Back in 1986, 19-year-old college dropout Richard Pyle was 75 meters deep in the clear waters off Palau, pursuing a small pink fish with red tiger stripes, when he noticed it seemed hard to breathe. His pressure gauge showed plenty of air in his scuba tank, and at this depth, far below where most scuba divers dare to venture, Pyle was certain the fish would be a species new to science. He caught the fish in his net, then headed up. When he reached 55 meters, though, he couldn’t breathe at all. The needle on his gauge, which had apparently been stuck, plunged to zero. Pyle did a rocket ascent, exhaling so his lungs wouldn’t burst from expanding gas. As he breached the surface, he was seeing stars, a symptom of shallow-water blackout. He gulped a few breaths and managed to holler to an eminent ichthyologist waiting aboard the boat: “Jack, take a look at this fish!”

Because of Pyle’s rapid ascent, nitrogen bubbles within his bloodstream and tissues had ballooned in size, tearing flesh and nerves. He had decompression sickness—the bends—and further mishaps delayed treatment. By the end of the day he was paralyzed, unable to control his arm, legs, or bladder.

And the fish? It wasn’t new to science after all: The ichthyologist, John E. “Jack” Randall of the Bishop Museum in Honolulu, had already collected, described, and named it.

Reflecting back on the incident 30 years later, Pyle says without a trace of irony: “It was the best day of my life. Everything good in my life can be traced back to that day.”

Sure, he spent the next 30 days in decompression chambers, worked for weeks to regain use of his limbs, and walked with a cane for more than a year. But in order to get health insurance, he re-enrolled at the University of Hawaii. Once there, he continued on to earn a Ph.D. in ichthyology with Randall as his adviser, and then went to work at the Bishop Museum. His crippling brush with the bends propelled him into the world of technical diving, where he emerged as a pioneering rebreather diver, using the technology to reach greater and greater depths.

Today, Pyle is still at the Bishop, working as an associate zoologist, database coordinator, and dive safety officer. But his impact on marine science goes much deeper than those titles suggest. He has carved out a niche as an explorer of the mysterious, dimly lit coral habitat that thrives from about 30 to 150 meters below the surface, in what he calls the Twilight Zone.
Shallow reefs, with their brightly colored hard corals and fish, get most of the attention from scientists, conservationists, and the public. But studies of these deeper habitats, technically known as the mesophotic coral ecosystems, have surged lately, in part because they may offer a refuge for species squeezed out of shallower reefs damaged by pollution, overfishing, or global warming (see sidebar, p. 903). The soft corals that dominate the mesophotic zone host a diverse and colorful community of wrasses, butterflyfishes, damselfishes, mollusks, crustaceans, and other sea creatures. Some of them dwell in both deep and shallow habitats, whereas others specialize in one or the other.

Pyle “was really the first to bring deep reefs to the attention of both the science community and the general public,” says Pim Bongaerts, a research scientist at the University of Queensland in Brisbane, Australia. Pyle helped develop the specialized diving equipment needed to explore the twilight reefs. He has already discovered more than 100 new fish species there, though he estimates that perhaps 2000 more coral reef fish have yet to be identified. He’s driven by a sense of urgency to help science build a card catalog to the world’s “biodiversity library,” as he calls it, before species are lost to long-term human impacts such as climate change and overfishing.

Pyle “does what little kids do: He asks questions and then follows up on them, fearlessly,” says Sylvia Earle, former chief scientist of the National Oceanic and Atmospheric Administration (NOAA), who is now president of Mission Blue, a nonprofit advocating ocean conservation in Oakland, California. “He’s a true pioneer and a courageous scientist.”

Identifying and describing the inhabitants of these reefs is just the first step. “We are just beginning to understand what lives there, but we don’t know how they feed, how they interact with each other, how they reproduce,” Pyle says. Whereas shallow reefs are sustained by photosynthesis, researchers still aren’t entirely sure just what energy sources sustain such low-light ecosystems, for example. “Compared to what we know about shallow coral reefs, everything in the deep coral reefs is a big question mark.”

FOUR DIVERS WERE SUITED UP, looking more machine than man with their masks, mouthpieces, wraparound hoses, valves, computer displays, and multiple tanks. Waves bounced them around on a small boat here in the middle of the Pacific Ocean, a hundred kilometers off an atoll more than a
Shadowy coral kingdoms

Tropical coral reefs extend to a surprising 150 meters below the surface. The brightly lit reefs in the top 30 meters, dominated by scleractinian or stony corals, make up about 20% of coral reef habitat and can be reached by divers using conventional scuba gear. Divers using rebreathers are just beginning to explore the remaining 80% of living reef habitat, called the mesophotic coral ecosystem.

Sunlit shallows
10 meters
This zone chiefly holds the familiar scleractinian corals that form diverse colonies and rely on sunlight to grow symbiotic algae that provide them color and food.

