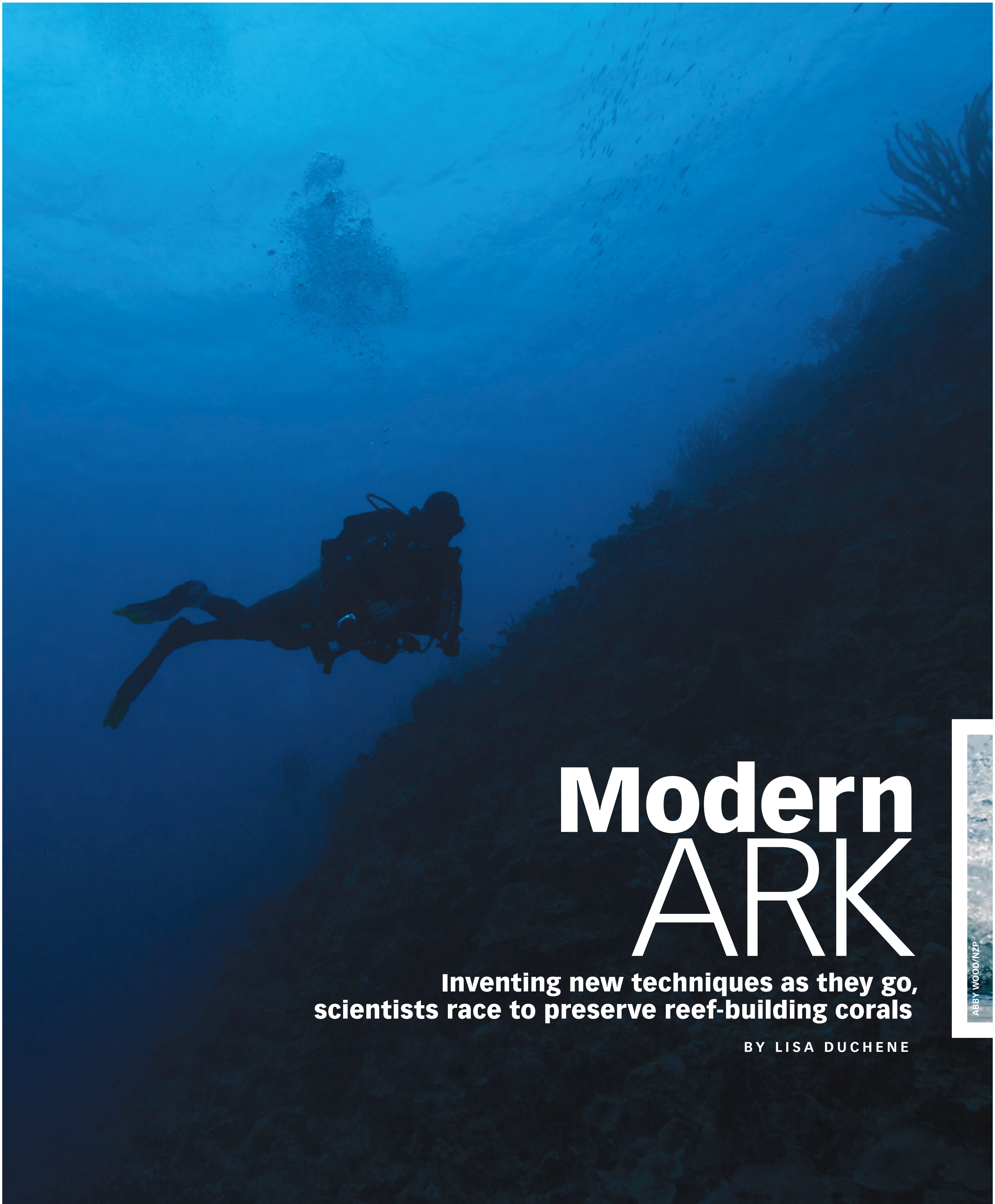
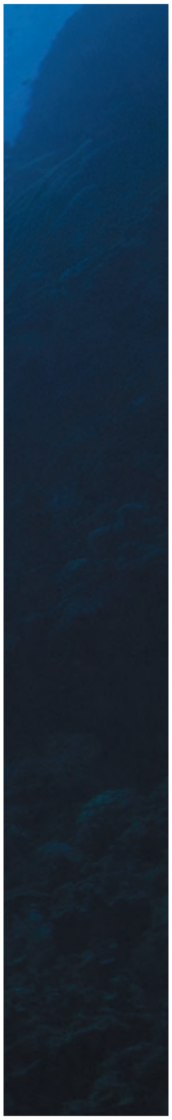


