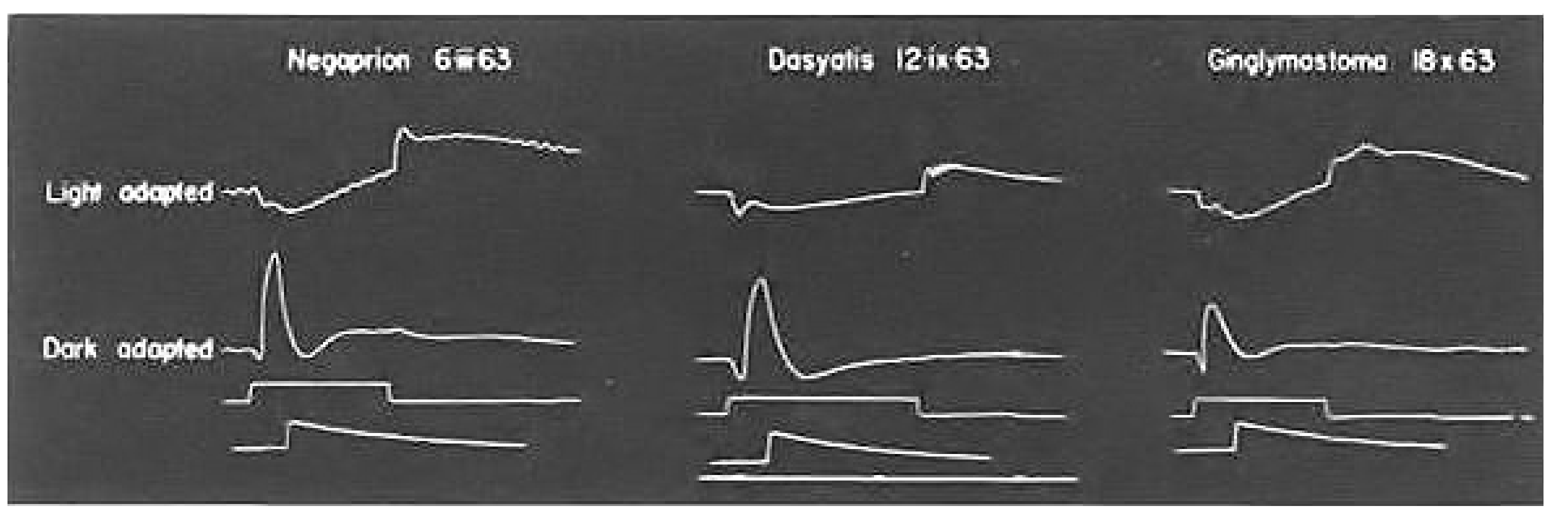
Year after year, Gruber worked in a histology lab comparing the retinas photographs of the many species of sharks to see whether they had both rods and cones. And, amazingly, every species he studied had them. Some species seemed to have better retinas than others, but they all had rods and cones. The great white shark had five rods to one cone, which was an especially high ratio.

It seemed that the earlier scientists had studied the cold-water, bottom-loving sharks of the northern seas off Europe, and those species had very few cone cells because they were adapted to dark conditions. Those inaccurate early findings had resulted in many false ideas about sharks taking root. The idea that they had an excellent sense of smell had spread because they came quickly to a scent, and so the concept of a shark as a swimming nose, with poor eyesight, was born a century ago.

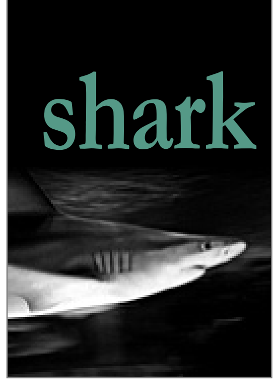
The forebrain of a shark, called the telencephalon, is considered one of the most important parts of the brain, like our cerebral hemispheres. And in the shark, the telencephalon was thought to be the centre that analysed scents, because that was how it looked to the early researchers. They did not know how the forebrain worked, and they had never looked at how sharks really behaved, or tried to do neural examinations, yet their primitive ideas about sharks had persisted.

Wisby was pleased with Gruber's discovery, but pointed out that just because the sharks had cone cells, didn't mean that they could see colours. "What do the rods and cones mean for sharks?" Wisby asked, and directed Gruber to experiment to learn whether sharks see colours, and investigate their other visual capabilities.

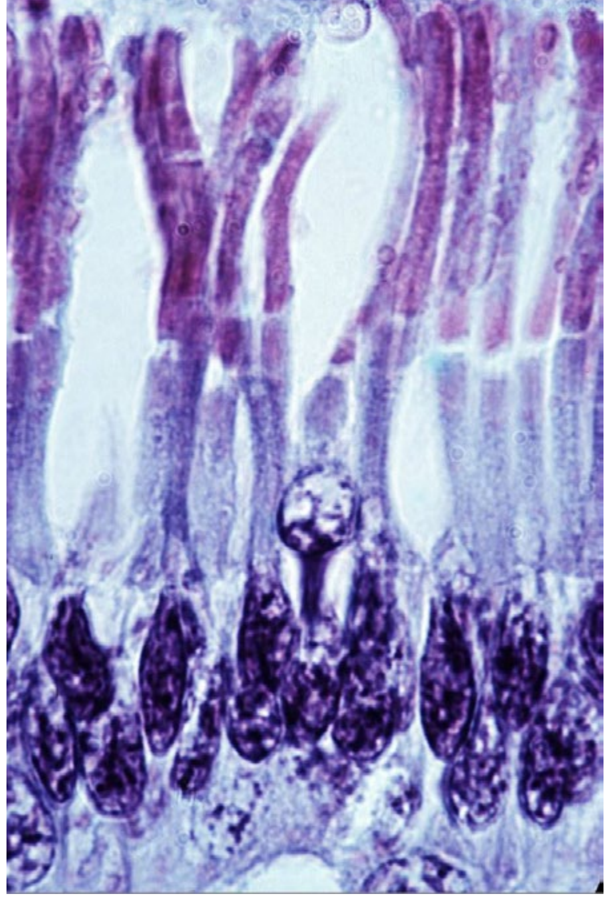
As the eyes of a human or animal adapt to darkness, rods take over the function of vision, providing high sensitivity to light, but no colour. The switching over between the cones and rods is something that can be mea-