Transition zone
30 meters
As sunlight dims to twilight and temperatures cool, hard scleractinian corals transition to soft gorgonian corals such as sea fans.

Twilight ends
150 meters
As the mesophotic zone yields to near darkness, coral reefs give way to deep-sea habitat.
and invertebrates living in the thickets.

On this day near an atoll, the divers pushed even deeper as the sea around them darkened to indigo. In the twilight, the hard corals gave way to soft gorgonian corals in myriad shapes and sizes, including sea fans, sea feathers, and whips in bushy clusters. Their silhouettes appeared dark until the divers’ flashlights revealed their true colors, as bright and diverse as a rainbow.

These soft corals are thought to feed on plankton, detritus, or dissolved organic matter, says postdoc Sonia Rowley of the University of Hawaii in Honolulu, “but we really don’t know what they eat.” She suspects they may farm bacteria just as stony corals grow algae. Rowley, who frequently dives with Pyle, is one of the few who study deep-living gorgonians. Most researchers stick to the shallow reefs, where more research dollars flow.

What compels scientists to plumb such depths? “It’s not thrill seeking,” Pyle says. “It’s the thrill of discovery. The magic moment comes when I see a fish that no one else has ever seen before.”

PYLE, A FOURTH-GENERATION HAWAIIAN, has been fascinated with fish since his boyhood in Honolulu. He was an active child, and to quiet him, his parents and three older siblings would plunk him down facing their home aquarium. He’d watch the fish for hours, mesmerized. As a preteen he collected fish and met another collector, Randy Kosaki, at an aquarium trade show. The pair began to dive together and continued to collaborate after both earned Ph.D.’s from the University of Hawaii. Today, Kosaki is deputy superintendent of Papahānaumokuākea, and together he and Pyle have spent decades exploring the Twilight Zone and documenting its inhabitants. “We call ourselves the fish nerds and fish geeks,” Kosaki says. “Rich is the king of fish geeks.”

On 5 June last year, halfway through the 25-day research cruise, a small pink and yellow basslet caught Pyle’s eye as he prowled the sea floor off Kure Atoll. The fish had an unusual eye-shaped orange spot on its dorsal fin, an adaptation to confuse predators. The fish darted under a rock, but Pyle managed to net it before he was out of time and had to begin a slow 2-hour ascent.

Later that day, Pyle plopped his tiny, colorful catch in an aquarium tank aboard the NOAA ship. He snapped a picture and emailed it to the world’s top tropical fish experts. The list included Randall, who at age 92 is officially retired but still producing papers. “Never saw it,” Randall fired back.

Pyle’s excitement rippled through the ship, as fellow scientists paraded by to see the discovery. The next day, Brian Greene, a longtime deep dive partner, spotted the female of the species in the last minute before he had to begin his ascent. “It was the luckiest collection I’ve ever been involved in,” says Greene, an expert fish collector and a director of the Association for Marine Exploration in Honolulu.

Both fish died shortly after coming aboard, probably because the seawater in the aquarium was not chilled. That suited Pyle just fine. Now he had a pair of holotypes, the first specimens of an unknown species. They needed to be pinned to a board, photographed, sampled for DNA, meticulously measured, fixed in formalin, and preserved in alcohol. Once their anatomy and DNA were compared with other species, the little fish could get a name.

Pyle’s an expert namer: He has named two dozen species in publications and has dozens more in the works. He’s also a commissioner of the International Commission on Zoological Nomenclature (ICZN), the arbiter of scientific animal names since 1895. He was recruited for his knowledge of fish taxonomy and to use his database expertise to help modernize the organization, says Ellinor Michel of the Natural History Museum in London. She says Pyle emerged as the architect and visionary behind ZooBank, ICZN’s online, open-access registry designed to capture all of shallow and deep populations of each species to see how much they had mixed in the past. In one species, the fragile saucer coral (Agaricia fragilis), the genomes of deep and shallow individuals showed significant divergence, suggesting limited genetic exchange. Another species, the blushing star coral (Stephanocoenia intersepta), showed no such divergence, suggesting recent mixing, the authors report.

Bongaerts and colleagues conclude that reseeding may happen in only a few coral species. “The deep reef refuge hypothesis ... can be very relevant to individual species, but should not be assumed as a broader ecosystemwide phenomenon,” Bongaerts says. “Deep reefs are unlikely to represent a lifeline for shallow coral reef biodiversity.”

Kosaki notes that even if deep reefs can’t be counted on as a refuge for many shallow corals, they may be more effective havens for fish, like the kumu, that traverse the two types of habitat. “The results show that it’s a case-by-case, species-by-species sort of thing,” Kosaki says.
named animals; it’s now at more than 175,000 names, or about 10% of the total.

