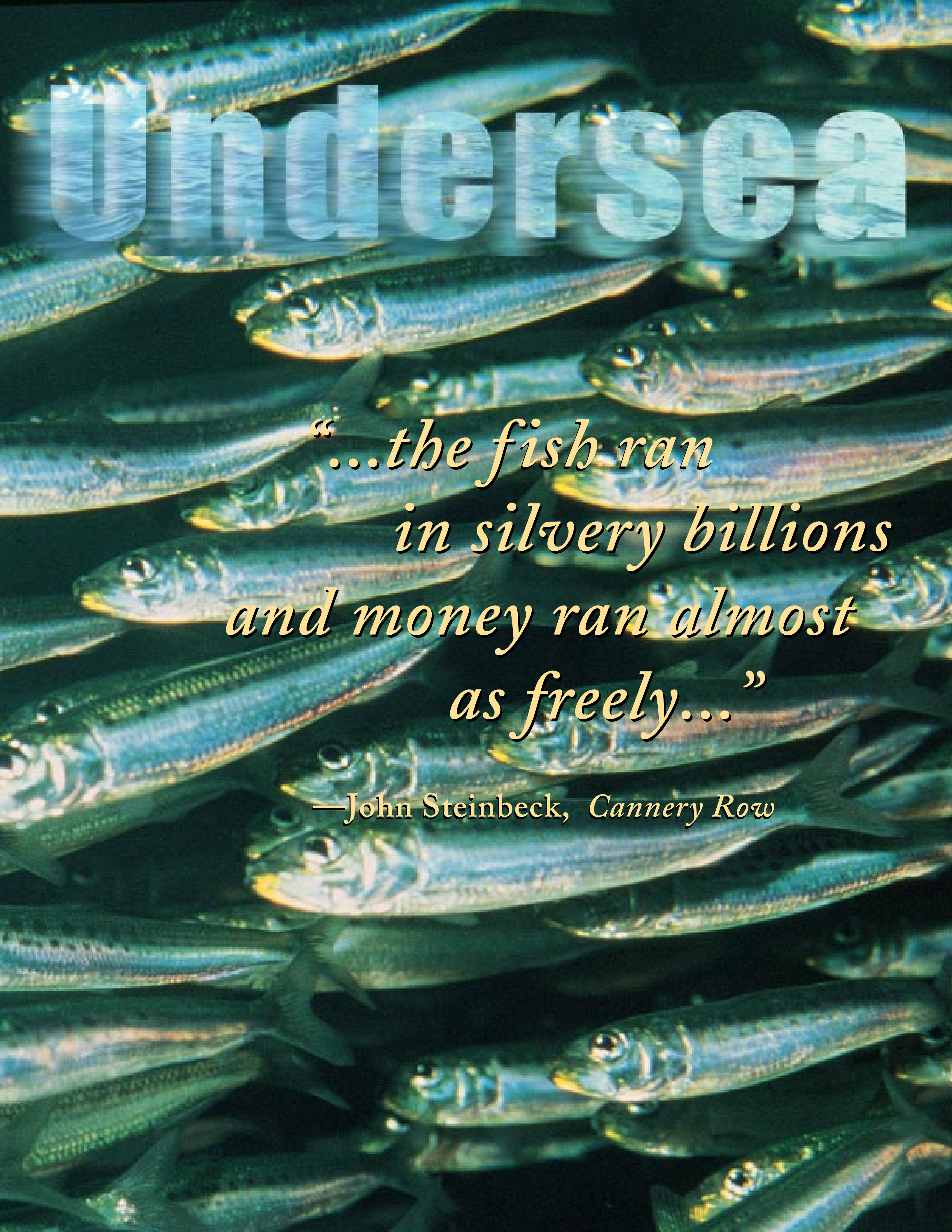