Modern ARK

Inventing new techniques as they go, scientists race to preserve reef-building corals

BY LISA DUCHENE

ABBY WOOD/NZP



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On a late summer night, National Zoo coral keeper Mike Henley slips through darkness into warm and salty Caribbean water near the Smithsonian's research station on a scrap of an island off Belize. Breathing air from the tank on his back, Henley shines his flashlight onto large, antler-like structures anchored to the sea floor.

Steadying his beam upon the "mouths" of the small polyps that make up a colony of elkhorn coral as big as an SUV, Henley looks for tiny pink balls that are bundles of the coral's egg and sperm. He finds them, loaded and ready to launch.

In 20 or 30 minutes, it will be like swimming in an "underwater snowstorm."

A quite fertile one—for now.

"There are probably as many eggs and sperm on the reef as there are stars in the sky. The number is sort of uncountable," says Henley, who will collect those bundles, manage their fertilization, and attempt to raise the embryos to adults.

A year in the making, those tiny pink balls represent the next generation of elkhorn coral, one of many coral species that over the last 10,000 years helped build the Caribbean reefs.

Like corals all over the world, elkhorn faces an onslaught of stresses including an ocean growing warmer and more acidic (see p 16: *Too Hot. Too Acidic.*), all taking a toll. Three-quarters of coral reefs are threatened, according to the World Resources Institute. The Great Barrier Reef has lost half of its coral cover in the last 27 years, while the Caribbean elkhorn coral population has plummeted 90-95 percent since 1980.

Facing an imperiled future for the world's coral and coral reef ecosystems—key to all marine life—Smithsonian scientists are developing and using cutting edge techniques to preserve them.

Henley is trying to figure out how to raise elkhorn and their Caribbean brethren staghorn corals from zygote to adult at the National Zoo. His field work is a key part of Smithsonian scientist Mary Hagedorn's work to preserve as much as she can of the world's coral reef ecosystems in a bank of frozen-but-alive samples of coral tissue, sperm, eggs, and embryos.

From their base in Kaneohe, Hawaii, Hagedorn and her assistant develop techniques to deep freeze—or cryopreserve—and store coral tissue, sperm, eggs, and embryos. Samples of staghorn and elkhorn sperm, for example, are already preserved and stored at -196 degrees C in a vault in Fort Collins, Colorado. It's like a sperm bank, but for an entire ecosystem.

Hagedorn's lab is one of the few, if not the only, in the world both creating the cryobiology techniques and applying them to the conservation of coral reefs. Her mission is to gather, preserve, and securely store enough genetic material from the world's ocean to rebuild entire coral reef ecosystems—upon which one-quarter of ocean animals depend.

In short, she is trying to save life in the ocean—and there is no time to waste.

Beautiful, Essential Architecture

Coral is an animal, despite its plant-like appearance and behavior. Each species needs a particular algae—called zooxanthellae—that provides it with often-brilliant color and nutrients photosynthesized from sunlight.

Reef-building corals grow polyps that each sit in a cup made of calcium carbonate. Over thousands of years, the tiny shells grow into the elaborate architecture that defines coral reefs.

They are "eco-dynamos," says Hagedorn. Beyond their sheer beauty, coral reefs provide food and a livelihood worth about $16 billion globally for millions of people and valuable protection in storms from pounding waves worth about $9 billion for coastal communities. They are even called the "medicine cabinets of the 21st century," due to the discovery of so many beneficial compounds.

Many scientists, including Hagedorn, warn that coral reefs are on course to becoming the world's first major ecosystem to be lost due to human activities.