A comparison of the light and dark-adapted ERG's from the three species of elasmobranchs



shark tales



Sharks can see color! Pictured here are rods and cones in an eye (left); Sharks possess the tapetum lucidum, the mirror-like membrane at the back of the eye which produces eye-shine in some animals (right)

Gruber

sured, and it was this line of research that Gruber began to pursue in 1962 for his master, and later his doctorate degrees.

He used the lemon shark as a model, and chose three methods to test the Duplexity Theory of vision in sharks. To assess the rod and cone activity in the retina, he put contact lens electrodes on anaesthetized lemon sharks, and recorded the electrical responses of the retina when illuminated. He used electrophysiology to record electroretinograms, which are similar to the electrocardiogram of doctors, in order to examine the electrical activity of the associated neurons.

His second method involved a behavioural study, following the Pavlovian method of testing called classical or respondent conditioning, and the third was the Skinnerian method, which is called operant conditioning.

Gruber's results were unambiguous. The three methods gave the same results—there was no doubt that sharks could see colour. The rods functioned as expected in the dark, and the cones were most active in the light-adapted state. He found that as sharks adjusted to darkness, the sensitivity of their eyes became greater and greater, and reached the maximum dark-adaptation after about an hour, achieving a million-fold increase in sensitivity!

They adapted better than humans because unlike us, they possess the tapetum lucidum.

This is the mirror-like membrane at the back of the eye which produces eye-shine in some animals. Light entering the eye passes through the retina, and is reflected, as if by a mirror, back from this membrane, potentially doubling the eye's sensitivity.

Learning rate

Another interesting finding that emerged from Gruber's research during his doctoral studies was the speed at which sharks learn. He was working on Pavlovian training conditioning, doing an experiment in which a shark would see a flash of light, and then receive a mild electric shock. After a certain number of trials, when the shark saw the light, it would have learned to anticipate the shock, and have a reaction. This is called a conditioned response.

The reaction that Gruber planned to use for the experiment was the pause in the shark's heart-rate resulting from the fear of the coming shock. Fear causes the heart to skip a beat, then accelerate, so at the moment that the shark realized that it was about to receive another shock, its heart paused, and this reaction could be measured. The number of trials it took for the animal to learn the association between the light and the shock, gave a measure of its ability to learn.

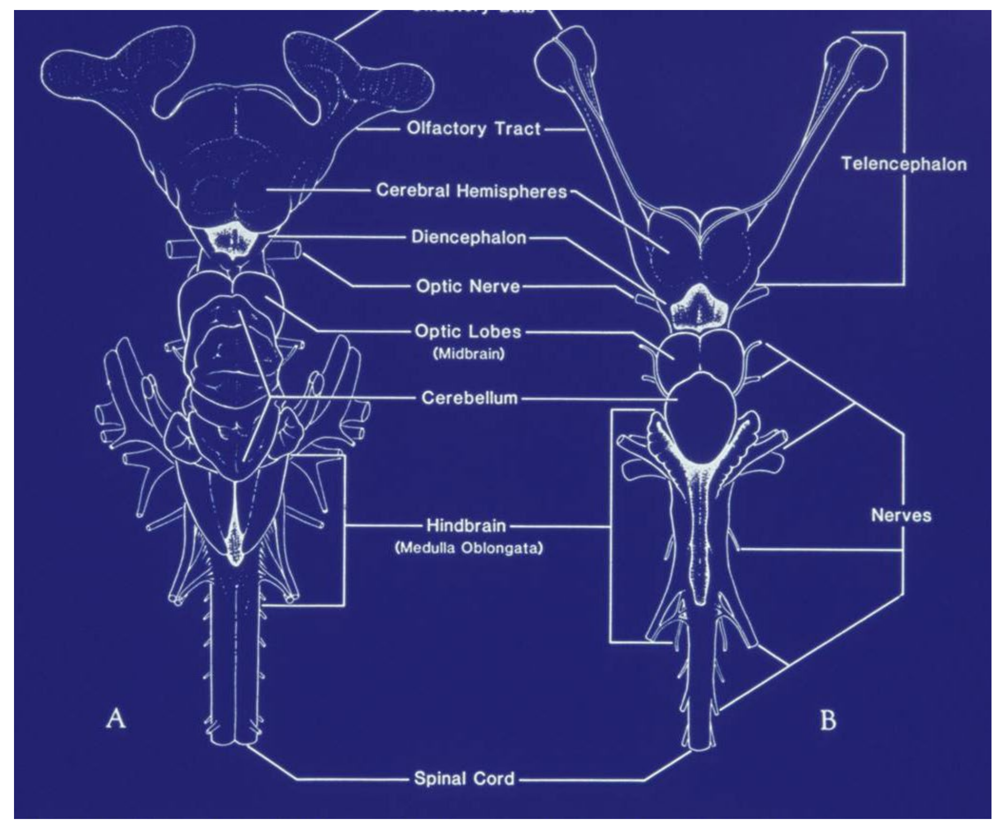
While Gruber was flashing the light, and giving the shock, he was looking at the readout on the oscilloscope, rather than at the shark, which was trussed up underwater, with an electrode in its cardiac chamber, looking out into the room through a big Plexiglas bubble.