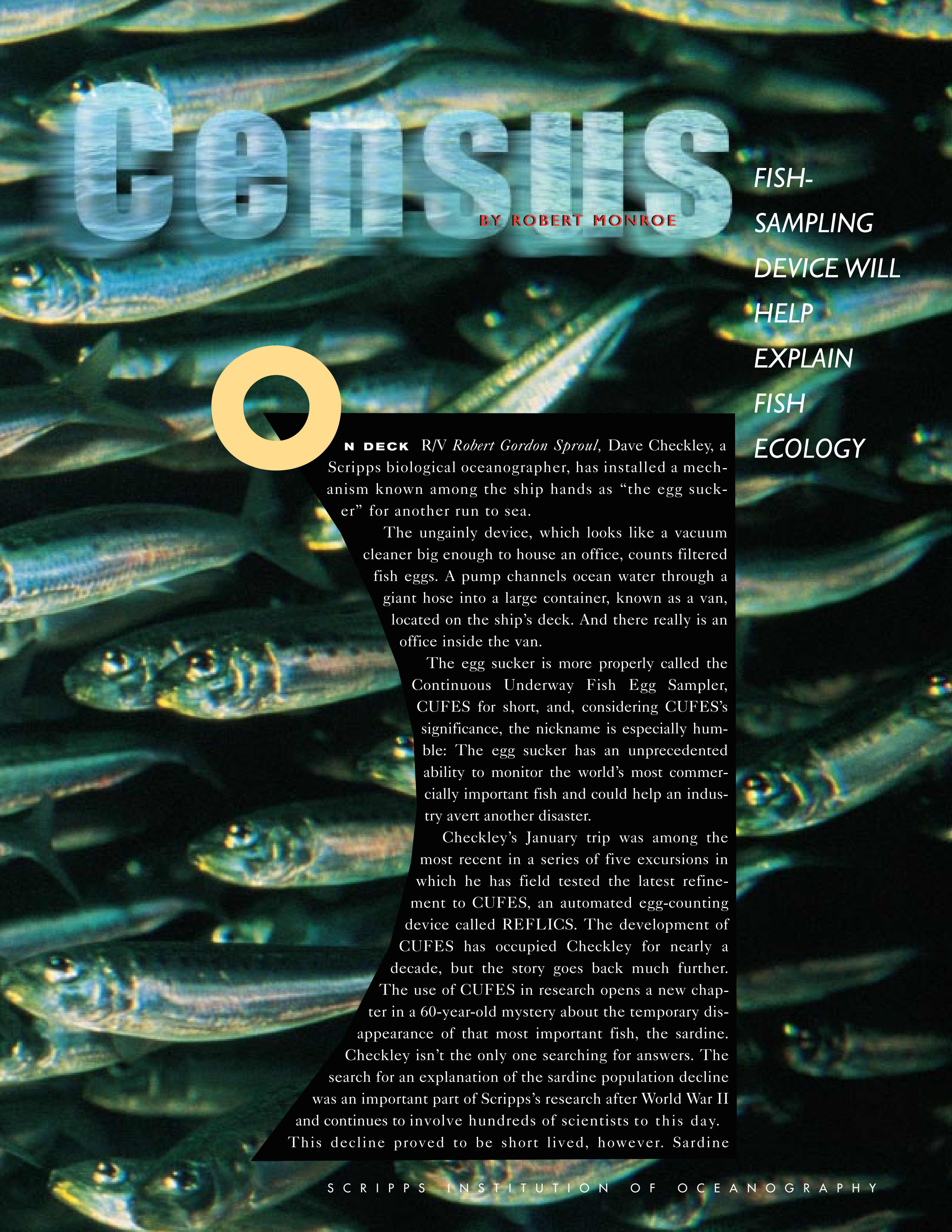