For this particular little fish, Pyle and his colleagues hatched a plot. When it was published in December 2016, they named it *Tosanoides obama*, in appreciation of then-President Barack Obama’s decision to quadruple the size of Papahānaumokuākea, making it the world’s largest marine protected area.

*T. obama* is just one of hundreds of fish known only in these waters. The recently published review of Hawaii’s reefs confirms that in contrast to shallow reefs, the deep habitats are recolonized from larvae elsewhere in the Pacific. But on deep reefs, the habitat simply shifts up and down the steep slopes, allowing inhabitants enough time to evolve into endemic species, Pyle explains.

He and Kosaki have assembled a team to test this hypothesis by comparing genetic signatures of species inhabiting deep and shallow reefs. If their hypothesis holds true, species restricted to shallow reefs will show genetic signs of recolonization across the Pacific within the past 20,000 years, whereas species restricted to deeper habitats will have telltale genetic divergences.

\[ \text{Gorgonian corals (yellow fans, bottom) and other invertebrates in the Twilight Zone show their true colors when illuminated. Among Rich Pyle’s discoveries are, from top left, the soapfish (*Belonopera pylei*), the peppermint angelfish (*Centropyge boylei*), and *C. narcosis*, named for the nitrogen narcosis Pyle suffered while collecting it.} \]

have extremely high levels of endemic fish. In the mesophotic zone surrounding Kure Atoll, 100% of fish were endemic to Hawaii—the highest proportion ever documented in the marine world, Kosaki says.

Pyle and Kosaki have long puzzled over such high levels of endemism, which they attribute in part to Hawaii’s remoteness. They also think it may have arisen because the deep reefs were unaffected by the rise and fall of sea levels during the ice ages. When glaciers grow and oceans shrink, the shallow reefs that sit atop steep-sided atolls go high and dry, triggering die-offs. Then, as sea levels rise again, these reefs shift will have telltale genetic divergences.

\[ \text{PYLE TYPICALLY SURFACES LAST} \]

on team dives. He errs on the side of caution these days, allotting extra time for nitrogen and helium to escape his bloodstream. Decades ago, he began to pause his ascent below 30 meters to vent the expanding gas from the swim bladders of fish he was bringing to the surface. If he didn’t puncture these buoyancy-control organs with a hypodermic needle, they would expand or burst and the fish would die. What was good for the fish turned out to be good for the fish collector. Pyle published his observation that he had less fatigue when he made such deep stops—now often called “Pyle stops”—which have become common practice on deep dives.

In the mid-1990s, Pyle teamed up with Bill Stone, president and CEO of Austin-based Stone Aerospace, to improve the company’s Poseidon rebreathers. Stone works on outer space vehicles for NASA but also probes the depths of Earth by mounting expeditions to the world’s deepest caves, which invariably means deep diving in hard-to-reach places. So he began to design and engineer lighter weight rebreathers.

A closed-circuit rebreather works by scrubbing carbon dioxide from exhaled air as it is recycled and then injecting fresh doses of oxygen into the gas mixture, which typically also includes nitrogen and helium. The trick is figuring out how much oxygen. “If you go too low, you go hypoxic and die,” Stone says. “If you go too high, the oxygen level becomes poisonous and you will suffer a grand mal seizure. That simple question has been the cause of many of the 200 to 300 rebreather deaths in the past 20 years.”

Pyle has a rare talent for poring over data and spotting patterns, Stone says. “It was Rich who went through tens of thousands of [rebreather dive] records, teasing out something from big data that no one has ever caught,” he says. Essentially, Pyle developed a lie detector test for the all-important oxygen sensor, so that the system will adjust for any misread.

All of this is merely the price of admission to explore where few others go. Although rebreather divers pay meticulous attention to their gauges and gear, they live for the precious minutes they spend at depth.

Pyle and Greene almost always record their dives on video cameras attached to their rebreather rigs, whether documenting the capture of *T. obama* or swimming through swarms of fish that billow like a murmuration. Divers can get closer to fish on rebreathers because they are quieter than traditional scuba and release no bubbles.

When on land, Pyle loves to regale audiences with vivid descriptions of this twilight world. Back in 2008, he was engaged in one of these unbridled bursts of enthusiasm at a dinner in Paris, recounting how a vast school of brilliant blue damselfishes swam by like sparkling jewels at a depth of 120 meters off Palau. At one point, his dinner companion held up a hand to interrupt the flow. “I have to stop you,” said evolutionary biologist Edward O. Wilson of Harvard University. “What an honor it is to be in the presence of a true naturalist.”

Kenneth R. Weiss, who won the 2007 Pulitzer Prize for Explanatory Reporting, is a journalist in California.
Into the Twilight Zone
Kenneth R. Weiss (March 2, 2017)

Editor's Summary

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