Then one day, he happened to look at the shark at the moment in which it anticipated the shock, and saw that it winked—the nictitating membrane photograph of the shark's eye closed. This provided another conditioned response to the light, which meant that there was no need for the heart monitoring—all Gruber had to do was observe. Due to the need for the heart monitoring, the sharks had been unable to survive long enough for him to get them trained, so his discovery was crucial to the success of this important experiment.

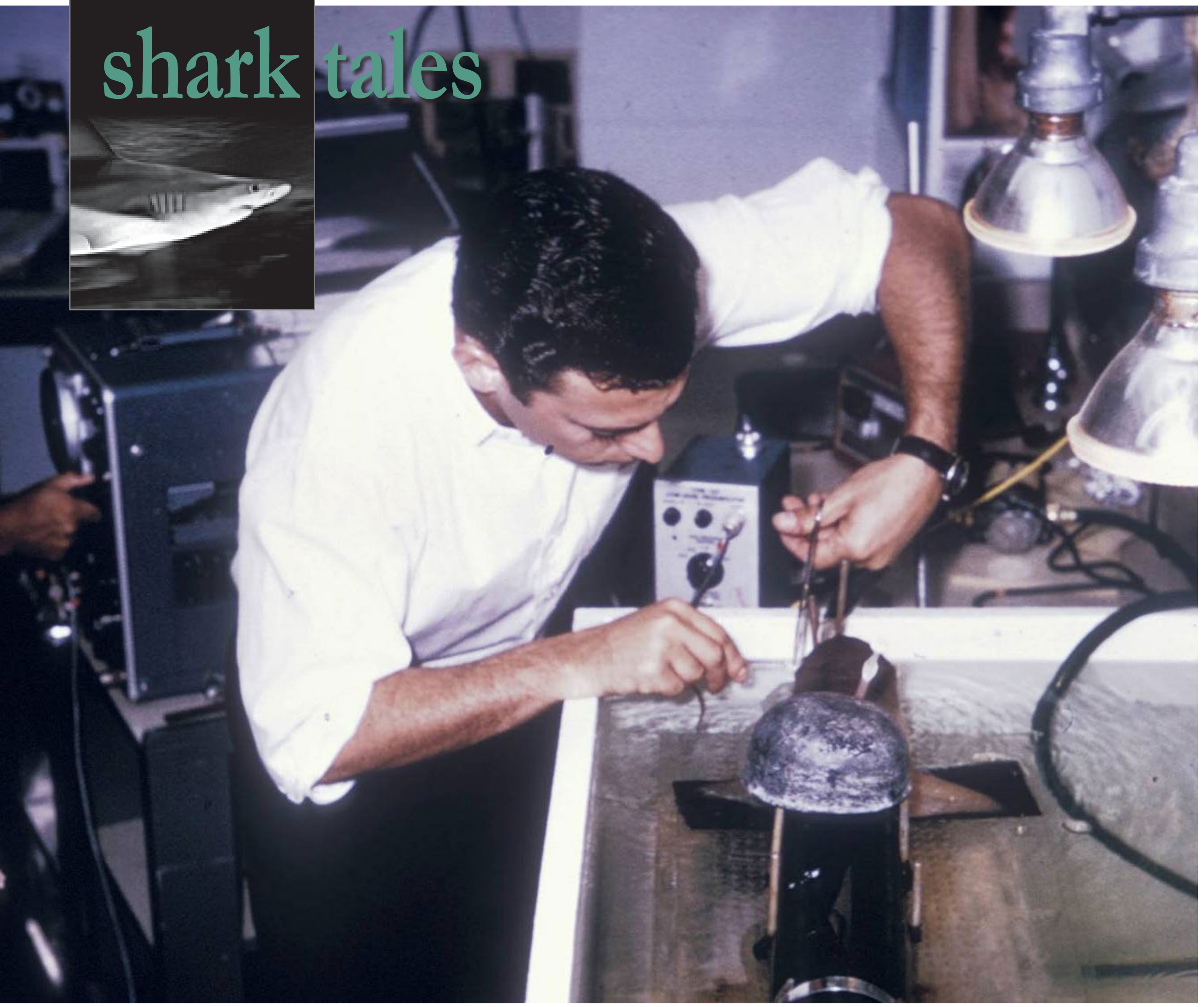
Now Gruber used a World War II infra-red sniper scope to observe the shark in total darkness, and found that after about ten trials, or repetitions, the shark would wink in expectation of the shock. It was a conditioned response that he got from a shark in only about three minutes!

One session consisted of ten sets of ten trials, and after about 80 trials, the shark was responding 100 percent of the time. The next day it took only three or four trials to get the shark to respond, and it responded 100 percent of the time after 40 trials. On the third day, it had a 100 percent response from the start.