Undersea

"...the fish ran in silvery billions and money ran almost as freely..."

—John Steinbeck, *Cannery Row*



Census

BY ROBERT MONROE

FISH-SAMPLING DEVICE WILL HELP EXPLAIN FISH ECOLOGY

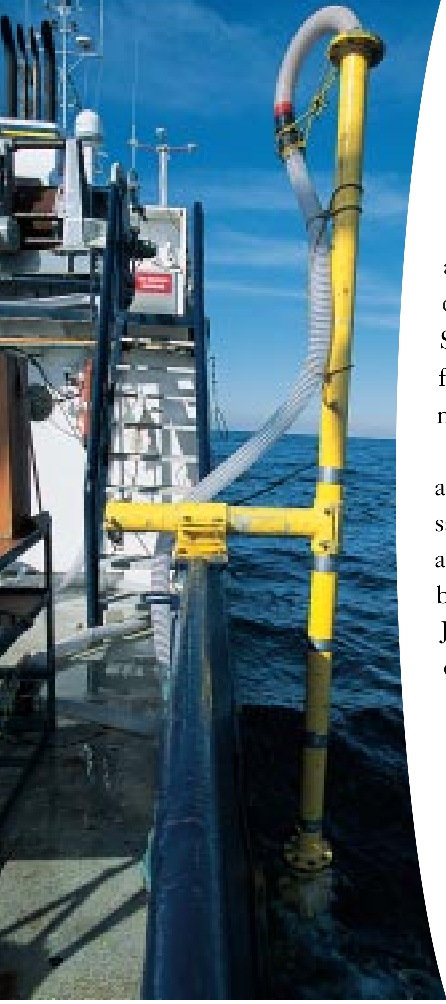
ON DECK R/V *Robert Gordon Sproul,* Dave Checkley, a Scripps biological oceanographer, has installed a mechanism known among the ship hands as "the egg sucker" for another run to sea.

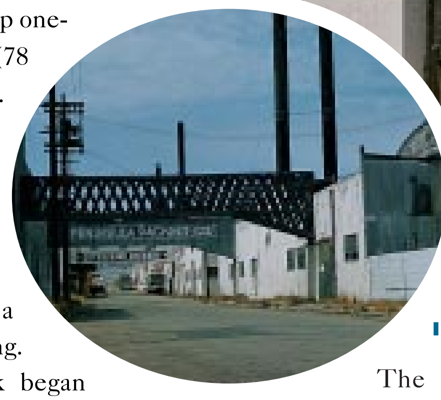
The ungainly device, which looks like a vacuum cleaner big enough to house an office, counts filtered fish eggs. A pump channels ocean water through a giant hose into a large container, known as a van, located on the ship's deck. And there really is an office inside the van.

The egg sucker is more properly called the Continuous Underway Fish Egg Sampler, CUFES for short, and, considering CUFES's significance, the nickname is especially humble: The egg sucker has an unprecedented ability to monitor the world's most commercially important fish and could help an industry avert another disaster.

Checkley's January trip was among the most recent in a series of five excursions in which he has field tested the latest refinement to CUFES, an automated egg-counting device called REFLICS. The development of CUFES has occupied Checkley for nearly a decade, but the story goes back much further. The use of CUFES in research opens a new chapter in a 60-year-old mystery about the temporary disappearance of that most important fish, the sardine. Checkley isn't the only one searching for answers. The search for an explanation of the sardine population decline was an important part of Scripps's research after World War II and continues to involve hundreds of scientists to this day.

This decline proved to be short lived, however. Sardine





and anchovy, another species tracked by Checkley, dominate commercial fishing worldwide today. Sardine, anchovy, and herring made up one-fifth of the world's 86-million-ton (78 million-metric-ton) fish catch in 1998.

Before World War II, sardine and anchovy were king. In California, sardine—used as food and bait—anchored a booming industry. Their bounty provided the backdrop to the John Steinbeck novel *Cannery Row*, a connection Checkley is fond of noting.

In the 1920s, when Steinbeck began drawing the characters that populate the novel, he wrote, sardine schooled "in silvery billions and money ran almost as freely," he wrote. His slice of Monterey life was published in 1945; that year the annual sardine catch off the California coast was 440,000 tons (400,000 metric tons).

The 1945 catch was only half what it had been in the seasons leading up to 1938, the year a worried fishing industry acknowledged a harvest drop-off and asked for help from the state government. By 1947, the sardine catch dropped to 143,000 tons (130,000 metric tons). The reduction was sharp enough to drag down the economy of the entire state. Canneries in California, Oregon, and Washington closed for good. The sardine industry declined.

