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"When I first started working in Baja, you could walk down the street, and every house had a turtle in the pot, or you could smell frying turtle down the street. It's a very distinctive odor."

Jeffrey Seminoff must be demoralized. He's on one of his frequent research trips to Baja California, Mexico and is strolling through a bustling *mercado callejero,* or street market, with rays of hot Baja sun beating down upon him. All around him, he sees turtles. Food stalls are steaming turtles in pots, preparing them to be sold for a measly couple of *pesos.* Vendors are selling off turtle eggs by the carton, like chicken eggs at the supermarket. Couples are basking in the streets, gulping turtle eggs down whole based on the flawed belief that they act as an aphrodisiac.

If this were chicken or cow, there would be no problem. But these are Pacific loggerhead turtles, an endangered species with only ~50,000 alive today. For Seminoff, Ph.D. in marine biology and program lead at the Marine Turtle Ecology and Assessment Program at NOAA's Southwest Fisheries Science Center, this is especially discouraging; Seminoff's research regards tracking Pacific loggerhead turtles, a species of hard-shelled turtle native to the Pacific Ocean. Each turtle Seminoff sees in the market is one less turtle to obtain data from, making working with an already endangered species even harder.

Seminoff's 35-year career has taken him on a wild turtle chase around the country. After graduate school at the University of Arizona and a postdoctoral fellowship in Florida, he has settled down at NOAA's lab in San Diego. Living in San Diego was of particular interest to him; he moved his family across the country for the chance to study Pacific loggerhead turtles.

The question Seminoff seeks to answer is this: how do Pacific loggerhead turtles manage to cross the Eastern Pacific Barrier (EPB)—a 4000-mile stretch of ice-cold water in the middle of the ocean deemed by famed biologist Charles Darwin to be "impassable" by marine creatures—and reach the coasts of California and Mexico? After years, he thinks he's finally found the answer: he hypothesizes that Pacific loggerhead turtles utilize "thermal corridors"—temporary streams of warm water—to pass through the EPB. His group's findings were published in the journal *Frontiers in Marine Science* on April 8, 2021.

The specific cohort of Pacific loggerheads that Seminoff studies lay their eggs on the beaches of Japan. When the newborns hatch, they immediately crawl into the ocean, and swim around the Pacific Ocean in journeys that can take the young turtles as far as the coasts of California and Mexico. The turtles don't return home for up to 20 years; their travels last until they are adults. When they reach maturity, the turtles return to the beaches of Japan to lay their eggs, and the cycle begins anew.

In the first part his study, Seminoff attached satellite tags to the fins of 231 of these turtles over a 15-year span from 1997-2012. He noticed something curious: of the 231 turtles,

only 6 of them ventured over to the coasts of California and Mexico. The rest of the turtles stayed in the middle of the Pacific Ocean, on the left side of the EPB. He started to wonder: why did only these turtles cross the barrier? Why these 6? He made a key observation: all 6 of the turtles that transitioned to California or Mexico passed through the EPB during the warmer summer months between April and September. This led him to formulate his hypothesis of thermal corridors: specifically, of thermal corridors that arise and pierce through the EPB during summer months and times when sea surface temperature is high, allowing turtles to travel through. Seminoff says, "We started to think there must be some sort of thermal corridor or gate offshore. If that gate 1000 miles offshore isn't open, if that's cold water, it serves as a barrier and the turtles can't get through." This would explain why only these 6 turtles were able to make it through the EPB: they were simply in the right place at the right time.

To test his hypothesis, Seminoff's team used a process called bone isotope analysis on the shells and bones of 33 dead turtles that washed up on the beaches of California and Mexico. Bone isotope analysis is the process of analyzing the atoms that make up these shells and bones. Isotopes are variations of elements that are differentiated by having different numbers of neutrons: for example, there are 3 different hydrogen isotopes that have 0, 1, and 2 neutrons respectively. The key observation Seminoff's group made is that the frequencies of isotopes change depending on what a turtle eats or where it travels in the ocean. By analyzing the frequencies of different isotopes in a turtle's bones, they can retroactively determine where the turtle has traveled in its lifetime. Seminoff says, "I can look at their tissue and I can say something about not only what they ate, but where they came from."

Calandra Turner, a postdoctoral researcher at Seminoff's NOAA lab, spearheaded the bone isotope analysis efforts. "These isotope signatures change as the turtle grows, starts to eat different types of food, and lives in different parts of the ocean," she says. "You can piece together what these turtles were doing throughout their entire lifespan." The results of the bone isotope analysis backed up their hypothesis: 20 out of the 33 turtles that washed up on the Pacific coastlines passed through the EPB during the summer months and when sea surface temperature was high. According to Seminoff's team's hypothesis, these are exactly the conditions that need to be met for thermal corridors to arise.

Tracking turtles is a challenge: Pacific loggerheads spend much of their time swimming in the middle of the ocean, too far from the coasts for either Japanese or American scientists to track them reliably. Marine biologists have dubbed this migratory period of a turtle's life the "lost decade": a turtle can pop up on the shore to be measured by marine biologists, then disappear back into the Pacific, not to be seen again for months. Finding a turtle is a rare occurrence, and it's always exciting to see one near the shore. "When you catch a turtle, you want to collect every piece of information you can from it," Seminoff says. "When we get a turtle in San Diego Bay, it's poked, prodded, weighed, sampled, and has a satellite tag put on it because it's just a gold mine of information." Turner has a personal anecdote regarding the scarcity of turtles: "We have one turtle that was caught for the first time in 1990." she recalls. "We only caught her 15 times over the years until 2014, when we sadly found her dead." Another strategy is to tag turtles with satellite chips, but opportunities to do so are few and far between: Seminoff's team was only able to tag 231 turtles over the course of 15 years. The rest

of his group's data was derived via bone isotope analysis, a process that can only be conducted on the bones of turtles that are already dead.

