An upended ecosystem in the Arabian Sea

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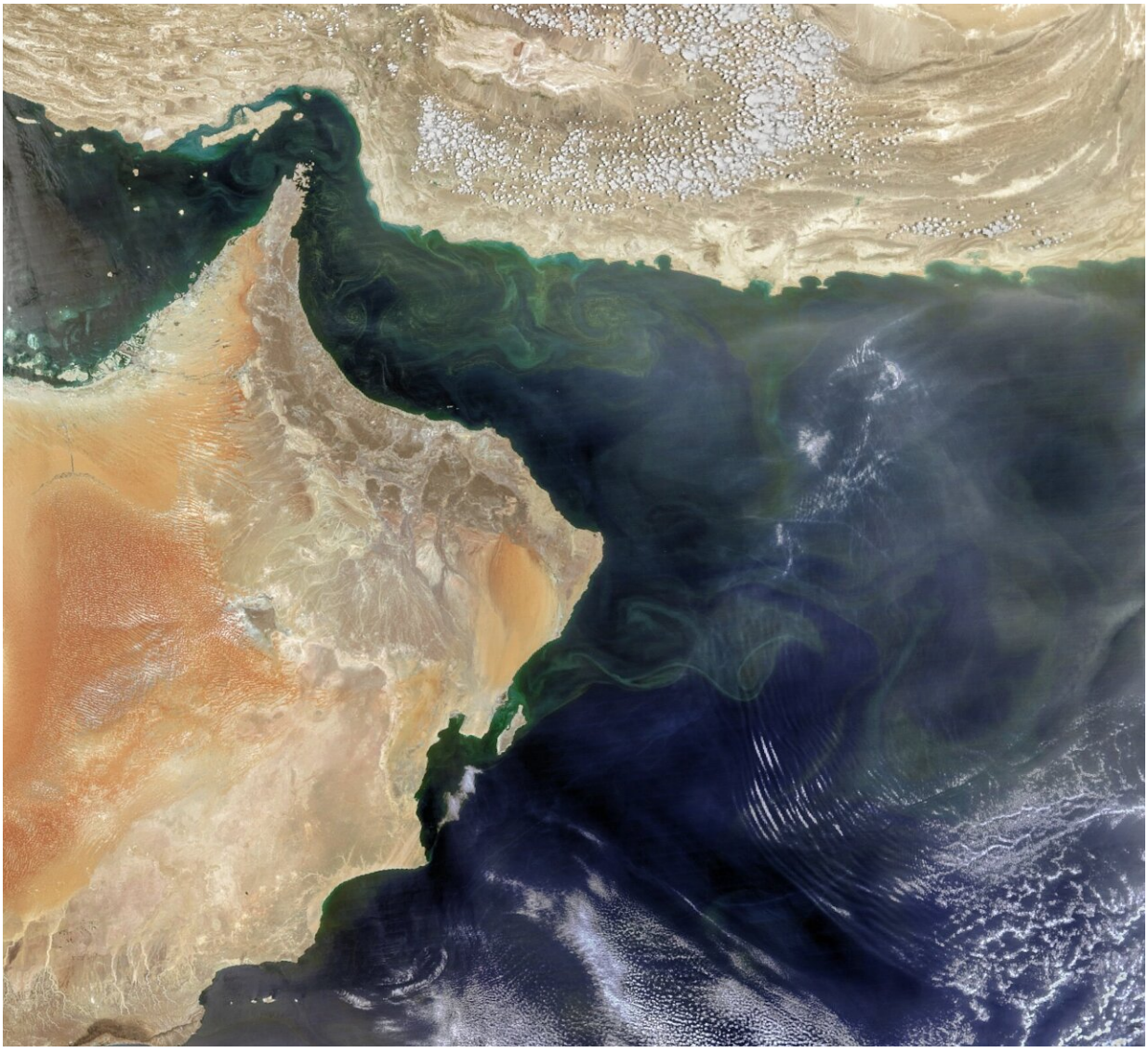


Credit: NASA Earth Observatory

How can snow cover on the Himalayas influence the species that thrive in the Arabian Sea? How could changes in wind speed and humidity lead to food and national security concerns a thousand kilometers away? Joaquim Goes, Helga do Rosario Gomes, and colleagues on two continents have spent the past two decades trying to decode these riddles.

The story begins in the early 2000s, around the time that NASA's Aqua satellite was launched. Goes, a specialist in remote sensing of the ocean, was examining data from SeaWiFS and Aqua. He was focused on chlorophyll-a, a pigment used by ocean phytoplankton (and plants worldwide) to harness sunlight and turn it into food energy. He was focusing on observations of phytoplankton populations in the Arabian Sea during the summer monsoon, but by chance he looked at winter data. There was far more chlorophyll-a than anyone should reasonably expect.

