Winter blooms in the Arabian Sea

"Why was this organism appearing in such large quantities?"

Joaquim Goes
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by Natasha Vizcarra

Two strange things unfolded in the Arabian Sea in the winter of 2003. Joaquim Goes, an oceanographer and remote sensing expert, studied satellite images of summer algal blooms when he thought to check winter blooms. The amount of algae astounded him. Then, Goes' colleagues found themselves sailing their research vessel through slushy, green waters. They took samples and sent word to Goes. "It was an organism called *Noctiluca scintillans*," Goes said. "It's never been seen in the Arabian Sea."

Noctiluca is a kind of microalgae, or tiny plant-like organism. Sailors call them sea sparkles because they glimmer at night. From space, they appear like most algae—emerald green swirls in cobalt blue seas. Under the microscope, they look like transparent, quivering balloons with whip-like tails. The green blooms could have been *Noctiluca* or other species of algae like diatoms,

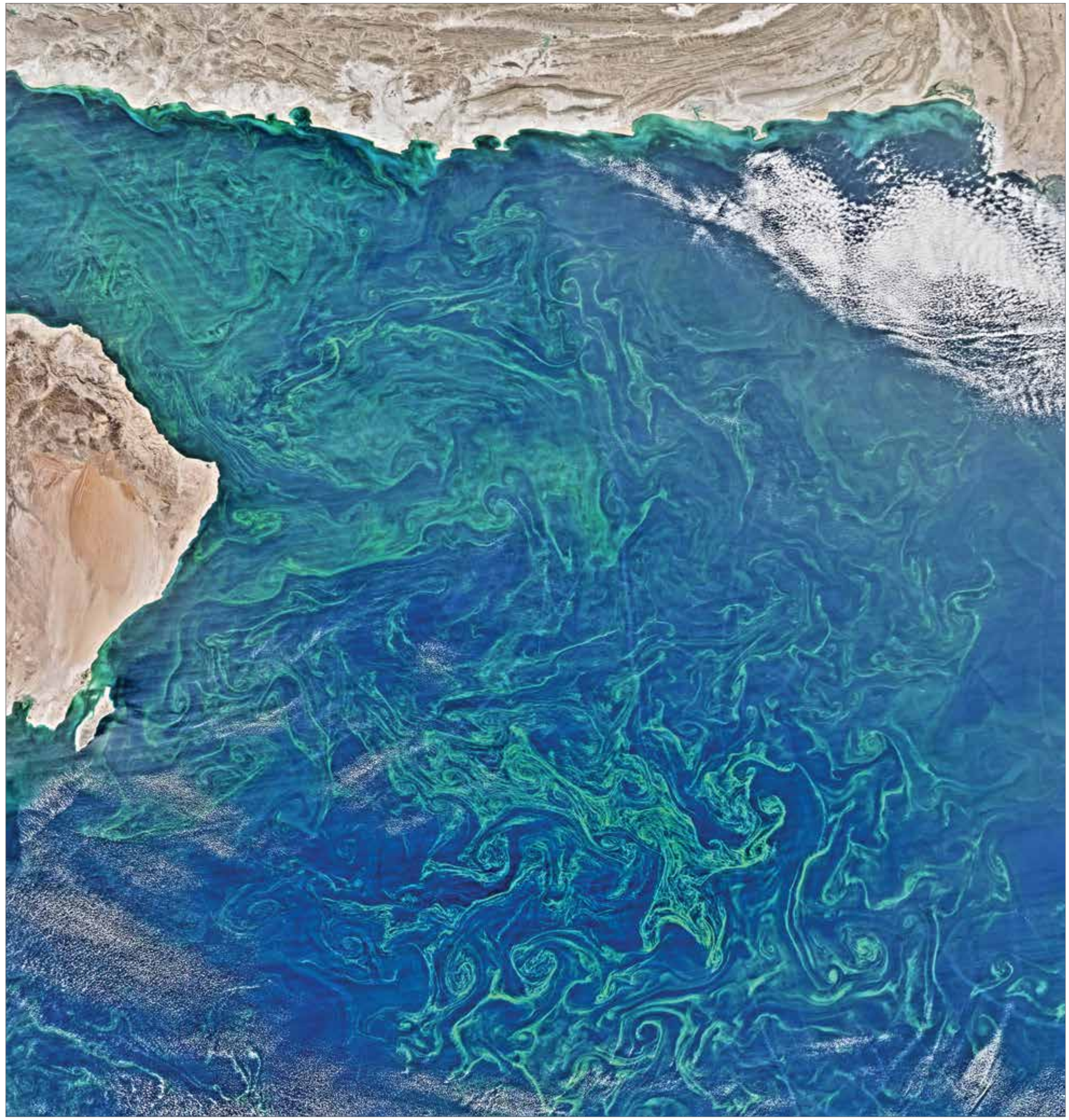
A bloom of *Noctiluca scintillans* turns water into green slush off the coast of Oman. (Courtesy K. Al-Hashmi) cyanobacteria, or coccolithophores. Whatever it was, Goes was intrigued. “Why was this organism appearing in such large quantities?” he said. “And why was it happening in the Arabian Sea?”