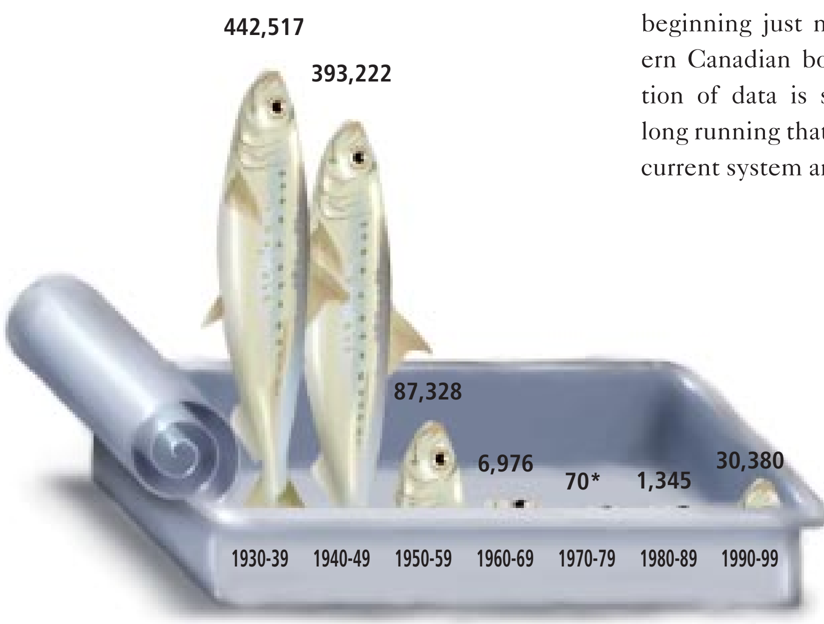
Where did the sardine and anchovy go? Had they been overfished? Did ocean conditions become unsuitable for them? And if so, what had caused the ocean to become so inhospitable?

CALCOFI IS CREATED

The search for an explanation led to the formation of the California Cooperative Oceanic Fisheries Investigations, or CalCOFI, a continuous study of the ocean for which the original research grid stretched from Baja California to the Canadian border. CalCOFI also spawned what is now the Marine Life Research Group, the Scripps division of which Checkley is a member.

Over the past 53 years, CalCOFI's ocean measurements, ostensibly a search for the sardine, became a broad survey of the ecology of the California Current System, which extends along the west coast of the United States beginning just north of the western Canadian border. The collection of data is so consistent and long running that the waters of this current system are now considered

Top left, *The CUFES pump routes ocean water into an analysis facility installed on the deck of R/V* Robert Gordon Sproul. **Top right,** *(both photos) By the 1960s, Cannery Row was all but deserted as the sardine population plummeted.*



Average annual sardine landings off California by decade, in tons of fish
**moratorium imposed in 1974*

Left, *Sampled seawater is discharged off the port side of R/V Robert Gordon Sproul.*

to be among the best understood, in an ecological sense, in the world.

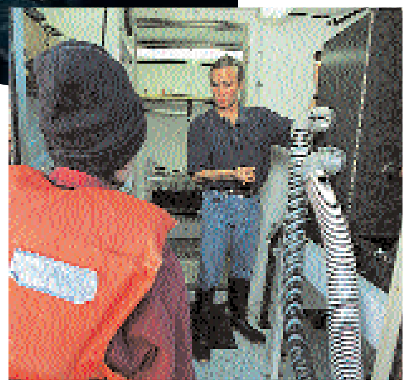
Since CalCOFI's inception, at least part of the answer to the vanishing fish mystery has been discovered. Sardine eventually returned to California waters in the 1980s, and the estimated biomass of the species has reached 1 million tons (900,000 metric tons) per year. The industry didn't revert to its old ways, however. A quota established last year capped the amount that California fishermen could catch at 138,000 tons (125,000 metric tons) annually. Cannery Row is back, but only as a tourist attraction.