At first Goes thought it was an error. But over the next decade, reports of increasing algae and decreasing fish catches came in from colleagues in southern Asia. Goes and Gomes made several sea-going expeditions and saw it for themselves: The Arabian Sea was teeming with Noctiluca scintillans, an organism that was scarcely reported in the region during previous winters.

The image above shows a bloom of Noctiluca scintillans in 2019, as observed by the NOAA-NASA Suomi NPP satellite. The floating, microscopic organisms are dinoflagellates living in a symbiotic relationship with green algal cells. Like ocean phytoplankton, Noctiluca scintillans can multiply rapidly under the right conditions. (Noctiluca often thrive in low-oxygen "hypoxic" waters.) Drifting with currents, they aggregate into vast masses near the surface. In the process, they can deplete oxygen in the sea, compete with other phytoplankton for nutrients or consume them for food, and suffocate small zooplankton predators in hypoxic "dead zones."

Credit: NASA Earth Observatory

"The changes we have seen in the Arabian Sea ecosystem are among the fastest of any oceanic water body on our planet," said Goes, a scientist at Lamont-Doherty Earth Observatory. "The habitat of the sea is changing, and that is short-circuiting the food chain."

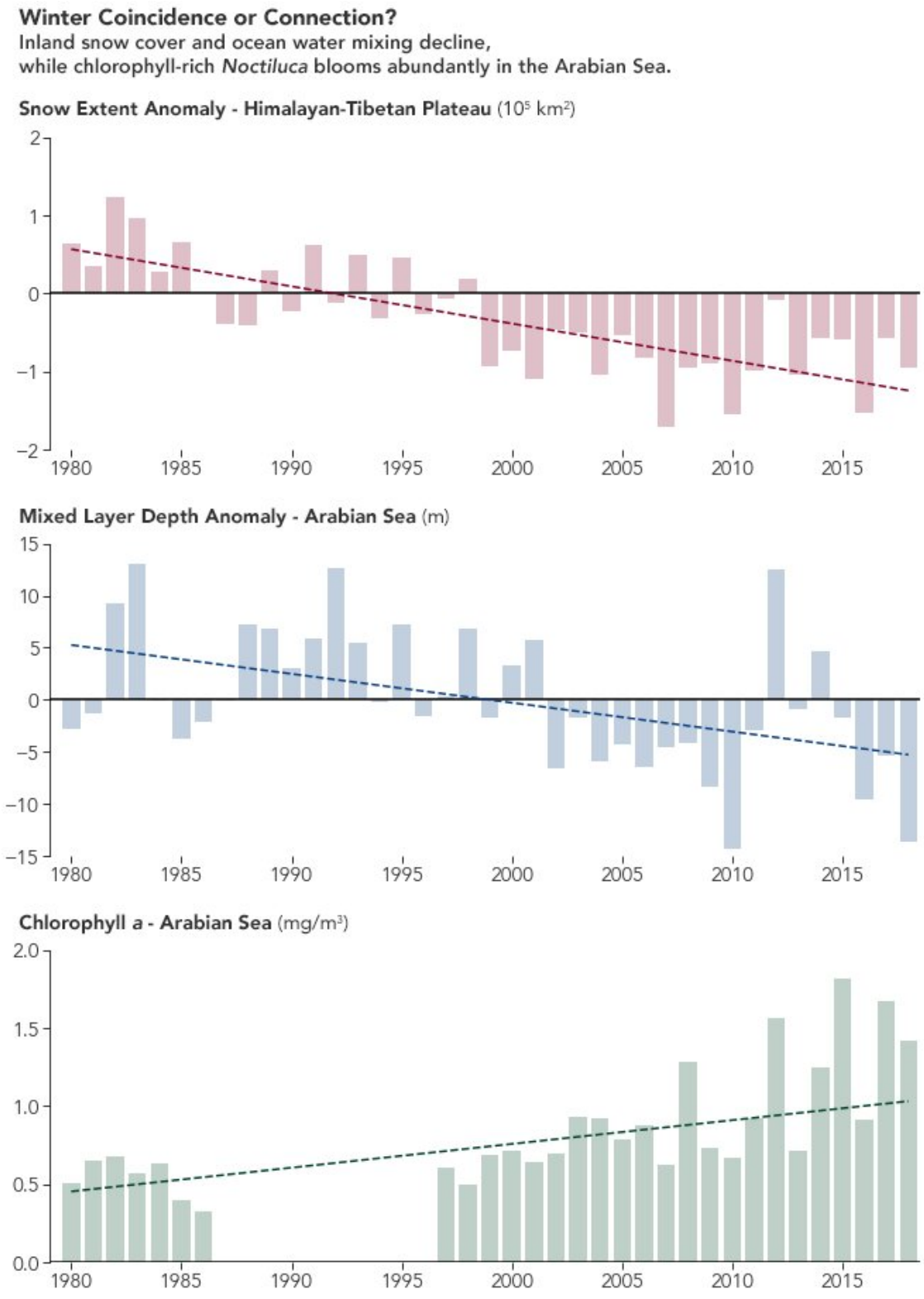
How and why Noctiluca has blossomed in the Arabian Sea is a complicated story of interconnections between Earth systems and the unexpected ripples that propagate from global warming.