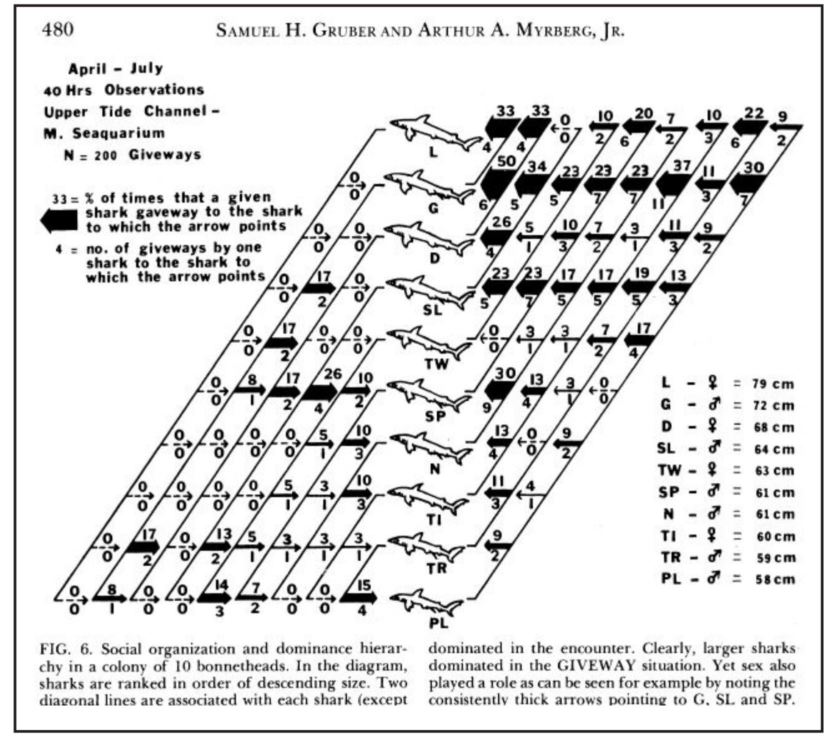
Shark winking nictatans



Examples of shark brains (dorsal views): a) smooth dogfish, *Mustelus canis*; b) sevengill shark, *Notorynchus cepedianus*. (Modified from Northcutt, 1978)



Electroretinogram: Gruber with anesthetized shark, 1966 (left); Bonnethead shark social hierarchy (right); Lemon shark (below)



So it took only about ten trials for the first response, 80 trials to get the 100 percent response, and only three days to the state in which the shark was conditioned long term.

By chance, psychologists had been studying Pavlovian conditioning in cats and rabbits using the same paradigm. They used the flash of light as the initial stimulus, and followed it with a puff of air onto the cornea, instead of an electric shock. As in Gruber's experiment, the conditioned response was the movement of the nictitating membrane, so the experiment was a terrestrial version of precisely what Gruber had been doing with sharks.

What was surprising was that the sharks had learned the relationship between the light and the shock ten times faster than the cats and rabbits! These had taken about 800 trials to achieve 100 percent conditioning, while the sharks had taken only 80 trials. Further, the sharks remembered what they had learned for over a year, which was far longer than anyone had expected.

Gruber discovered many more interesting things in the course of his research. He found that sharks have different "IQs" and different personalities, and that some are left-handed and some are right-handed. He also found that they have an occlusable tapetum, a further refinement of their vision, as well as a mobile pupil in a variety of shapes, which only sharks and rays, and no other fish, have.

Published

Arthur A. Myrberg, the youngest full professor at the University, took Wisby's place in 1964, and mentored Gruber during the last years of his master and doctorate degrees. While Gruber and his student, Joel Cohen, were studying shark vision, Myrberg and his students worked on their hearing, and others (not at the University of Miami), were working on olfaction, taste, and electoreception.

In 1976, the Navy asked for a summary of all of the work it had funded about the sensory systems of sharks, and they put their findings together in a major book, which was published in the government printing offices. Gruber's discoveries about shark vision filled a large chapter.

Ethology

With his findings published, Gruber no longer wanted to work in a dark and damp laboratory, and longed to understand the role sharks play in the marine environment. He dreamed of studying their behaviour in a similar, systematic way, in the wild, and decided that he would find a way to do it, using the lemon shark he had come to know so well, and wanted to understand more deeply.

By then he had become an assistant professor at the University of Miami Rosenstiel School of Marine and Atmospheric Sciences, teaching advanced courses in animal behaviour, tropical marine biology, and the physiology and behaviour of marine organisms. He had done a post-doctoral study in 1971-72, at the Max-Planck Institute in Germany, under Nobel laureate Konrad Lorenz, the famous Austrian ethologist, just as Myrberg had done a decade before.