Much ado about algae

Algae range from minute organisms to billowy, underwater forests of kelp. But in the algal pecking order, size is not king. One-celled algae, known as phytoplankton, form the base of the ocean’s food chain. Minute cyanobacteria and coccolithophores drift on the ocean’s sunlit surface, converting carbon dioxide (CO_2) and water into high-energy compounds through photosynthesis. Larger phytoplankton like diatoms and dinoflagellates photosynthesize too and feed on nutrients floating nearby. These phytoplankton are gobbled up by small sea animals, or zooplankton, which are in turn eaten by larger fish and sea creatures.

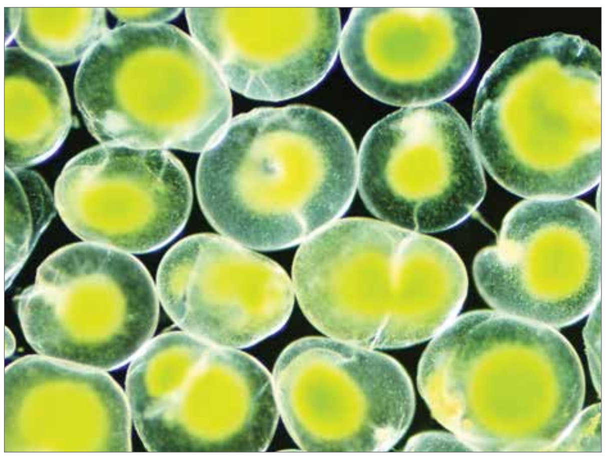
In a bigger role, phytoplankton produce half of Earth’s oxygen. They also suck CO_2 from the atmosphere and sequester it into the ocean depths when they die and sink. Annually, phytoplankton absorb 20 percent more carbon than the world’s forests. A small change in phytoplankton growth can affect the global carbon cycle.

Scientists are particularly interested in phytoplankton blooms that grow out of control. Harmful blooms produce toxins that can kill marine animals and poison humans. Goes and biological oceanographer Helga do Rosario Gomes have been studying blooms in the Arabian Sea, a pirate-infested stretch of water northwest of the Indian Ocean bound by the Horn of Africa on the west, Pakistan in the north, and India in the east. They monitor these using data from the Moderate Resolution Imaging Spectroradiometer (MODIS), a satellite sensor that detects changes



Filaments of phytoplankton twist and curl in the Arabian Sea near the coasts of Oman, Iran, and Pakistan. This February 14, 2015 image was acquired by the Moderate Resolution Imaging Spectroradiometer (MODIS) flying on the NASA Aqua satellite. (Courtesy N. Kuring/NASA Ocean Color Web)

A researcher collects a sample of seawater from a *Noctiluca scintillans* bloom in the northern Arabian Sea. (Courtesy J. Goes)



Noctiluca scintillans, a species of one-celled phytoplankton, are shown in this magnified image. Unlike most phytoplankton, *Noctiluca* are not capable of photosynthesis. They survive by trapping smaller phytoplankton with their whip-like flagellum and flushing them into their gullets. Otherwise, they grab free energy from millions of green phytoplankton living within their cell walls. (Courtesy K. Al-Hashmi)

in the green pigment chlorophyll, present in all plants and essential in photosynthesis.

In the summer of 2003, satellites detected that the sea was crazy with photosynthetic action. "The Arabian Sea's productivity was rapidly increasing," Goes said. The researchers found that intense southwest monsoon winds caused the summer uptick in phytoplankton.

Shrinking snowcaps in the Himalaya caused the Indian subcontinent to become warmer than usual in the summer. This formed an intense low-pressure area over the subcontinent, which sucked in a stronger southwest wind from the Arabian Sea. These winds then generated strong upwelling near the coasts of Yemen and Oman, drawing colder, nutrient-rich water from the depths to the surface. The influx of nutrients overfed phytoplankton, causing populations to explode.