CalCOFI scientists have determined that the disappearance and reappearance of sardine populations occur, at least in part, within a cycle of abundance that perpetually waxes and wanes, peaking about every 30 to 50 years. In fact, sediment records show, that the catches of the 1920s and 1930s were unusually large because sardine had reached an abundance not seen for 800 years.

Despite more than 50 years of research and the return of sardine to California, there remain questions about the suddenness of the disappearance and about sardine and anchovy behavior in general. On the bow of R/V *Robert Gordon Sproul*, Checkley said he hopes to fill in some of the significant gaps in current knowledge.

He wonders whether sardine populations have now reached a critical mass that has triggered a drastic self-regulation or whether the latest trends in the sardine cycle are linked to climate warming trends.

"There is no smoking gun," he said.

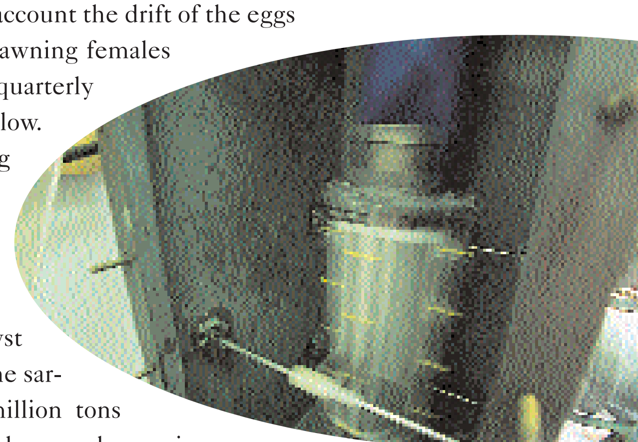


Above, *Dave Checkley tests analysis equipment inside an on-deck van.* **Lower right,** *Oscillating rapidly, a concentrator separates fish eggs from other material pumped through the line.*

A COMPREHENSIVE COUNT

Enter CUFES. This device measures concentrations of sardine and anchovy eggs in various areas of the ocean and compares concentration levels with ambient conditions such as surface temperature and salinity in these areas. In Checkley's excursions, CUFES has collected data on various fishes off the California and North Carolina coasts. Other scientists have used CUFES to sample fish eggs in waters off Africa, South America, and Europe.

CalCOFI scientists have taken similar measurements for decades before CUFES, but have been limited to fixed locations based on the predetermined grid. To this day, researchers dip nets into the ocean during cruises that take place four times a year at stations about 5.6 miles (9 km) apart within the CalCOFI grid. These samples give scientists only an idea of fish egg concentrations at those spots. They cannot take into account the drift of the eggs and therefore the migration of the spawning females that produced them. Processing the quarterly samplings can also seem painfully slow. "You might say we'd been managing fisheries as if we were looking through a rear-view mirror," said Paul Smith, a National Marine Fisheries Service biologist and adjunct professor at Scripps. An analyst of CalCOFI fish egg data, he thinks the sardine catch might have reached 1 million tons (900,000 metric tons) 20 years ago had researchers using CUFES been around to encourage sustainable fishing.



CUFES samples now regularly augment the count taken at 66 CalCOFI stations between Del Mar and Monterey Bay, California. The samples are taken from

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Collecting Below the Surface With MOCNESS

Student Erica Goetze holds a cross-section of life from below the surface.

THE MOCNESS CAN BE A MONSTER. The Multiple Opening–Closing Net Environmental Sensing System, or MOCNESS, is an innovative device that enables researchers to collect living ocean creatures from several depth levels all in the same tow. The operator opens a new mouth of netting in the same act of closing another as the MOCNESS returns to the surface from a predetermined depth. Multiple collections allow for sampling at different depths of the ocean.

At least that's how researchers hope it goes. Operators of the system liken their experience to flying a kite underwater, and some admit that the MOCNESS (yes, they do rhyme the name with the famous Scottish lake) can be intimidating.