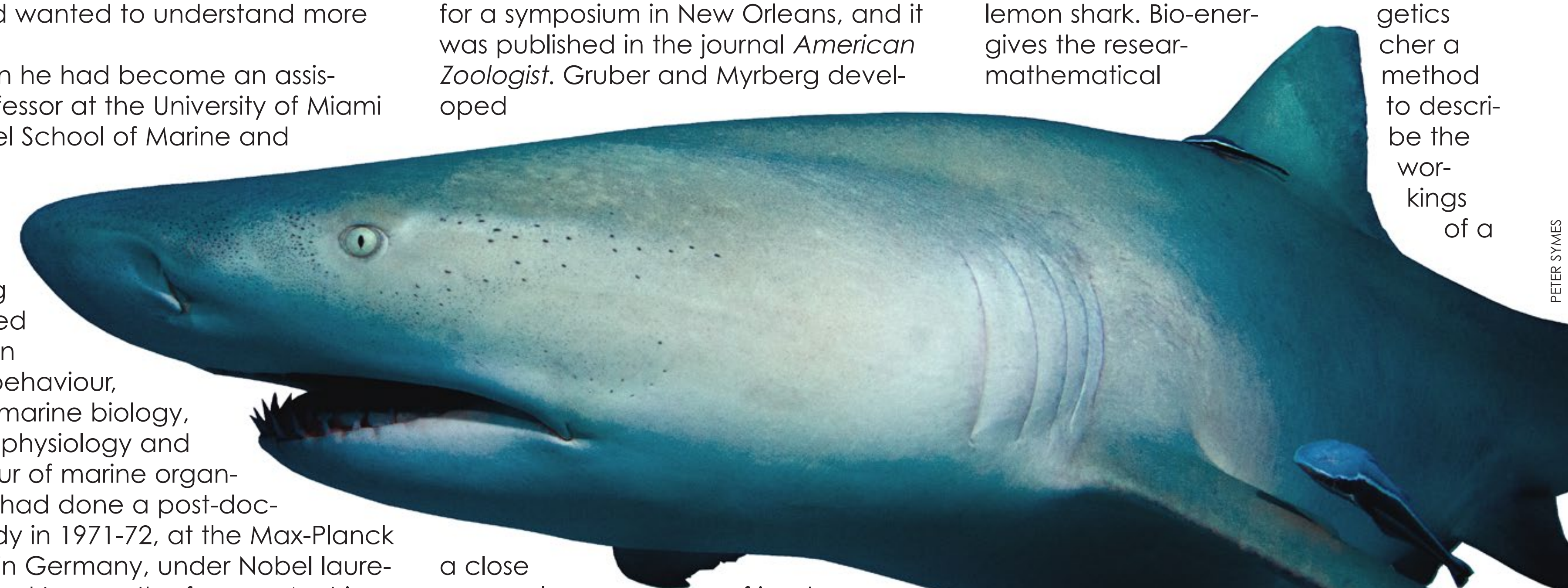
Both men were interested in pursuing their interest in ethology, and as a side project, they had put together an observational study on a captive colony of bonnethead sharks, which was published in the journal *Copeia* in 1974. It remains the only ethogram, which is an inventory of the repertoire of behaviour patterns displayed by a species, that was ever published for sharks.

Then in 1976, they gathered together all of their information on shark behaviour for a symposium in New Orleans, and it was published in the journal *American Zoologist*. Gruber and Myrberg developed a close personal friendship that was to last all their lives. They travelled together as they pursued their research in Europe and the Middle East. They dove with Cousteau in Monaco, travelled through Europe visiting friends and colleagues, and studied sharks in the Florida Keys and the Caribbean. And when Gruber got engaged, it was at Myrberg's home.

Gruber left Navy research in 1976, and in 1977 he proposed a study to the National Science Foundation, on the role lemon sharks in the tropical marine environment. His goal was to do an autecological study designed to examine many aspect of this species' biology, with an emphasis on behavior and ecology. It was funded in 1978 and is still continuing today in 2014. At last he was fulfilling his dream, of discovering what a shark is, and what it does in its life in the wild.

Bio-energetics

Gruber chose bio-energetics as way of understanding the biology of the lemon shark. Bio-energetics gives the researcher a mathematical method to describe the workings of a living system. Like all things in nature, a shark conforms to the laws of thermodynamics, that decree that in a system, the energy that comes out, no matter how it is chan-



