LI LING HAMADY

BIOLOGY

Clues in Shark Vertebrae Reveal Where They've Been

Scientists take advantage of a silver lining in mushroom clouds

It's 1963. The escalating arms race and the horrific power of nuclear bombs cause world leaders to sign the Limited Test Ban Treaty, prohibiting weapons testing in the atmosphere and in the ocean.

Fast-forward 49 years. Escalating fishing has gravely diminished the populations of some of the world's largest fish, including basking sharks, and they are fast disappearing. In a curious connection, the lingering remnants of a past nuclear age are helping me find ways to conserve remnant populations of basking sharks and other endangered marine species.

Highly valued for their fins and overfished, basking sharks are now included on the Convention on International Trade in Endangered Species and are considered "vulnerable to endangered" by the International Union for Conservation of Nature. They're slow growing, long lived, slow to mature, and have low fertility, making them vulnerable to continued fishing pressure, whether they are caught intentionally or accidentally.

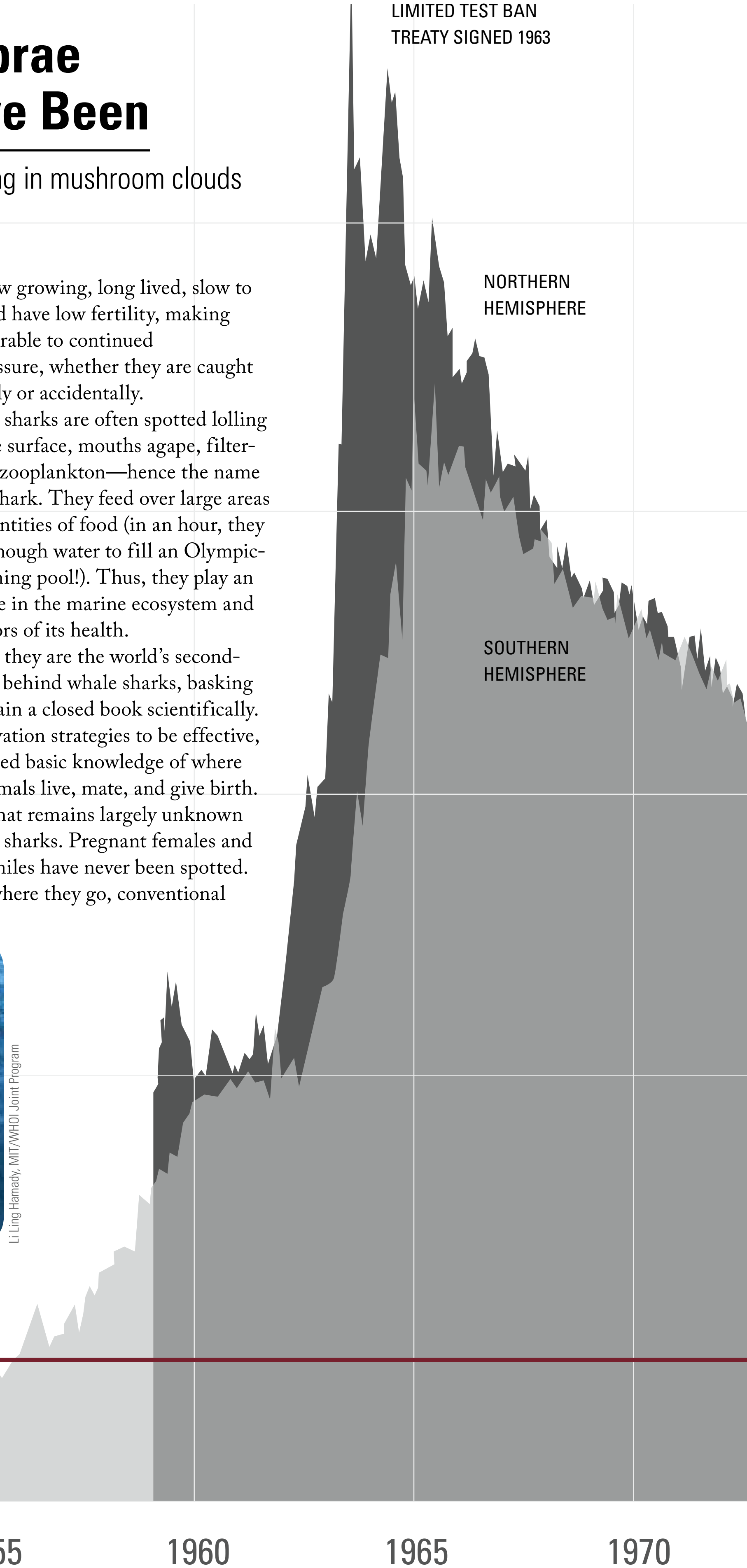
Basking sharks are often spotted lolling lazily at the surface, mouths agape, filter-feeding on zooplankton—hence the name "basking" shark. They feed over large areas on vast quantities of food (in an hour, they can filter enough water to fill an Olympic-size swimming pool!). Thus, they play an integral role in the marine ecosystem and are indicators of its health.