They're dragging a 330-pound (150-kg) device with hundreds of moving parts to depths a mile below the surface and pulling it back up as steadily as possible. If there is slack in the line, the MOCNESS could sink out of a desired range, ruining results. If all goes well, the operator has to hope the net controls, flowmeters, battery packs, release indicators, and dozens of other instruments also operate properly.

"It is pretty mind-boggling that with the number of moving parts it has, it is reliable," said Dave Griffith, a fishery biologist with the National Marine Fisheries Service.

It's reliable and essential to Scripps fifth-year graduate student Catherine Johnson, who has frequently borrowed the MOCNESS from the fisheries agency and has led 90 tows to date. She thinks use of the MOCNESS is well worth the risk.

Like her mentor Dave Checkley, Johnson is interested in understanding some of the Pacific Ocean's most important creatures. A series of 13 short cruises she conducted off the California coast is providing a first look at certain behavioral aspects of copepods, small crustaceans that are a crucial link in ocean food webs and can influence ocean

optics and acoustics.

Specifically, Johnson is interested in what happens when a species of copepod called *Calanus pacificus* enters dormancy from late summer to early winter. Among her many questions, she wants to know why part of the population remains active year-round while another group retires for the long sleep. She is interested in why there is latitudinal variation in *C. pacificus*'s dormancy response and whether her findings can be generalized to describe behavior of other important copepod species. Basic research must come first, though.

"I can't even ask the really interesting questions until we answer questions like what induces dormancy," Johnson said.

Those first steps require data gathered by the MOCNESS, a device invented some 25 years ago by Scripps alumnus Peter Wiebe and others. Johnson has used it to identify the depth ranges to which *C. pacificus* descends during dormancy. Although the interesting answers are still a way off, the stratified snapshots of life the MOCNESS brought to the surface on a recent Johnson cruise were anything but mundane.

After carefully guiding the MOCNESS's ascent to the surface, Johnson, with fellow students, carefully raised the net array back on deck R/V *Robert Gordon Sproul*. Each of the MOCNESS's ten nets feeds into a small canister. Samples from various strata are preserved in glass jars. In addition to gathering copepods, the nets sweep up neighboring species. From the 1,500–1,600 feet (450–500 m) depth range come a menagerie of medusae, krill, and lanternfish.

Johnson began leading such tows in 1999 under the tutelage of Griffith, who has operated the MOCNESS tows for 12 years. Since then, her research has proceeded free of major snags.

"If you want to do what she's done, being self-sufficient as an operator, taking data and analyzing it, you need a lot of training," Griffith said. "She's gone from hands-off to completely hands-on and she's done extremely well. She's probably even better at it than I am now."

Top, *Catherine Johnson readies a Niskin bottle for collecting seawater.* **Top left,** *Erica Goetze straightens MOCNESS netting.* **Above,** *A tunicate in a collection canister.* **Bottom,** *Catherine Johnson and fellow student Alexandra Curtis prepare MOCNESS for a tow.*

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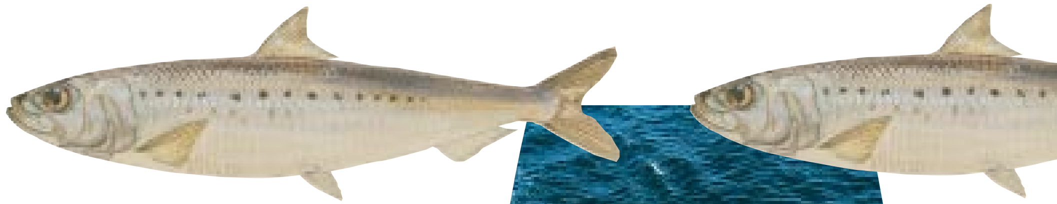


moving vessels, hence the *underway* in CUFES's name. The pump routes ocean water from 10 feet (3 m) below the surface into the van installed on a ship's deck. Researchers inside scan the water for sardine or anchovy eggs. Samples are taken at 20-minute intervals. Eggs are counted once on the ship, then again on land after they have been preserved.