Winter was another story. "The Himalayan snowcap was shrinking and winter winds were also warmer and more humid," Gomes said. "We thought winter convective mixing should have been decreasing along with phytoplankton populations." But satellite data showed these conditions had the opposite effect on phytoplankton. Something else was causing the burgeoning winter blooms.

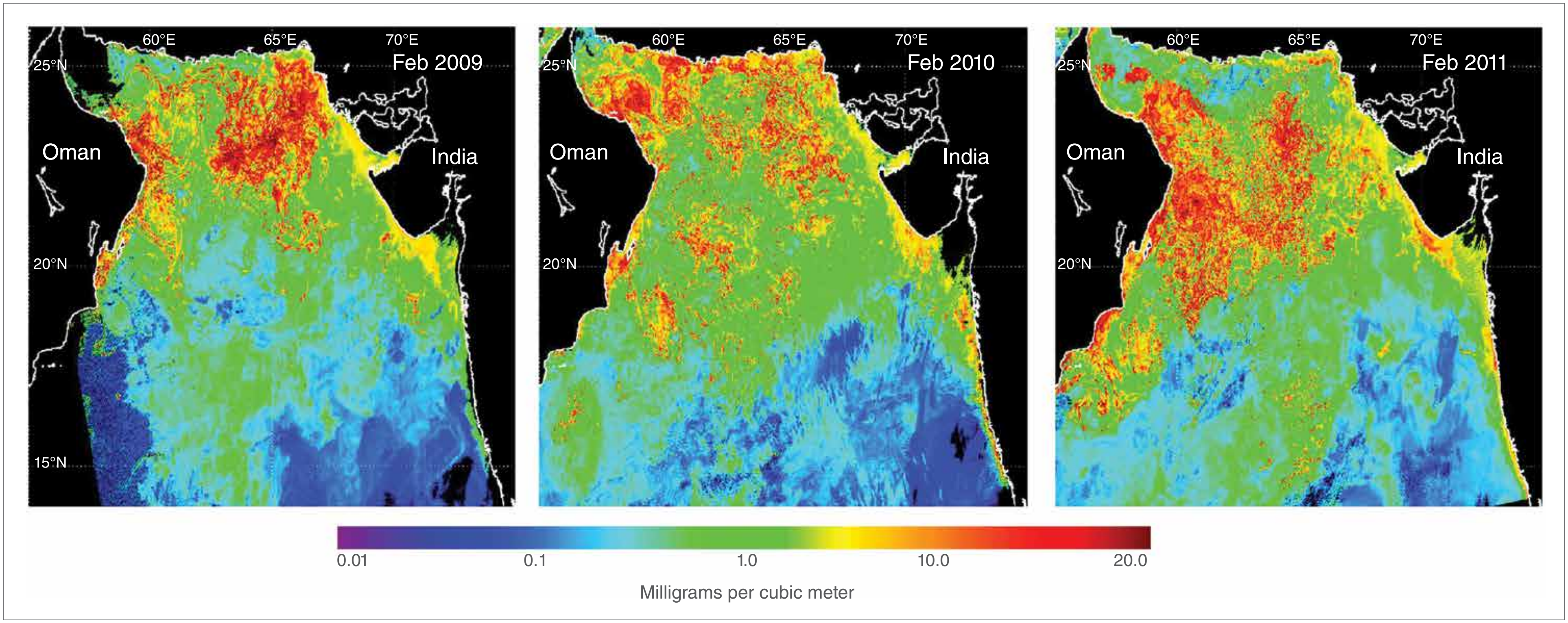
An ominous switch

Beginning in 2009, Goes and Gomes spent three winters on the research vessel *Sagar Sampada*, sailing off the coast of Goa transecting through blooms in the northern Arabian Sea. The satellites were indeed seeing *Noctiluca*, the green kind that lives in tropical waters. Red *Noctiluca* lives in temperate waters. The researchers monitored satellite data, collected bloom samples, and performed shipboard experiments, which led to more questions than answers.

Goes and Gomes collaborated with NASA oceanographer Jeremy Werdell on an algorithm to detect green *Noctiluca* blooms in MODIS data. "Since they were first detected in the early 2000s, blooms of the green *Noctiluca* now occur every year with predictable regularity from January to March," Gomes said. According to historical records and other research missions, diatoms dominated the Arabian Sea before 2000. Khalid Al-Hashmi, a researcher at Oman's Sultan Qaboos University, said there were sporadic *Noctiluca* sightings in the 1950s and 1980s, but only along India's western coast. Goes said, "Within a decade, *Noctiluca* had totally replaced diatoms at the base of the Arabian Sea's food chain."