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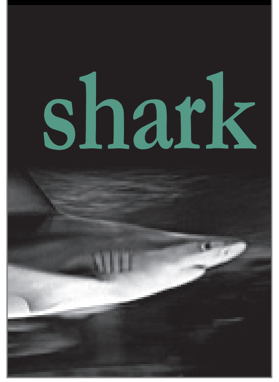
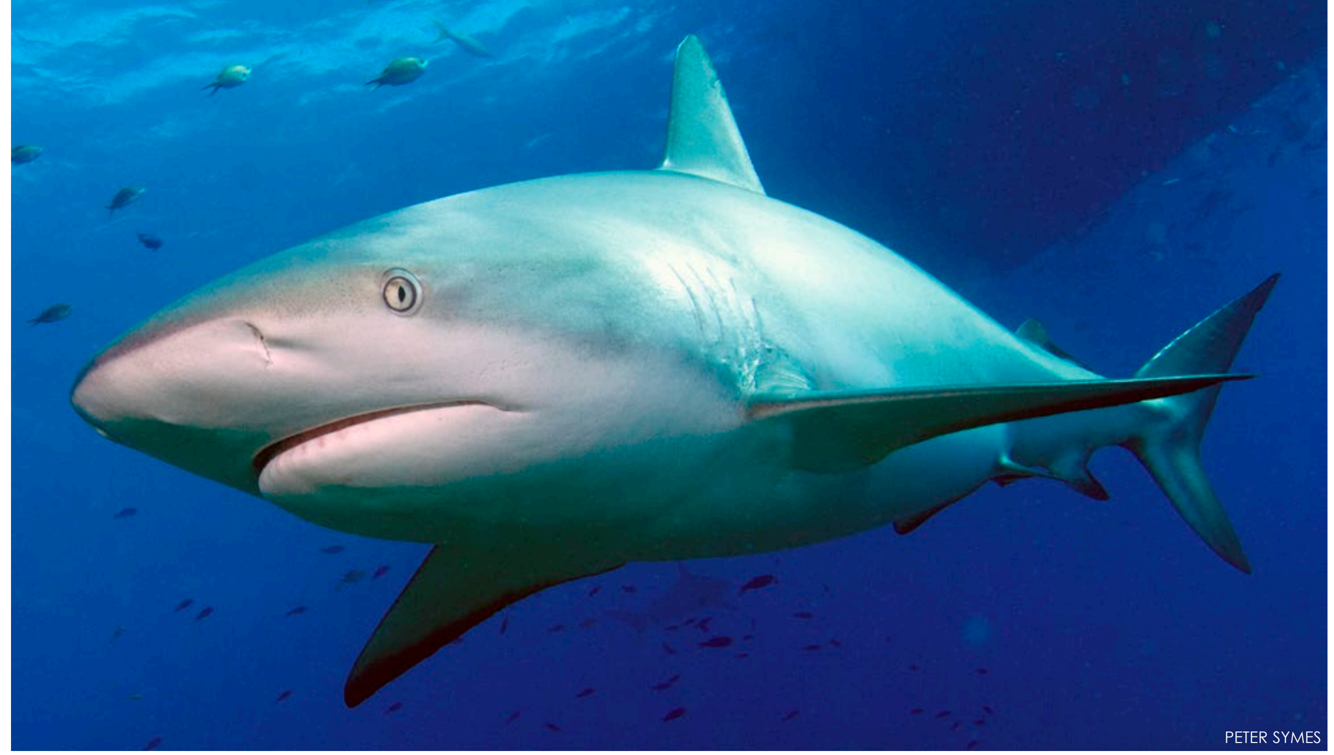


shark tales

Sharks can learn! And they learn ten times faster than cats. Plus, like elephants, sharks have long memories and can remember experiences a year later. At right is a reef shark; below is a lemon shark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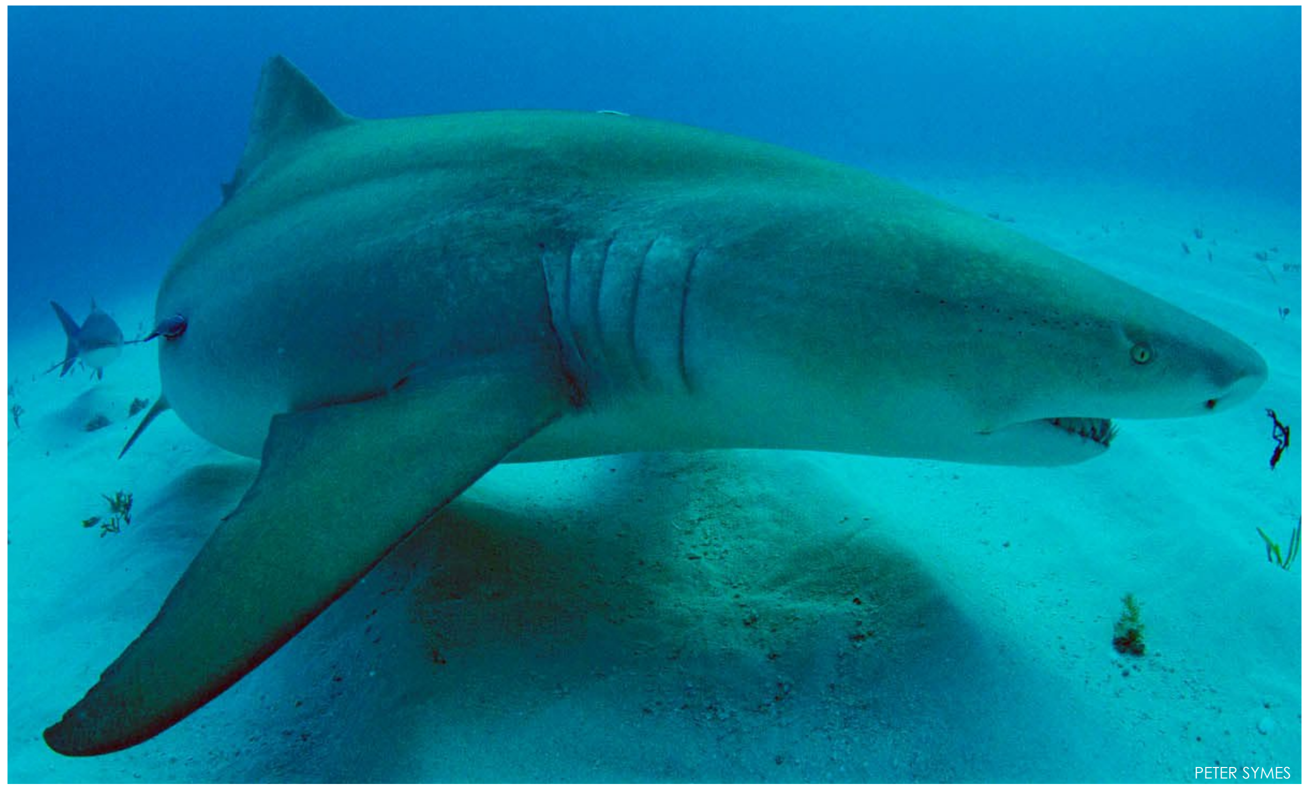
neled or converted, has to equal the energy that has gone in.