Although Checkley seeks answers to questions concerning long-standing anchovy and sardine behavior, fishermen stand to benefit first, as CUFES will likely raise a red flag to signal the next decline of sardine and anchovy stocks. CUFES is such a popular resource for the fishing industry that Smith is creating a web site to which fishermen can link to get real-time data from twice-yearly cruises.

"I would call it a revolutionary addition to our suite of materials for studying fisheries around the world," Smith said.

At CUFES's current collection rate, Checkley, colleagues, and Scripps graduate students such as Alexandra Curtis can determine the average concentration of eggs in a 3-mile (5-km) swath of ocean. Using the data, scientists are painting a picture of the subtle differences in the habitats that anchovy and sardine prefer for spawning. It's known that sardine spawn in the open ocean, releasing clouds of eggs as cohesive as the schools of adults, whereas anchovy are not as cohesive a group and spawn closer to land. How the sardine choose exactly where to spawn and how they maintain their bearings are processes scientists are only beginning to understand with CUFES's help.

CUFES is a major improvement to the egg-counting process, but Checkley's colleagues such as Mohan Trivedi, a professor of electrical engineering, and some students at UCSD are taking it one better with REFLICS, the Real-Time Flow Imaging and Classification System.

SAMPLING SIMPLIFIED

Checkley and Curtis boarded R/V *Robert Gordon Sproul* on a sunny January day to test REFLICS, which measures concentrations on a much more detailed scale than CUFES. REFLICS can also perform the task faster than can the most skilled technician using a dissecting microscope. Fish eggs pass through an intense strobe light like a film reel in a projector while REFLICS snaps images at 60 frames per second. A computer identifies the backlit eggs by shape, size, and transparency and then saves images of them.

Checkley hopes to have REFLICS fully operational by fall and intends for it to supplement hand counts. Once it is in use, the concentrations of eggs REFLICS records in a given area will give clues to the whereabouts of spawning females and what in their immediate surrounding might be attracting or driving them away.

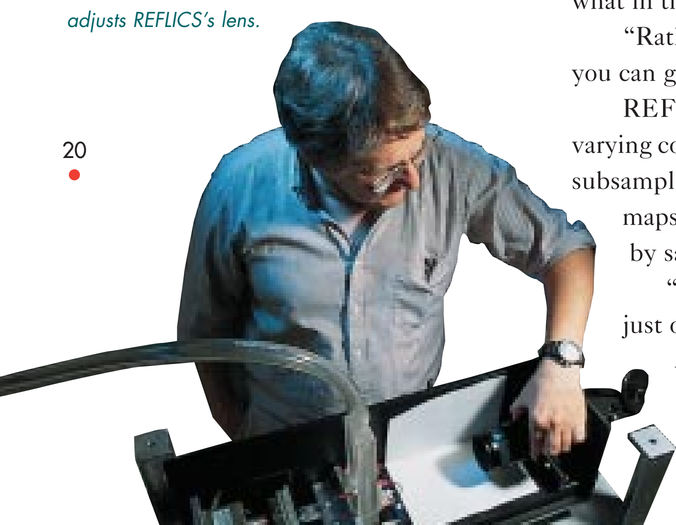
"Rather than acquiring information for 10-minute intervals on a scale of miles, you can get information on a scale of meters or tens of meters," Checkley said.

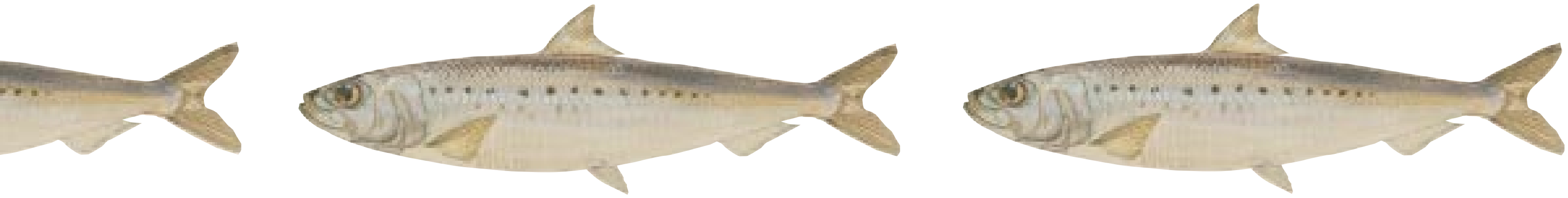
REFLICS could determine the dimensions of spawning areas and pinpoint varying concentrations of eggs within them, matching perhaps a dearth of eggs in one subsample with an eddy in that same area or a streak of unusually warm water. The maps of spawning areas could be paired with chlorophyll concentrations measured by satellite to seek causal patterns between the two sets of data.