Beyond their sheer beauty, coral reefs provide food and a livelihood worth about **$16 billion** globally for millions of people and valuable protection in storms from pounding waves worth about **$9 billion** for coastal communities.

Dive into the Tropics—in D.C.

See coral up close and learn about reef ecosystems at the Zoo's new coral exhibit, opening in the Amazonia Science Gallery this fall.

The exhibit will highlight Mary Hagedorn's scientific work on coral conservation, and will feature live Pacific corals and anemones, including a purple-tipped Elegance coral that has been at the Zoo since 1986 and is among the largest on exhibit anywhere in the world. Thank you to exhibit sponsors Mr. and Mrs. Rueben Bajaj, and the Bajaj Family Foundation.

That places all ocean life at risk. An estimated 25 percent of ocean species live on coral reefs for some or all of their lifecycle, and others depend upon those species that depend upon the reef. While the total number of affected species is unknown, biologists do know that billions of individuals live on reefs.

"They are the homes for a lot of creatures," says Hagedorn. "If we lose coral reefs, we lose fish, we lose biodiversity."

Reefs support more than 800 species of hard coral and 4,000 species of fishes. One-quarter of the world's fish biodiversity and 9 to 12 percent of the world's fisheries depend on coral reefs. Another one million to nine million undiscovered species are estimated to live in and around reefs, according to NOAA. And one Smithsonian study found 525 different species of crustaceans living on 20.6 square feet of dead coral heads, suggesting the diversity of organisms living on reefs may be seriously underestimated.

"That biological genetic diversity is really important for supporting populations, species, and ecosystems as a whole," says Hagedorn. "Especially for coral reefs, we are in a race to prevent the loss of that genetic diversity in the oceans."

Genetic diversity equates to resilience because every time an organism reproduces sexually there is a new genetic combination and the possibility of a new adaptation to changing conditions. When a population is diverse, there is a greater chance of at least some individuals surviving adverse conditions. For corals to survive in today's oceans, the more chances to adapt—the greater the diversity—the better.

"We want that resilience. With cryopreservation, we can help maintain that

ABBY WOOD/NZP

resiliency because we can help diversify shrinking populations with additional genetics and can also preserve the species themselves," says Hagedorn.

No one knows for sure how much time she has to get it done. "We have this critical time window," says Hagedorn, who estimates 20-30 years but also wonders if some corals and coral reefs, like those in the Caribbean, have already changed so much that 20 years is wishful thinking.

Hagedorn has developed enough techniques to begin training other scientists who she hopes will replicate her work in other parts of the world.

"We have the capacity to do it. Now we just need an army to help us," she says.

Frozen but Alive

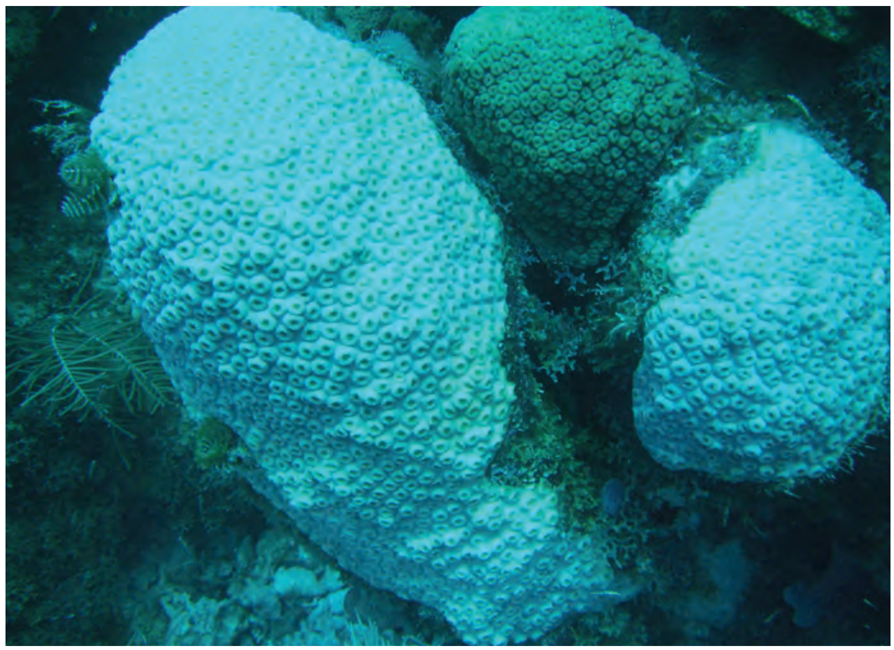
When coral bleaches, it expels its zooxanthellae, losing its color and primary source of nutrients. The first mass coral bleaching events occurred in 1983 in the eastern Pacific Ocean and Caribbean Sea, followed by several more regional bleaching events, especially in the Caribbean. The first global bleaching events occurred in 1998 and 2010—and a possible third is predicted for 2015.