Across human history, the Arabian Sea has been strongly influenced by monsoon winds that reverse direction seasonally and change the direction of ocean currents. In winters past, air temperatures over the Himalayan-Tibetan Plateau and southern Asia would drop significantly and cause dry, northeasterly winds to blow out over the Arabian Sea. In turn, the cooling of the surface waters and changes in density would propagate through the water column, moving the pycnocline—where water density changes due to salinity and/or temperature—up and down. The depth of this ocean layer affects how nutrients well up from the depths and fuel the growth of phytoplankton.

These winter shifts in currents and nutrient availability once fueled blooms of diatoms, another type of phytoplankton. The diatoms were a key link in an ocean food chain that fed copepods and finfish through the winter and, ultimately, humans who caught those fish.

But with global warming in recent decades, less snow cover has been falling and accumulating on the Himalayan-Tibetan Plateau and more snow and ice has been melting. Temperatures over the highlands and lowlands have been rising, as has the humidity. In the past two decades, the winter winds blowing over the Arabian Sea have become warmer, calmer, and more humid. As a result, the seas churn less and there are fewer nutrients for diatoms and most other phytoplankton.

"With calmer and warmer winds and waters, there is less ventilation and mixing," said Helga do Rosario Gomes, a biological oceanographer, also at Lamont-Doherty. "This leads to more stratification and less nitrate enrichment from below. In some cases, it is causing hypoxia."



Credit: NASA Earth Observatory

Those changes have been pretty much perfect for Noctiluca scintillans. Unlike diatoms, Noctiluca can thrive when there are fewer dissolved nutrients in the water. The plots above show the coincident changes from 1980 to 2018 in the extent of snow cover over the Himalayan-Tibetan Plateau, the depth of the mixed layer in the Arabian Sea in winter, and the concentration of chlorophyll-a (an indicator of phytoplankton). The "anomaly" plots show how much each year was above or below the long-term mean for each variable. Snow extent and the depth of the mixed layer have been steadily declining, while wintertime blooms have been increasing.

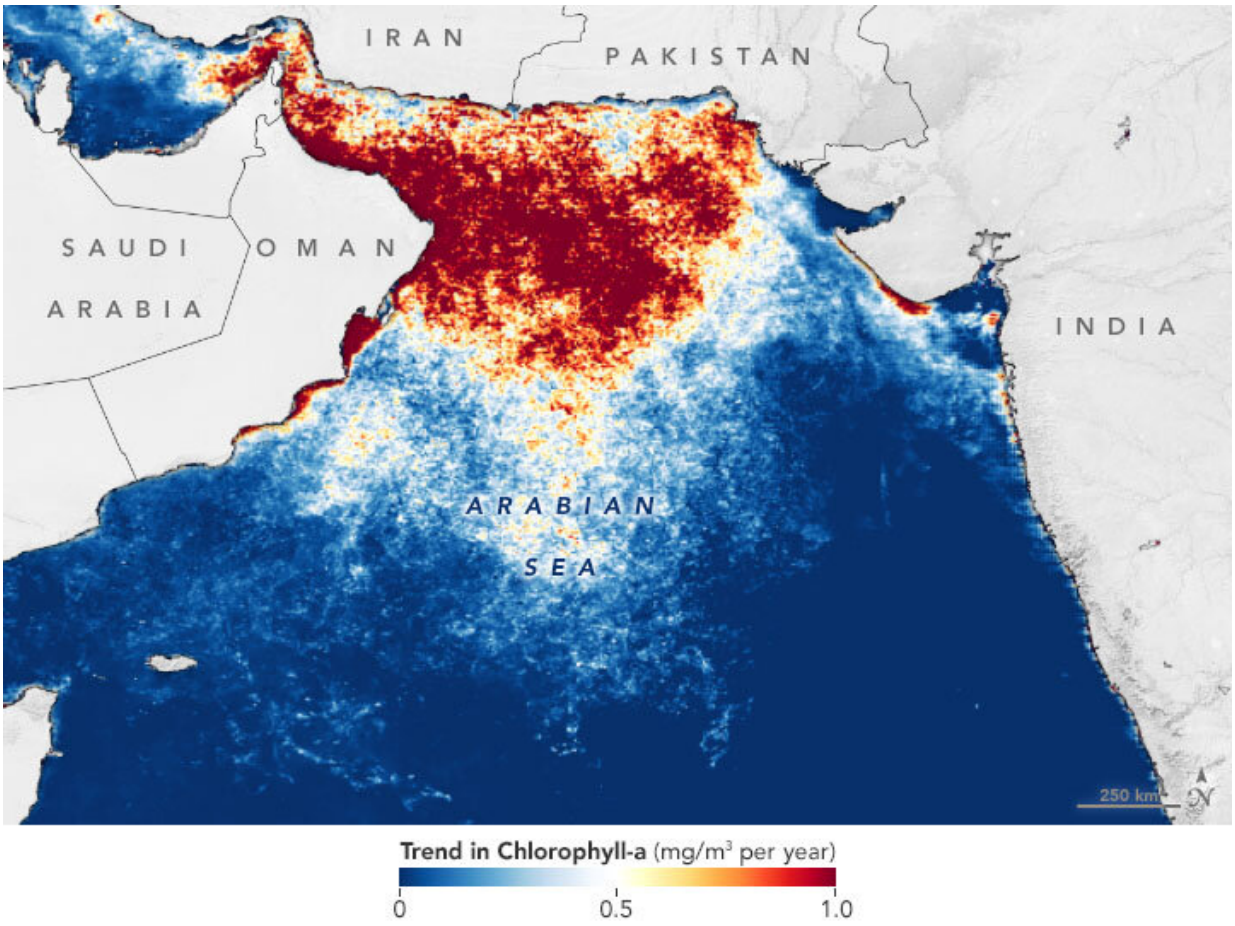
"The changes observed in the Arabian Sea are an example of potential ecosystem changes that are induced by climate change," said Laura Lorenzoni, ocean biology and biogeochemistry program scientist for NASA. "As Earth warms, we can expect greater stratification in the ocean and the migration of species poleward. There will also be greater chances of harmful algal blooms and of some more resilient species outcompeting others and shifting the entire ecosystem structure."