"You have the beginnings of a biophysical picture of spawning rather than just of egg abundance," Smith said.

Aboard R/V *Robert Gordon Sproul*, a malfunctioning pump nearly sabotaged

Top, *Dave Checkley and students aboard ship before REFLICS testing.* ***Middle,*** *UCSD graduate student Ed Childers works with Dave Checkley to help improve REFLICS's eyesight.* ***Below,*** *Ed Childers adjusts REFLICS's lens.*





the REFLICS field test. Its motor apparently burned out, but Checkley had no way to reach over the side of the underway research vessel and inspect it.

Instead he decided to wait until dark and collect the eggs by an alternative means. Checkley then caught the emerging nightlife of the ocean surface with a ring net and ran the material through the sampler. The waters just below the surface, vacant during the day, were teeming with life just after sunset.

The crew of R/V *Robert Gordon Sproul* dropped the net into the ocean and dragged it for 10 minutes, filtering for small life forms. The contents formed a bioluminescent mass that glowed blue in the dark night. The catch was dispensed into a white painter's bucket on deck where small, transparent creatures were undetectable at first glance. But the seawater in the bucket was quivering with this tiny life.

Poured into a clear beaker and raised to the light, the animals lost their cover. The collection included several small jellyfish and a mollusk whose 2-inch (5-cm) diameter made it the behemoth of the bucket. Ubiquitous crustaceans called copepods darted about. The glowing cilia of a ctenophore pulsated rhythmically like neon bubbles up the side of a glass.

Checkley filtered out the larger creatures and ran the smaller ones through REFLICS, passing them through the xenon flashlamp. Images popped onto his computer screen, object after object filling row after row.

There are still bugs to be worked out in the new computerized counter. Checkley and Curtis are improving REFLICS's resolution so that it can tell the eggs of different species apart and distinguish eggs in general from anything else that could pass through the hoses.

Dave Checkley scans CUFES images while student Alexandra Curtis adjusts the REFLICS viewer.

"We've gotten to the point where we get pretty nice images," said Curtis, a fourth-year student.

REFLICS must still learn to definitively pick out the sardine eggs in water flowing past its camera at 5 gallons (20 l) per minute. The newest lessons in its ongoing education have come from Ed Childers, a UCSD graduate student and member of Trivedi's team. He is creating virtual eggs that the computer can learn to recognize through creation of a neural network. The network is created when thousands of egg images are imprinted into the computer's memory, a drill that seagoing searches for real eggs cannot always guarantee.

Checkley's own hope for REFLICS is that its widespread use could lead to standardized data collected over a period of time, similar to the CalCOFI data set, to consider ocean physics and biology on comparable scales.

But before then, Smith thinks the message that comes from CUFES and REFLICS data will reverberate through the new cannery rows first. From its survey data will come evermore detailed maps presenting trend data of sardine and anchovy eggs in understandable terms. Already, private fishing fleets have volunteered to help conduct CUFES surveys.

Since the boom days of the sardine industry, fishermen have been skeptical of scientists trying to encourage them to limit their catches to sustainable levels. Smith thinks CUFES and REFLICS might provide the proof that has been missing since CalCOFI's beginnings.

"When you have a map laid out, it's easy to convince them," he said.

Editor's note: For additional information on CalCOFI, you can refer to the Summer 1999, Vol. 6, No. 1 issue of Explorations *or go online at scripps.ucsd.edu/explorations/. You may also reference calcofi.org online.*