In 1998, the World Resources Institute produced a seminal report on the threats to the world's coral reefs, sparking global interest in coral conservation and research. That year, Hagedorn was finishing a three-year fellowship for mid-career scientists funded by FONZ. A trained marine biologist, she had spent 10 years in basic science before seeking to use her science to solve conservation problems. She found a home in the Smithsonian's Conservation Biology Institute, then the Conservation Research Center.

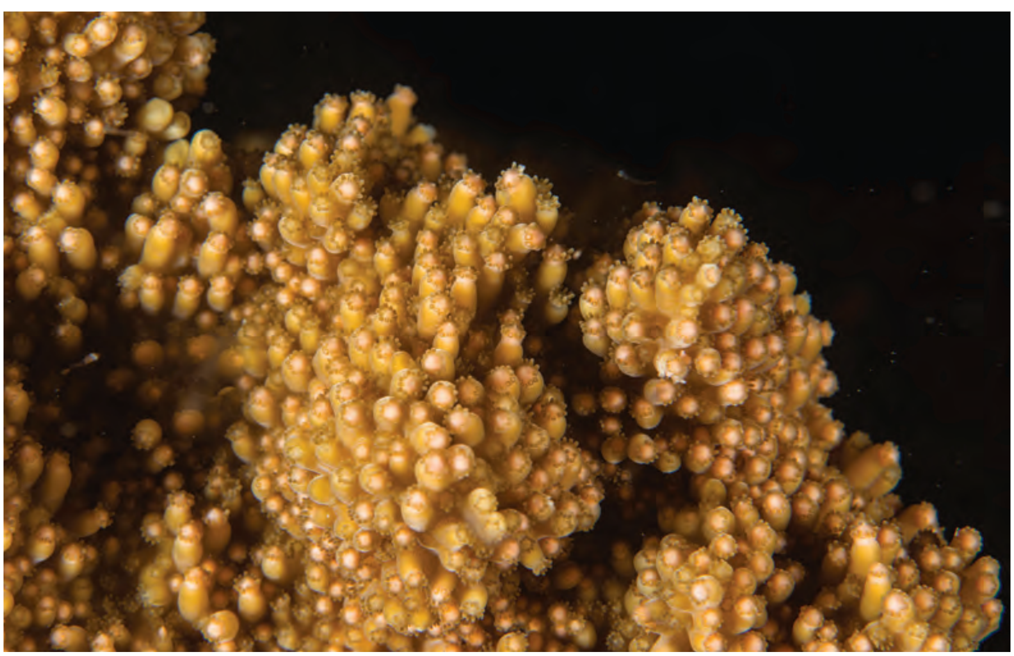
Hagedorn had read how the common wood frog's physiology allows it be "frozen but alive"—to freeze in the winter and thaw in the spring without cellular dam-

CLOCKWISE FROM TOP: **Rising water temperatures cause corals to expel their colorful zooxanthellae algae, leading to a bleached appearance and sometimes death; Six-week-old elkhorn coral polyps; The polyps of this elkhorn coral are swollen with egg-and-sperm bundles, ready to be released for a spawning attempt; Elkhorn coral takes its name from its distinctive shape.**

PREVIOUS PAGES: **Mike Henley descends to a reef after sunset, seeking evidence of spawning; Henley at the surface before a day dive to survey the reef.**