This does not bode well for the region's fishermen. Zooplankton have no trouble eating diatoms but cannot eat *Noctiluca* because they are too big. If zooplankton starve and die, larger creatures up the food chain are compromised. Shipboard experiments confirmed that *Noctiluca* were indeed outcompeting the diatoms. "They were short-circuiting the food chain," Goes said. Only jellyfish, sea salps, and turtles can feed on *Noctiluca*, so this trend could upend the Arabian Sea's fishing industries.

The researchers also noticed that blooms coincided with hypoxic seawater, or water low in oxygen. "Big cities in India and the Middle East release lots of sewage water into the Arabian Sea. Nitrogen and phosphorus from agricultural runoff contribute to a decrease in seawater oxygen concentration, causing the spread of hypoxia," Goes said. The researchers checked historical archives again to see past levels. "We saw a trend



These images show February phytoplankton blooms in the Arabian Sea, dominated by *Noctiluca scintillans*, for (a) 2009, (b) 2010, and (c) 2011. Data are in milligrams per cubic meter, and are from the Moderate Resolution Imaging Spectroradiometer (MODIS) on the NASA Aqua satellite. (Courtesy Gomes, H., et al., 2014, *Nature Communications*)

of rapid decreases in oxygen concentration in the last seven years," Goes said. The trend roughly coincided with the switch from diatoms to *Noctiluca*, so they suspected the two were connected. But how?

In the dead zone

In hypoxic waters, slow-moving creatures like crabs and lobsters do not stand a chance. Fish fall unconscious and suffocate. These biological dead zones form when phytoplankton feast on a flush of nutrients and reproduce dramatically. Huge populations of bacteria need oxygen to metabolize the waste as well as the dead phytoplankton sinking from the sea surface. "In the process, they strip the water of oxygen," Goes said. Water circulation is sluggish in the Arabian Sea, so oxygen-starved water does not get replaced as fast as it does in the Pacific or Atlantic Oceans.

But the connection between hypoxia and the phytoplankton switch did not make sense. Diatoms need CO_2, not oxygen, for photosynthesis. *Noctiluca* eat smaller phytoplankton which also only require CO_2. So the researchers took a closer look at how the two organisms behave in hypoxic conditions.

In the ship lab, the researchers transferred *Noctiluca* and its diatom competitors into air-tight bottles of oxygen-starved seawater. They looked at how well the organisms converted CO_2 to energy—a way to measure productivity. *Noctiluca*'s rate rose by 300 percent, while the rate of the diatoms' fell by nearly as much. "*Noctiluca* just did better," Gomes said. "It started growing faster." They also found that *Noctiluca* grew faster in light than in the dark, thanks to millions of sun-loving endosymbionts living within its cell walls.

The endosymbionts seem key to *Noctiluca*'s advantage. These are smaller phytoplankton that convert CO_2 to energy by photosynthesis and pass the energy on to *Noctiluca* like rent. It is

Colorful parrot fish lie with other species on a fishmonger's mat in Muscat, Oman. (Courtesy T. Schmurr)

additional food for *Noctiluca*, which are not capable of photosynthesis and usually feed on other phytoplankton, zooplankton eggs, and decaying organic particles in seawater.

"This endosymbiont evolved 1. 2 billion years ago in an atmosphere that was rich in CO_2 and low in oxygen," Goes said. "We think that it conserved this gene for photosynthesizing in a low-oxygen environment and now that hypoxic waters are coming to the surface, these genes are overexpressing themselves and allowing the Rubisco enzyme to function better."

The chief architect

Rubisco is an ancient enzyme present in all plants and responsible for the conversion of CO_2 into organic compounds. Old sedimentary rocks in Zimbabwe and Canada place its appearance 2.9 billion years ago when Earth was a much different place. Continents were still forming and stabilizing, and air was mostly CO_2. There were no plants or animals, just bacteria-like life and multicellular organisms. Somehow, Rubisco enabled Precambrian phytoplankton to capture CO_2 from the atmosphere and produce oxygen. The change was radical. Scientists have called Rubisco "the chief architect of the atmosphere."