Scientists have modeled and speculated for years that global warming could change the snow and ice cover on the Himalayas and the Tibetan Plateau and that the effects might ripple across the sea. The belief was that the Arabian Sea would become less productive from December to March. Instead, it has become more productive, but for an entirely different set of creatures.

"There are far less diatoms now, and so there is a clear loss of biodiversity," said Gomes. "There used to be more copepods, sardines, kingfish, mackerel, and pelagic fish." The plankton and diatoms have been replaced by mats of Noctiluca scintillans and an over-abundance of jellyfish and salps. The finfish have been replaced by turtles, squid, and

animals that can survive in lower oxygen environments.

In a 2020 research paper, Goes and Gomes used ocean color data from NASA and snow and ice cover data from the National Snow and Ice Data Center to piece the puzzle together. They found that winter chlorophyll-a in the Arabian Sea has been increasing steadily since the 1990s—as much as four times higher in some winters. Chlorophyll-a is a key pigment in ocean phytoplankton, including Noctiluca scintillans. The map above shows the trend—mostly increasing—in the Arabian Sea from 1996 to 2018.



1996 - 2018. Credit: NASA Earth Observatory

The result is trouble for fisheries, particularly in a region with a lot of artisinal and subsistence fishing. "We are passing a tipping point," said Goes. "The food chain has been turned upside down."

The changes are trouble for the people of the Middle East, eastern Africa, and southern Asia. An estimated 150 million people around the region rely on fishing for food and economic development. Yet the surplus of jellyfish and salps and the decrease in diatoms has depleted the food supply for edible fish."

"There will be cascading effects that will probably affect food availability for several countries in the region," Goes said. "Noctiluca blooms, jellyfish, and salps are also posing huge challenges to desalination plants along the coast that supply freshwater to coastal Oman." Masses of jellyfish have been known to clog seawater intake pipes.

And the change to Noctiluca-dominated waters has an unusual ripple effect on national security. Noctiluca scintillans are bioluminescent: they glow when stimulated and this is especially visible at night. This trait can be used to track the movements of ships that churn up the plankton as they cruise. Sailors and pilots have been following such sparkling tracks for decades.

"There are many examples of phytoplankton running amok around the planet," said Norman Kuring, a scientist in NASA's Ocean Biology Group. "The Baltic Sea has a new summertime normal of toxic cyanobacteria blooms. Green algae routinely clog the waters around China's Shandong Peninsula. Sargassum is becoming a real headache in the Caribbean. Lakes in the United States and globally are becoming increasingly eutrophic. There are troubling suggestions by respected scientists that our oceans may be headed towards a hypoxic, bacteria-dominated future."

More information: Joaquim I. Goes et al, Ecosystem state change in the Arabian Sea fuelled by the recent loss of snow over the Himalayan-Tibetan Plateau region, *Scientific Reports* (2020). DOI: 10.1038/s41598-020-64360-2

Provided by NASA