MIKE HENLEY/NZP



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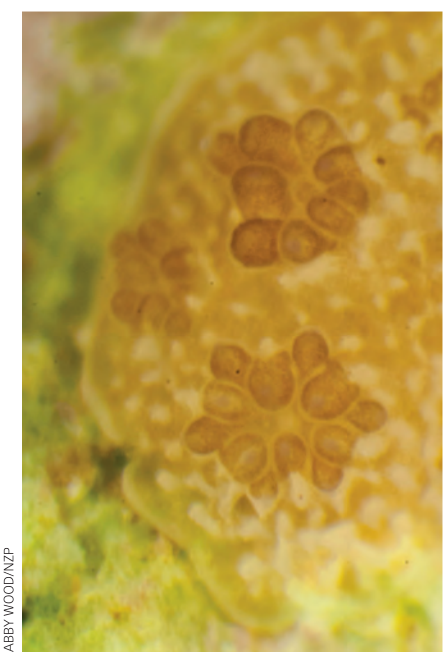

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Too Hot. Too Acidic.

This year is likely to be grim and historic for coral bleaching.

"We're really concerned that 2015 may bring the third global coral bleaching event," says Mark Eakin, Coral Reef Watch coordinator for the National Oceanic and Atmospheric Administration (NOAA).

NOAA scientists warned in February that they have spotted a pattern in global ocean conditions similar to conditions that led to global coral bleaching in 1998 and 2010.

Decades of carbon dioxide pollution have led coral reefs to experience higher ocean temperatures and greater acidity than at any other time in at least the last 400,000 years, stated the World Resources Institute (WRI) in a 2011 update of its report, "Reefs at Risk, Revisited." Those factors, combined with localized threats like overfishing and nutrient runoff mean 75 percent of the world's reefs are threatened, according to WRI.

When exposed to too much thermal stress, the coral's zooxanthellae algae produces too much oxygen, leading the coral to expel it. This doesn't necessarily kill the coral, but does leave it vulnerable to other stresses—of which there are plenty.

"Most studies indicate that by 2050 most coral reefs around the globe will be seeing temperatures that will cause bleaching on an annual basis," says Eakin.

In addition to warming, excess CO2 is also causing ocean acidification.

The ocean's absorption of carbon dioxide changes the chemistry of seawater, lowering its pH and making the water more acidic. That reduces the amount of available calcium carbonate in seawater, impacting the coral's ability to grow new tissue and shell structures. The acidic seawater also corrodes those small calcium carbonate cups at the base of the polyps.

Some scientists believe carbon dioxide concentrations have already passed the "tipping point" that would allow coral reefs to be saved.

Reef scientists in the 2011 WRI report recommended a drop in atmospheric CO2 levels from 388 parts per million in 2010 to 350 ppm "if large-scale degradation of reefs is to be avoided."

The warning went unheeded. The 2014 average annual concentration of CO2 in the atmosphere, as recorded at the Mauna Loa Observatory in Hawaii, was 398.55 parts per million. The average for February 2015 reached 400.26.

STEVE CLARKE/AUSTRALIAN INSTITUTE OF MARINE SCIENCE

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LEFT: **Mary Hagedorn and SCBI biotechnician Ginny Carter cryopreserve genetic material.**

BELOW: **Mike Henley and Mary Hagedorn work together to place young corals into holding tanks.**

FAR LEFT: **Striped grunts swim through the branches of staghorn coral, an important reef-building coral found throughout the Caribbean.**

SMITHSONIAN NATIONAL ZOO

ABBY WOOD/NZP

Mike Henley uses a net and funnel to collect egg and sperm bundles from a spawning coral.

age. During her first decade at the Smithsonian, she learned cryobiology techniques by working on fish embryos. Then, about 12 years ago, she started working on corals.

The concept of a bank is as old as the story of Noah's Ark. Hagedorn has taken this idea and applied modern techniques and a better understanding of the complexity of life. Her coral bank is part of the Smithsonian's Global Genome Initiative, announced in 2013, with the goal to cryopreserve 50 percent of the diversity of life by 2018.