Although turtles are elusive, new technology makes tracking them easier. Gail Schofield, Lecturer of Aquatic Ecology at Queen Mary University of London in London, England is particularly excited about recent developments of drone technology: she utilizes drones to track the whereabouts of turtles in Greece and on the coasts of Africa. She says, "I hope drone research is going to change the whole field and [our] understanding of turtles." Turner is also excited to add drones to the turtle tracking toolbox. "The more tools that you can use the better. Using all these tools helps you fill in the gaps," she says. "It'd be a great way to validate some of the assumptions we make with the bone isotope work."

Turtles are not the only animals that make tracking them difficult; humans create significant challenges for turtle trackers as well. Pacific loggerhead turtles are an endangered species whose plight has been exacerbated by commercial fisheries. In 2012, Mexican fishing boats inadvertently killed at least 438 Pacific loggerhead turtles in Baja in a 1-month span. The turtles were caught as "bycatch", marine animals unintentionally caught by fishers seeking other species. It gets worse: 438 turtles washed up dead on the beach in the Gulf of Ulloa in Baja. The actual number killed was probably much greater; Seminoff estimates that over twice as many turtles were killed. He says "The fishermen, they're all targeting *hipoglosa*, or halibut. And there have been huge bycatch interactions between the loggerhead populations and the artisanal fisheries in Mexico. So much so, that in 2012, in a perfect storm of sorts, there was a mass stranding event where there were upwards of about 1000 loggerheads dead stranded on a small index beach over the course of about a month."

The United States has regulations in place to prevent such events from occurring, and these killings did not go unnoticed: in January of 2013, NOAA Fisheries specifically mentioned Mexico in its biennial report to Congress for failure to regulate Pacific loggerhead bycatch. As a result, Congress enacted a trade embargo on Mexican imports until Mexico presented a suitable reformation plan. When Mexico submitted its initial reformation plan in August of 2015, it was given a negative certification. Finally, in September of 2016, Mexico's plan was given a positive certification.

The conflict has affected Seminoff's tracking efforts personally: the bridge between turtle biologists and Baja fishermen was burned due to the trade sanctions negatively affecting fishermen's sales. He says, "When that embargo happened, everyone turned on the turtle biologists. [The fishermen] burned [the biologists'] boats, the biologists received death threats, they were forced out of town. It's never been the same since 2012." These tensions have been a significant hindrance to the NOAA lab: remember, of the 231 turtles that they were able to tag with satellites over a 15-year span, only 6 turtles ventured from the CNP to the coasts of California/Mexico. It's like looking for a needle in a haystack; except in this case, it's 6 turtles on the entire coastline from California to Mexico. Without access to many regions of the Mexican coastline due to this conflict, the chances of finding one are even slimmer.

Returning to the present, the problem has still not been resolved. In September of 2020, the Mexican Center for Environmental Law reported that in the period from January of 2020 to

September of 2020, 351 Pacific loggerheads were found dead in the Gulf of Ulloa. Under the regulations worked out in 2016, only 90 sea turtle deaths per year are allowed before a temporary ban on commercial fishing is enacted. 351 far exceeds this number. It remains to be seen whether this is enforced, but Seminoff is worried that this could further affect his research efforts. He says, “This loggerhead population, it’s responsible for a lot of very raw nerves, and tension and frayed relationships between the US and Mexico.”

Turner offers a silver lining to the situation: the mass killings of turtles in 2012 provided an ample supply of bones to study with bone isotope analysis. She says, “When these big stranding events happened, that’s where the bulk of my samples came from.” Regarding the 2020 turtle deaths in the Gulf of Ulloa, she says, “I hope that they’re still able to collect some of those bones because that’s a great sample set we could look at.”

So, what next? Is there any hope for turtles? Thankfully, yes: the unified theme expressed by marine biologists is that there is an air of optimism regarding the survival of turtle populations. In 2017, Schofield compiled a list of global sea turtle conservation success stories detailing how turtle populations are recovering all over the world: in the Pacific, Atlantic and in Greece, things are looking up. She says, “We looked globally at longer term trends and nesting populations. Our overarching message was that sea turtle populations seem to be increasing.” Kenneth Lohmann, Professor of Biology at the University of North Carolina-Chapel Hill in Chapel Hill, NC, studies Atlantic loggerheads that nest on the beaches of Florida. He remains hopeful as well; he says, “I’m generally optimistic about their prospects for survival.”

In Mexico, the culture around turtles is changing. Seminoff says, “We’ve done outreach to explain to them the importance of turtles. The population is in total recovery mode. Not that they don’t eat turtle anymore, but you don’t see it like you used to.” Due to this anecdote, he sees a stable future ahead for turtles. He says, “Discovery Channel would have you believe that all turtles are teetering on the edge of extinction. And that’s absolutely not true.” Lohmann also subscribes to this belief: he says, “Sea turtles have been around for a long, long time, over 100 million years. They’re a tough, adaptable group of animals. I think there are reasons to be optimistic that they can in fact survive.”