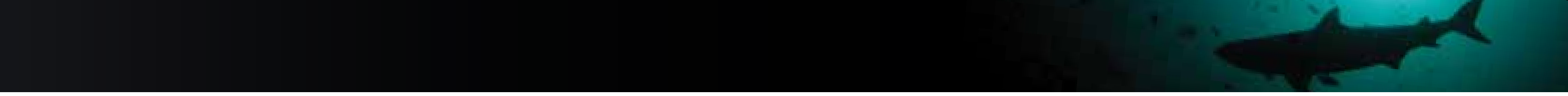
Though they are the world's second-largest fish behind whale sharks, basking sharks remain a closed book scientifically. For conservation strategies to be effective, you first need basic knowledge of where marine animals live, mate, and give birth. But all of that remains largely unknown for basking sharks. Pregnant females and young juveniles have never been spotted.

As for where they go, conventional

Li Ling Hamady, MIT/WHOI Joint Program

A professional harpoonist tags a basking shark with a device that will record where the shark swims for up to a year before the tag pops off and transmits the data back to scientists on shore.





knowledge has pegged basking sharks as a relatively shallow, temperate-water species, with populations in each hemisphere, along the margins of each continent. Yet they seem to disappear for half the year.

Where are they going?

Playing tag with sharks

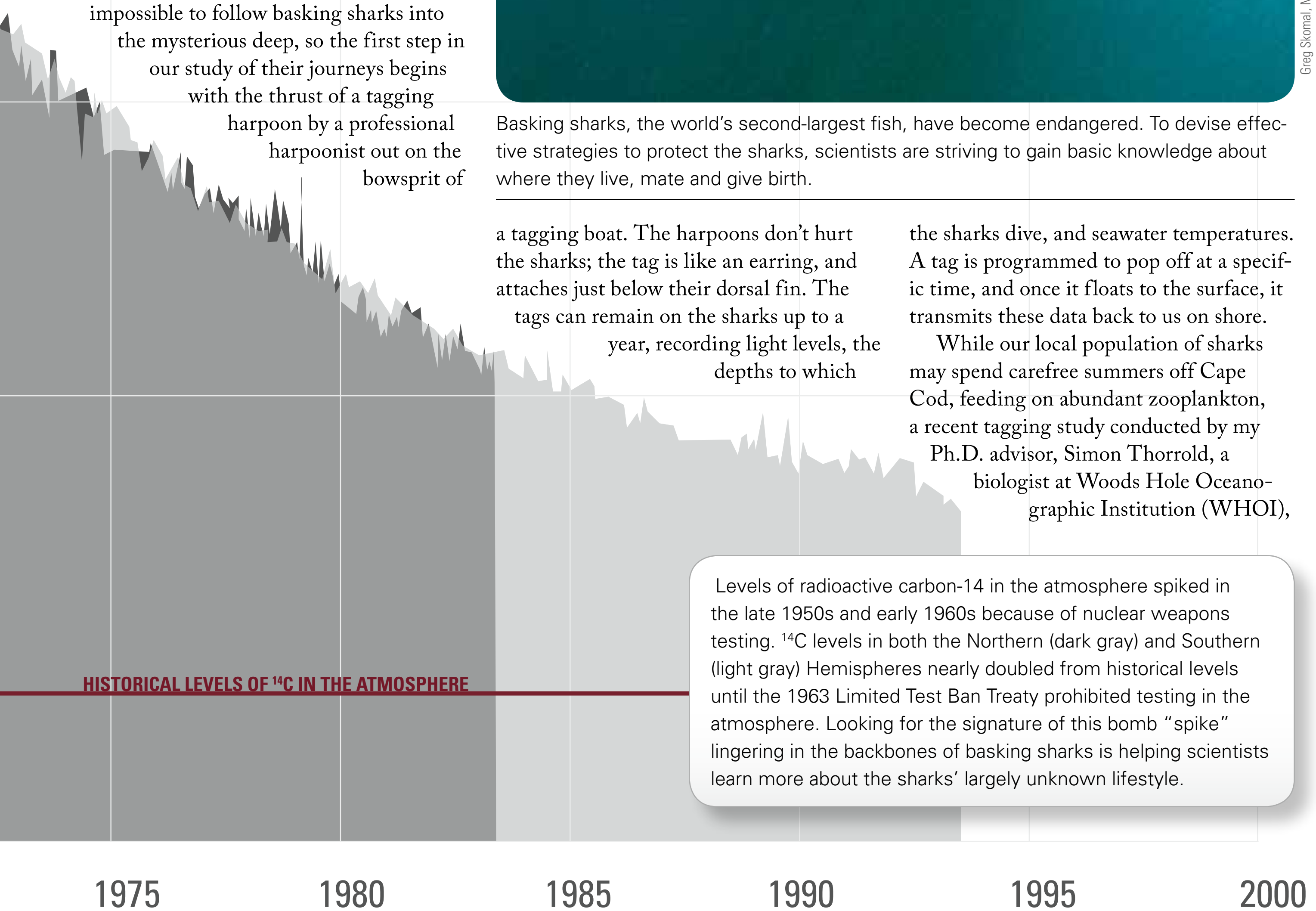
Right now, we have only a few clues hinting at basking shark behavior. A recent genetics study found that basking sharks worldwide appear to be fairly closely related, perhaps indicating that populations we thought were separate are actually interbreeding.