The initial "deposits" in the coral bank were "hard-won," says Hagedorn. So far, there are sperm samples from six species of reef-building coral found on the Great Barrier Reef. They are stored at –196 degrees Celsius in the world's most comprehensive coral bank, held at Taronga's Western Plains Zoo, in Dubbo, Australia. In the United States, the freezers of the USDA National Animal Germplasm Program in Fort Collins, Colorado, hold sperm from two species of Hawaiian coral, plus that of the Caribbean elkhorn and staghorn corals.

These deposits represent a small percentage of total coral species.

"Ideally, I'd love to get all 800 species of stony coral," says Hagedorn, noting that the limiting factor in collecting eggs and sperm is spawning times—once per year for many species, including Henley's elkhorn and staghorn corals in the Caribbean. "We're also looking at freezing small pieces of coral. We could move very fast if we had both techniques going. In any bank, you want a wide variety of strategies."

Supporting an Ecosystem

But it's not enough to bank only the corals, because they cannot survive alone. A coral requires at least two other organisms to live: its zooxanthellae—which feeds the coral via photosynthesis—and coralline. A type of red algae with a hard, calcium-based "shell," coralline provides structure to coral reefs and helps "cement" the structure together. It also produces a chemical signature that encourages coral larvae to anchor to the reef.

Hagedorn is beginning to cryopreserve and bank species of both types of algae—plus other key species of coral reefs, such as sea urchins and some reef fishes.

"We understand we cannot recreate the complexity of a coral reef, but we are starting to preserve some of the main components," says Hagedorn. "We're creating a scientific framework and the infrastructure globally to take that further," she says. Once graduate students are trained, starting this September, she hopes to replicate what she does at other key coral reefs around the world.

"We're going to have nodes," says Hagedorn. "We're going to have a global conservation program, call it a network, in every ocean of the world."

In the near-term, Hagedorn envisions that her coral tissue and fertility banks can help conserve reefs. The sperm of Caribbean corals could be used, for example, to help boost the genetic diversity and resilience of the struggling elkhorn and staghorn.

"We can create coral and husband them and place the corals back out," says Hagedorn. "These kinds of interventions can have extraordinary results in a short period of time."

Raising the Ecosystem Builders

"Husbanding" the coral is where Mike Henley's work fits in. His task is to learn to nurture those little pink balls of egg and sperm into adults in human care.

When it comes to reproduction, corals are especially fascinating. Depending on the species, the individuals can be male, female, or both, and have a number of ways to reproduce.

One method of reproduction occurs when a fragment breaks off, perhaps in a storm, and re-roots in another location—just as a piece of a divided perennial plant can be rooted elsewhere in a garden. However—and this is why Henley's mission is critical—those newly anchored fragments are clones, with genetics identical to the parent coral. If the coral bank relied only on collected coral fragments, the genetic composition itself would essentially be frozen in time from a limited number of individuals. The ability to store eggs and sperm, and then raise embryos to adulthood, greatly increases the genetic diversity of the bank.

"Timing is everything when it comes to coral spawn," says Henley.

Corals do not have brains. Yet, elkhorn and staghorn are among the many types that coordinate the release of their egg and sperm in a synchronized spawn, allowing them to mate with their own species in nearby colonies.

The corals contain proteins that sense moonlight, and typically spawn two to six days after a full moon in late summer. Peak water temperature and daylight are the two other cues that determine the exact time. Spawn typically occurs two hours after sunset.

In late summer, Henley gets one chance to collect those little pink balls, launched by the polyps. They contain egg and sperm, bundled together, with fat that makes them float upward.

"They've spent an entire year's energy budget to make that egg-sperm bundle and they'd better spawn with their neighbors. If they're just one hour apart, the currents take their babies and take them away," says Henley.

Swimming among that frenzy of coral fertility, Henley places a net made of sewn silk fabric—like an underwater butterfly net—over a portion of the colony to funnel hundreds of the egg-sperm bundles into a plastic collection tube attached to the small end of the net. He'll do this across a dozen or so colonies on one night, collecting more than 10,000 bundles.