In other words, the energy that goes into a shark as food, will come out through growth, metabolism, waste, other biological products. The processes of metabolism—the nerves, digestion, muscles, respiration, and other biological processes—will likely burn half of the calories, and such materials as mucus, urine, and faeces can be burned up in a calorimeter to find how many calories were lost that way. The calories consumed must be partitioned within the body into only four unknowns, and the process can be analysed.

As an example, the common practice of dieting and exercising to reduce one's weight, utilizes the principle of bioenergetics to achieve a goal. By decreasing the energy going into the body in the form of food, we can force it to use stored fat to make up the deficit, and thus lose weight. Gruber described it this way:

"It is possible to make an equation that balances in four unknowns. It is a simple thing to do mathematically and it reveals a great deal about the animal. It shows how they make their living, what they require for food, their metabolic needs, what they need to digest food, how much of what they eat is assimilated, how much is lost in waste products, how quickly they grow, and how much food it takes them to grow. That's what you can tell about a shark's life and what it takes to grow a shark in the environment and that's what we did. It took us over ten years."

Through a combination of laboratory research and studies in the field, Gruber and his colleagues and students focused so much research on the lemon shark that they discovered much about its life history characteristics, its population dynamics, its growth, reproduction, and genetics. He was determined to make sure that their experiments were realistic by always comparing laboratory results to what could be learned from sharks in the marine environment.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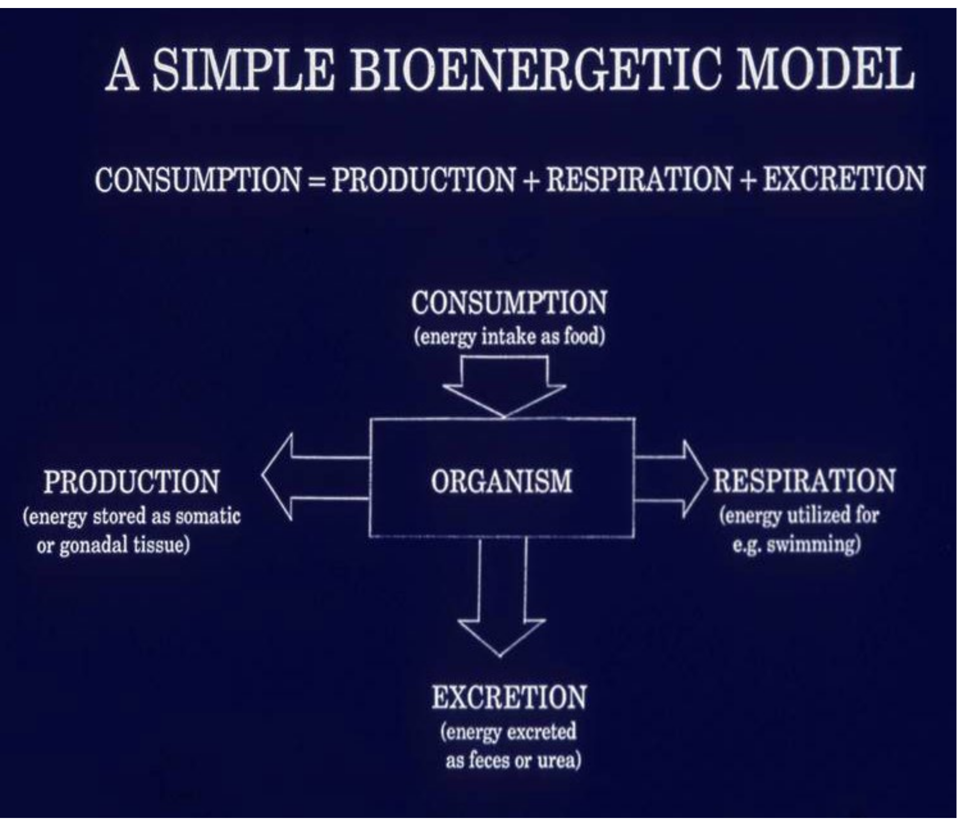
Fieldwork

Initially Gruber studied lemon sharks in Coupon Bight in the Florida Keys. Using nets, he and his colleagues would reliably catch 100 to 120 juvenile lemon sharks there, each summer season, which they would work up and release.

But in the early 80's, their numbers began to fall, and in three years he could not catch one shark there. All of the work he had done during all of those years was wasted. He found out that it was due to overfishing. Fishermen had been catching the little baby sharks in the nursery for crab traps and had fished them all out. The mothers that were supposed to be coming back to the place they were born to give birth had been fished too, so the entire local population of sharks had disappeared.

Gruber knew that the sharks were in trouble again, because this had already happened to him in Florida. So he began doing his research at a small island in the Bahamas at the place where he would later establish the Bimini Biological Field Station.

Four times a year, he went there for his field research using National Science Foundation research vessels photograph which were at his disposal from the University of



Bioenergetic equation

shark tales

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THIS PAGE: Lemon sharks in the Bahamas; Portrait of Gruber with shark (center); Bimini Shark Lab founded by Gruber (right)

Miami. Later, when he had the Bimini field station set up, they could do permanent work there without the need to go back and forth to Florida, which allowed them to expand their research.