Humans' terrestrial lifestyle makes it impossible to follow basking sharks into the mysterious deep, so the first step in our study of their journeys begins with the thrust of a tagging harpoon by a professional harpoonist out on the bowsprit of a tagging boat. The harpoons don't hurt the sharks; the tag is like an earring, and attaches just below their dorsal fin. The tags can remain on the sharks up to a year, recording light levels, the depths to which the sharks dive, and seawater temperatures. A tag is programmed to pop off at a specific time, and once it floats to the surface, it transmits these data back to us on shore.

While our local population of sharks may spend carefree summers off Cape Cod, feeding on abundant zooplankton, a recent tagging study conducted by my Ph.D. advisor, Simon Thorrold, a biologist at Woods Hole Oceanographic Institution (WHOI),

Greg Skomal, Massachusetts Division of Marine Fisheries

Basking sharks, the world's second-largest fish, have become endangered. To devise effective strategies to protect the sharks, scientists are striving to gain basic knowledge about where they live, mate and give birth.



HISTORICAL LEVELS OF ^{14}C IN THE ATMOSPHERE

Levels of radioactive carbon-14 in the atmosphere spiked in the late 1950s and early 1960s because of nuclear weapons testing. ^{14}C levels in both the Northern (dark gray) and Southern (light gray) Hemispheres nearly doubled from historical levels until the 1963 Limited Test Ban Treaty prohibited testing in the atmosphere. Looking for the signature of this bomb "spike" lingering in the backbones of basking sharks is helping scientists learn more about the sharks' largely unknown lifestyle.

and his collaborators revealed that some sharks are actually "snow birds," migrating thousands of kilometers to sunnier locales in the winter. From eighteen sharks that were tagged in Massachusetts waters, ten tags popped up well outside their known range, with some migrating across the equator and going as far south as the Caribbean Sea and Brazil! These aren't exactly uninhabited locales, and basking sharks can grow up to 13.7 meters (45 feet) in length, so why haven't they previously been spotted in the tropics?

The answer lies in the tag data. Once they move off the continental shelf of the U.S. East Coast, which is about 150 meters or 490 feet deep, the sharks dive down to 800 to 1,000 meters (2,600 to 3,300 feet), spending up to months at a time at depth in the tropics. This may be where pregnant females and pups reside. Transequatorial migrations may also result in an interbreeding worldwide population.

Deep in the bones

Tags can remain on sharks only a year at the most, and basking sharks may live for more than 50 years. So to figure out shark migrations over their lifetimes, we use another technique. That's where my razor blade comes into play.

Shark vertebrae are constructed of distinct layers of tissue, laid down sequentially over an individual's lifetime in an alternating light/dark banding pattern. Similar to tree rings, the layers may preserve a chemical record of environmental conditions the sharks are exposed to.