Then, back at the lab, he mixes the batches from different colonies and makes coral babies. Fertilization takes place within an hour or so.

In the coming weeks and months, he'll stow those developing embryos in a cooler for the flight back to Washington, where he will do everything possible to keep them alive in tubes, bottles, and aquariums as they progress from fertilized eggs to swimming larvae to young polyps.

It's not easy. There are many ways things can go wrong and only one night per year to start all over again. One year the coral spawned before the team arrived. Another year, a hurricane forced the team to evacuate the research station, and then cut power to the pumps that circulate seawater in the tanks holding coral larvae.

This summer marks Henley's sixth attempt to rear a generation to adulthood. So far, the longest-lived cohort was some elkhorn coral that survived about three months at the Zoo before an equipment malfunction exposed them to too much light.

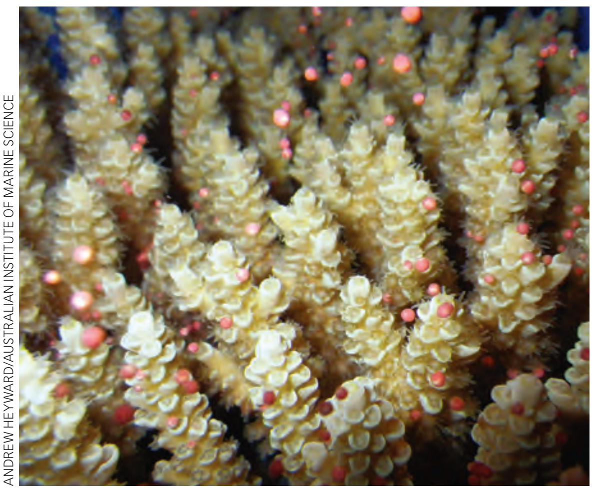
While it comes with disappointment, the work and the corals captivate Henley.

"I see these amazing, tiny brainless animals which make these ecosystems that are just incredible," says Henley. "I don't know how to stop climate change. I don't know how to stop ocean acidification. I'm a pretty good educator and know how to tell their stories, and I know how to grow coral, so that was my piece I could contribute to keeping them around."

Lions and tigers are amazing—and we need all the animals, says Henley. But he adds with pride, "My animals build ecosystems." SZ

LISA DUCHENE *is an independent writer and editor with more than two decades' experience writing about marine issues.*

CLOCKWISE FROM TOP RIGHT: **Corals rely on a variety of environmental factors to time the release of their sperm and egg bundles so that different individuals of the same species spawn at the same time; Approximately one-third of marine fishes spend part or all of their lifespans on coral reefs, including the sharpnose puffer shown here; yellow stingrays can be found on the sandy bottom near Belize's reefs; sea urchins, such as this West Indian sea egg urchin, are an essential part of the coral reef ecosystem, eating algae that might otherwise overwhelm the corals.**



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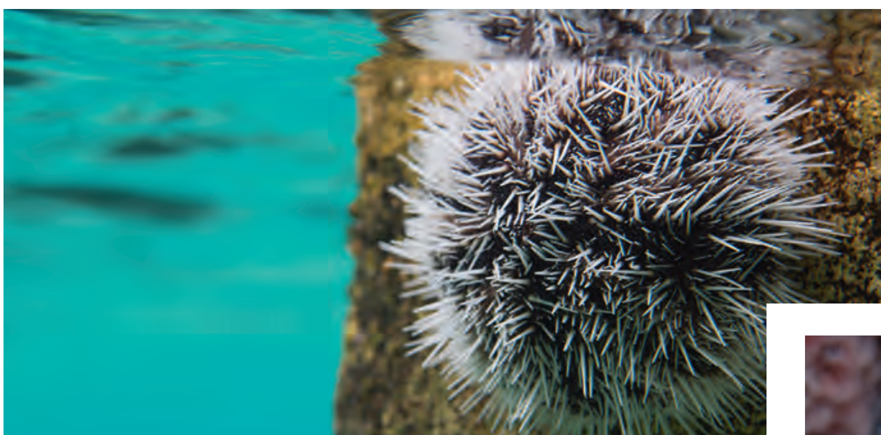

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