The research

The main thrust of Gruber's research was trophic ecology and autecology, the ecology of one species, the lemon shark. Bimini's lagoon was like a marine lake, where the juvenile lemon sharks were obliged to remain, and each shark could be looked at year after year for six or seven years before it left the area. The location was ideal. There were two to three hundred sharks divided between three to four nursery areas, and he tagged nearly all of them, and focused hard on learning all about their lives as he tried to unravel the ecology of the lemon shark. How many sharks were there? How many lived? How many died? How many grew up to maturity? How fast did they grow? What would it take to grow a lemon shark up from a pup to an adult of 80kg?

Each spring, when the lemon shark pups were born, photos Gruber and the students did a comprehensive tagging study. They built a large pen, which could hold up to 150 sharks. Then they caught the sharks in nets, tagged them with an electronic micro-tag, took a genetic sample, weighed them, measured them, sexed them, and put them in the giant pen. Every year they would catch, tag, and work up between 180 and 230 sharks. The sharks were released, and then the next year the same sharks that survived, could be caught and measured again. The year 2014 was their 20th year.

After more than a decade of research, they balanced the bio-energetic equation for a young, fast-growing, 2kg lemon shark at 25°C, and discovered that the little shark was an energy conserver, and ate only about seven times its body weight in a year. By comparison, many fish, such as tuna, blow a lot of energy and have to eat a lot of food. And humans, in comparison with lemon sharks, eat an enormous amount.

With the sharks living free in a place where they could be watched from year to year, many experiments were possible. For example, they were able to study their movements, their relationship to temperatures, their food, their place in the ecological system, and their social networks. The nursery was a region of mangroves, and certain little snails called Batillaria were low on the food chain and were the keystone species. The next level was crabs, then fish, then sharks—sharks were on the fifth level.

The countless studies took years and years, doctoral dissertations, and masters theses, and thousands of students all coming to Bimini to study sharks. Gruber taught a University of Miami course there for 22 years, sometimes twice a year; now he teaches five university courses at the station. He had graduate students, built big holding pens at his research facility, and kept dozens of lemon sharks.

And as time passed and he learned of its abilities and capacities, the lemon shark became an animal of complete fascination. To Gruber, the lemon shark had gone from a predatory fish with fins and teeth to being more like a family member. Gruber said:

"As I went through my early career and I got married and we had children, then we got a house and we got cars, I realized that the lemon shark had provided a living for me in the human world, whereby I could become a functional and useful citizen and have a family. It was all because of the lemon shark. That's why I get so nervous when I think that they are having problems underwater, not only with being overfished, but also with us handling them. So I have not been able to remain objective in my feelings for them, although I have tried to remain objective in my research of them." ■

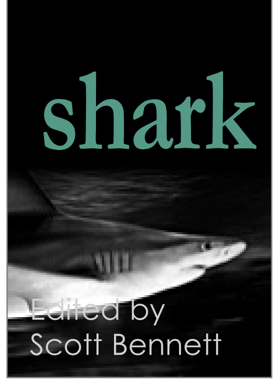
Stay tuned for Part II of Dr Gruber's remarkable story in the next issue of X-RAY MAG.

Ila France Porcher, author of The Shark Sessions, *is an ethologist who focused on the study of reef sharks after she moved to Tahiti in 1995. Her observations, which are the first of their kind, have yielded valuable details about their lives, including their reproductive cycle, social biology, population structure, daily behaviour patterns, roaming tendencies and cognitive abilities. Her next book,* On the Ethology of Reef Sharks, *will soon be released.*

PETER SYMES

shark tales

Edited by Scott Bennett



New light cast on hidden life of salmon sharks

As the saying goes, you are what you eat. Researchers at Stanford University's Hopkins Marine Station are using this adage to better understand the life history of the salmon shark. An important apex predator and cousin of the great white, this far-ranging species roams the entire North Pacific Ocean, from Alaska to the warm sub-tropics of Hawaii and the Baja Peninsula.

"Until relatively recently, it's been pretty poorly studied," said Aaron Carlisle, a researcher with Stanford University's Hopkins Marine Station in Monterey. "Salmon sharks just for some reason kind of fell through the cracks."

"Until relatively recently, it's been pretty poorly studied. Salmon sharks just for some reason kind of fell through the cracks."

ANDY MURCH / ELASMODIVER.COM

Salmon on the menu

Despite their relative obscurity, the sharks are fished in Alaska when they arrive in autumn to feed on congregating salmon. Wanting to know more about the sharks' travels, Carlisle and his team turned to an experimental process in which isotopes are taken of the sharks' vertebrae. Possessing skeletons composed entirely of cartilage, annual growth bands are laid down like the rings of a tree.

By comparing their chemical "fingerprints" to that of known prey items found in different regions of the North Pacific, researchers determined where these sharks were feeding, all the way back to the very beginning of their lives. Research revealed some sharks that visited Alaska turned up near the research center on Monterey Bay, along with Hawaii and Baja California.

Tracking

The team is using the isotope track in conjunction with traditional electronic tagging to get a more elaborate picture of the sharks' travels. "What's really becoming cutting edge," said Hopkins research coordinator Steve Litvin, "is using these advanced techniques together to give us much deeper knowledge than we ever could with only one." Stanford researchers may also attempt to utilize isotope tracing with other marine life, including white sharks.

Information collected about the sharks could be used by fishery managers to set regulations for shark protection, such as continuing bans on gill nets in areas that salmon sharks frequent. "If you actually want to conserve and manage the population," Carlisle said, "what you really need to understand is the survival." ■