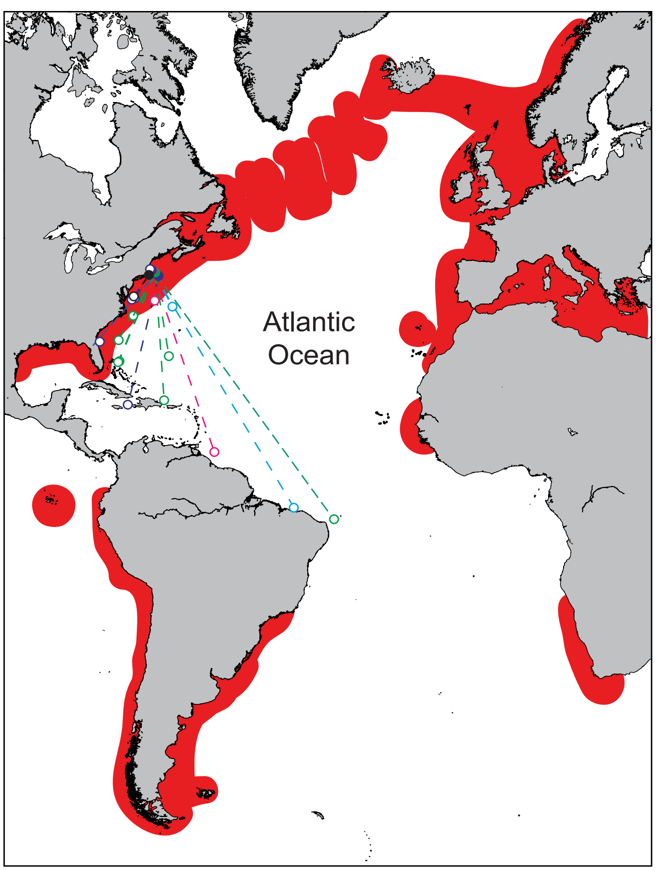
We have a number of vertebrae from sharks that have stranded on New England shorelines over the years. I cut the vertebrae in half and take a thin section. Then, using a microscope, I subsample the rings with my trusty razor blade to prepare them for chemical isotope analysis.

Most tissues in living organisms get replaced on a regular basis; we shed our skin cells every few weeks, and even the cells in our bones are replaced after several years. But some cells, like human hair and nails, don't get replaced once they've been made. We're not yet sure whether basking shark vertebrae are replaced, and we also don't know how often the layers get deposited.

The bomb 'spike'

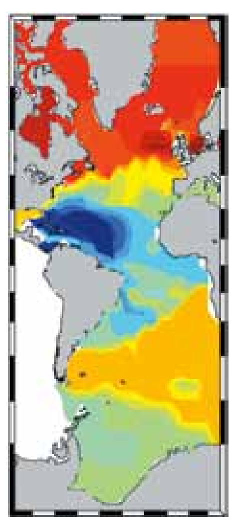
To try to answer those questions, I'm measuring ^{14}C, working with the National Ocean Sciences Accelerator Mass Spectrometry Facility (conveniently located two buildings away from me at WHOI). ^{14}C is a naturally occurring radioactive isotope of carbon created by cosmic rays bombarding nitrogen gas in the atmosphere. It's not harmful at natural abundance. In fact, all living things contain ^{14}C, and when they die, the radioactive ^{14}C in their tissues begins to decay at a measurable rate. Therefore the ratio of ^{14}C to stable, non-radioactive carbon isotopes provides a way to determine the time elapsed since the tissue was deposited or the organism died.

I'm not using this type of carbon dating, however, because this method isn't precise enough to find annual differences. Instead, I'm looking at the ^{14}C signature from those nuclear bomb blasts set off in the 1950s, which has subsequently mixed from the atmosphere into the ocean. This "spike" of enriched ^{14}C gives us a specific spot in time that we can pinpoint in the vertebra layers. By counting the layers and matching the ^{14}C signature in the layers with the known decay signal from the spike, we