Goes and Gomes have a hunch that the Arabian Sea's low-oxygen waters are somehow causing the Rubisco within the endosymbiont to perform better, resulting in more energy for the *Noctiluca*.

James V. Moroney, a molecular biologist at the Louisiana State University, thinks it's possible. "Oxygen competes with CO_2 in Rubisco. If you lower oxygen, that could enhance carbon fixation in the endosymbiont," he said. Diatoms, on the other hand, have the ability to concentrate CO_2 around Rubisco to make it perform better. "Dropping the oxygen a bit shouldn't make much difference to the diatoms," he said.

Moroney does caution that not enough is known about *Noctiluca* nor its endosymbiont to draw any conclusions. Senjie Lin, an expert in phytoplankton genomics at the University of Connecticut, agrees. "Rubisco may very likely play a role here," Lin said. "But the situation may be more complex than we understand right now." Lin is analyzing the endosymbiont's RNA to see whether a gene that codes for the Rubisco enzyme is indeed responding to hypoxic conditions in the Arabian Sea.

Though the Rubisco hypothesis is fascinating, Goes and Gomes are also checking other leads. *Noctiluca* could be responding to nutrients brought by dust plumes from Iran, Afghanistan, and Pakistan. And because hypoxic waters tend to be acidic, the researchers are looking at the sea's pH levels, wondering whether acidification is also promoting the growth of *Noctiluca*.

Goes, Gomes, and their colleagues continue to chase more questions. Meanwhile, cities and populations around the Arabian Sea expand. What will the rise of *Noctiluca* bring? Will it leave a sparkling dead sea, or will it shift the food web, restructuring the ecological design of these waters?

To access this article online, please visit https://earthdata.nasa.gov/sensing-our-planet/winter-blooms-in-the-arabian-sea.

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For more information

NASA Ocean Biology Distributed Active Archive Center (OB.DAAC)
http://oceancolor.gsfc.nasa.gov

NASA Socioeconomic Data and Applications Center (SEDAC)
http://sedac.ciesin.columbia.edu

NASA Moderate Resolution Imaging Spectroradiometer (MODIS)
http://modis.gsfc.nasa.gov

Goes-Gomes Lab at Columbia University's Lamont Doherty Earth Observatory
http://helgagomes.com

About the data

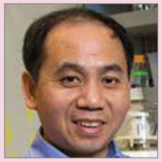
Satellite	Aqua	
Sensor	Moderate Resolution Imaging Spectroradiometer (MODIS)	
Data sets	Level 2 Ocean Color Web	Gridded Population of the World
Resolution	2 kilometers	2.5 arc-minute ¼ degree, ½ degree, 1 degree
Parameters	Chlorophyll a concentration	Population density
DAACs	NASA Ocean Biology Distributed Active Archive Center (OB.DAAC)	NASA Socioeconomic Data and Applications Center (SEDAC)

About the scientists

Khalid Al-Hashmi is a researcher at Sultan Qaboos University in Muscat, Oman. His research focuses on phytoplankton ecology and biological oceanography. The Research Council of Oman supported his research. Read more at http://goo.gl/phiAr3. (Photograph courtesy K. A. S. Al-Hashmi)

Joaquim Goes is a research professor at the Lamont-Doherty Earth Observatory at Columbia University in Palisades, New York. His research focuses on the structure and function of plankton ecosystems and their response to physical forcing, and forecasting the responses of marine ecosystems to global change. NASA and the National Science Foundation supported his research. Read more at http://goo.gl/zDpvOq. (Photograph courtesy J. Goes)

Helga do Rosario Gomes is a research scientist at the Lamont-Doherty Earth Observatory at Columbia University in Palisades, New York. Her research focuses on remote sensing of climate change and its effect on ocean biogeochemistry, and how coastal megacities change the biodiversity of the Arabian Sea. NASA and the National Science Foundation supported her research. Read more at http://goo.gl/fYljWj. (Photograph courtesy H. d. R. Gomes)



Senjie Lin is a professor of marine sciences at the University of Connecticut. His research focuses on phytoplankton molecular ecology and functional genomics. The National Science Foundation and China's National Natural Science Foundation supported his research. Read more at http://goo.gl/CILXc6. (Photograph courtesy D. Buttrey/University of Connecticut)

James V. Moroney is a professor of biological sciences at Louisiana State University. His research interests focus on how plants and algae acquire the carbon dioxide they need for photosynthesis. The National Science Foundation supported his research. Read more at http://goo.gl/EMivzG. (Photograph courtesy J. V. Moroney)