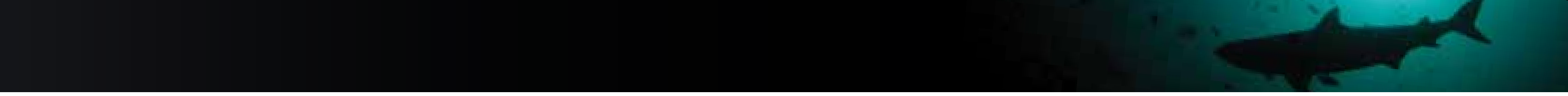
Skomal et al, *Current Biology*, 2009

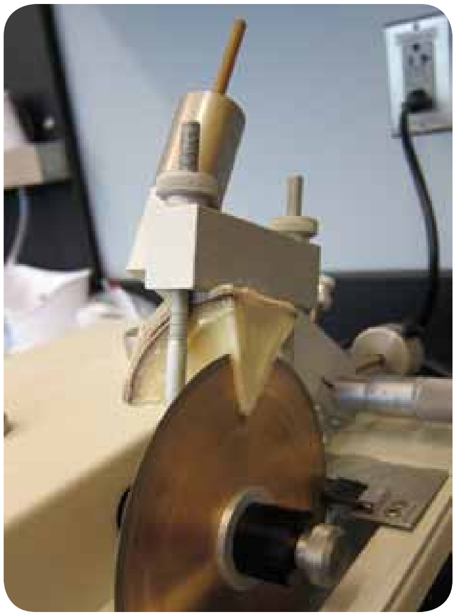
Tags on basking sharks tagged off the coast of Massachusetts showed that the sharks migrated far beyond their previously known ranges (red shading), with some going across the equator as far as Brazil.



Kelton McMahon, WHOI

Different areas of the ocean have different ratios of carbon and nitrogen isotopes. As sharks forage through these isotopically distinct habitats, they can absorb the isotopic signatures of local prey, giving scientists a natural "tag" to track their movements. In the map at left, color variations represent different isotope ratios of nitrogen ($^{15}N/^{14}N$) in the ocean.





Li Ling Hamady, MIT/WHOI Joint Program

Using vertebrae of stranded sharks (far left), graduate student Li Ling Hamady cuts a thin section showing distinct alternating light and dark layers of tissue, laid down sequentially over a shark's lifetime. Similar to tree rings, the layers may preserve a chemical record of environmental conditions sharks are exposed to and reveal their habits and habitats.

can determine the timing of the banding pattern. And if the layers record the entire range of values from the bomb spike, we know they aren't replaced and can be used for other chemical analyses.

The ocean has a three-dimensional structure, and it takes a long time for chemicals to completely mix, so the ^{14}C bomb blast signature also forms a distinct gradient with depth. With this, we may also be able to detect if the deep-diving behavior of sharks that we see in the short term using tags occurs over their lifetimes. Preliminary results from our vertebrae analyses indicate that sharks may make regular excursions into the deep.

Global ocean travelers

Along with this newfound knowledge of when and how deep sharks dive, we'd also like to know how extensively they range through the global ocean. To do that, we need to use yet another technique.

Different areas of the ocean have different ratios of stable carbon and nitrogen isotopes. When overlain on a map of the ocean, these isotopically different areas form distinct patches, creating an "isotope landscape" called an isoscape. As sharks pass through these areas, their bodies absorb and record the specific isotope signatures of these environments, passed to them via the food they eat.

In our lab in the Marine Research Facility building at WHOI, I've been analyzing the carbon and nitrogen stable isotopes in specific amino acids in vertebrae, to reveal sharks' movements through the ocean. Since you are what you eat, by comparing the signatures in the vertebrae to isoscape maps of their zooplankton food sources in the Atlantic Ocean, we should be able to pinpoint the pathways of their migrations.

Even if there were road signs in the ocean, basking sharks couldn't read them. But they're worldly travelers that pass through the jurisdictional zones of many countries. Along their journeys, basking sharks are exposed to different degrees of protection. To come up with a feasible multinational conservation plan, we first need to know where they go and when. And the techniques we're developing to study basking sharks will also be applicable to other highly mobile, understudied, endangered ocean species, such as whale sharks and great whites.

Li Ling Hamady is supported by a National Science Foundation Graduate Fellowship. This research is funded by the National Science Foundation.

LI LING **HAMADY**

Li Ling Hamady has always loved the ocean. At age four, she knew she was going to be a marine biologist, ballerina, and pilot when she grew up. Born and raised in California, she has proud memories of being the only girl in a first-grade summer marine biology course, in which she dissected a fish all by herself since her lab partner was too squeamish to cut through bone. She graduated from the College of Creative Studies program at University of California-Santa Barbara, where her research took her to Baja, Australia, and South Africa. After several years as a technician in a paleoclimatology lab, she decided to meld her lab skills and fishy passions in the MIT/WHOI Joint Program. When not elbow-deep in shark, she enjoys early-morning swims, biking, and for good measure, some run-staggering, all followed by copious amounts of food. And a nap. Her mentor for this article was Jayne Iafrate, former editor at the *Los Angeles Times* and now assistant director of development communications at WHOI.