Study shows how historic red tide event of 2020 was fueled by plankton super swimmers

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Bioluminescent waves off Scripps Pier on April 24, 2020, during a major red tide event. Credit: Michael Latz

A major red tide event occurred in waters off Southern California in the spring of 2020, resulting in dazzling displays of bioluminescence along the coast. The spectacle was caused by exceedingly high densities of

Lingulodinium polyedra (L. polyedra), a plankton species renowned for its ability to emit a neon blue glow. While the red tide captured the public's attention and made global headlines, the event was also a harmful algal bloom.

Toxins were detected at the height of the bloom that had the potential to harm marine life, and dissolved oxygen levels dropped to near-zero as the extreme biomass of the red tide decomposed. This lack of oxygen led to fish die-offs and other destructive impacts on local ecosystems.

Now, for the first time, a study led by scientists at UC San Diego's Scripps Institution of Oceanography and Jacobs School of Engineering has pinpointed how this plankton species—a dinoflagellate—was able to create such an exceptionally dense bloom. The answer lies in dinoflagellates' remarkable ability to swim, which lends them a competitive advantage over other species of phytoplankton. According to the authors, this swimming ability can lead to the formation of dense blooms, including those of the bioluminescent variety.

"The idea that vertical swimming gives dinoflagellates a competitive advantage actually goes back more than half a century, but only now do we have the technology to conclusively prove it in the field," said oceanographer Drew Lucas, senior author of the paper and an associate professor at Scripps Oceanography and the Department of Mechanical and Aerospace Engineering at UC San Diego.

Lucas and former graduate student Bofu Zheng led the work alongside several colleagues in the midst of the red tide event in April and May 2020. The researchers seized the opportunity to deploy sophisticated ocean instruments off the coast of San Diego, resulting in unprecedented measurements. The team's findings were published in the Aug. 28 issue of the *Proceedings of the National Academy of Sciences*, showcased as the cover story.

The dinoflagellates—L. polyedra specifically—were shown to be highly mobile, swimming upward during the day to photosynthesize and downward at night to access a deep nutrient pool. This resulted in the intensified ruddy coloration of the water at the surface, hence the term "red tide," seen most prominently in the afternoon. A large population of the dinoflagellates was documented making the downward journey at night, though a portion remained near the surface waters, leading to nighttime displays of bioluminescence. The authors found that this vertical migration is what allowed the dinoflagellates to outgrow their non-mobile competitors, including other species of phytoplankton.

The study validates a 50-year-old hypothesis originally presented by Scripps Oceanography biological oceanographer Richard "Dick" Eppley. He and colleagues posited that the vertical migration of dinoflagellates was linked to harmful algal blooms, which have been documented off Southern California for at least 120 years. Extensive lab research was conducted to support this idea, but it had never been tested in the field until the 2020 event.

As in many dinoflagellate species, L. polyedra is endowed with a pair of flagella—whip-like appendages that propel the single-celled organism through the water. In addition to its ability to swim, L. polyedra is remarkably fast, with a maximum swimming speed of up to 10 body lengths per second for almost 24 hours.

"In the plankton world, they are Michael Phelps," said Lucas, describing the dinoflagellates. "For comparison, fast-burst swimming in species like bluefin tuna or shortfin mako is around 9–10 body lengths per second, but only for very short periods. Their exceptional swimming allows L. polyedra to dive to cold depths where they can take up nutrients, allowing these organisms to really bloom and explode in population."

The team used the Wirewalker—an autonomous, ocean-wave-powered vertical profiling system that was developed at Scripps Oceanography—to continuously measure physical and biochemical conditions from the sea surface to the seafloor, reaching a depth of 100 meters (300 feet).

Powered by wave energy, the instrument moves up and down a mooring line attached to a buoy, while taking measurements of temperature, salinity, depth, sunlight levels, chlorophyll fluorescence, and nitrate concentrations. They also captured near-surface images of the bloom using an Imaging FlowCytobot (IFCB), a robotic microscope installed on an offshore mooring; this site is now part of a larger IFCB network overseen by SCCOOS.

Data and images collected by these instruments validated Eppley's original hypothesis, showing that indeed L. polyedra descended at dusk, reaching a maximum depth of about 30–40 meters (100–130 feet) after 18 to 24 hours of swimming. While in the deep, the dinoflagellates would take up nitrate, which acts as a growth nutrient for plankton, before returning to the surface around noon to photosynthesize during maximum sunlight.

The growth of phytoplankton biomass, or the "bloom," correlated with proportional decreases in nitrate concentrations at depth, linking the important role that swimming phytoplankton have in the development of certain types of red tides. On cloudy days, the subsurface vertical migration was much less apparent, suggesting that the intensity of sunlight is an important trigger for vertical migration.

Lead author Zheng, now a postdoctoral investigator at Woods Hole Oceanographic Institution (WHOI), was impressed by the many advanced functions of the dinoflagellates, which are comparable in size to the diameter of a human hair.

"These single-celled organisms, namely L. polyedra, are so functionally complex and amazing," said Zheng. "In addition to their swimming speed, which is far beyond human limits, they can coordinate their behavior according to the day-night cycle by migrating down at night and coming back to the ocean surface during the day; they can produce spectacular bioluminescence; they can photosynthesize; they can even prey on organisms that are smaller than them."

The researchers also looked at long-term ocean monitoring data captured by the California Cooperative Oceanic Fisheries Investigations (CalCOFI), and long-term mooring data maintained by the Ocean Time-Series Group at Scripps Oceanography to see other consequences from the bloom. Looking at more than 70 years of climate data, the results showed that the bloom created physical and chemical conditions in the water column that deviated from the norm, showing the potential for massive blooms to alter characteristics of the coastal ocean.

Study co-author and SCCOOS director Clarissa Anderson said this research stands out for its use of novel ocean technologies, which allowed for unparalleled measurements of how phytoplankton respond to small-scale changes in the coastal ocean, as well as calculations of nutrient uptake by dinoflagellates at such fine scales. She also noted the importance of long-term observations as being key to any future efforts to better understand harmful algal blooms.

"The more we understand complex mechanisms that allow a particular species or population of plankton to thrive and persist, the better we can predict runaway events like the 2020 red tide that lasted much longer than theory might dictate," said Anderson, who is also a biological oceanographer at Scripps Oceanography. "With longer time series of rapid change in coastal nutrient delivery, circulation, light regimes, and algal toxins, we could build more accurate dynamical models for predicting plankton blooms, including those that turn harmful."

According to the authors, linking phytoplankton behavior and changes in the coastal environment may help researchers better understand the conditions that cause and that arise from harmful algal blooms, aiding in predicting blooms and mitigating their effects.

More information: Zheng, Bofu et al, Dinoflagellate vertical migration fuels an intense red tide, *Proceedings of the National Academy of Sciences* (2023). DOI: 10.1073/pnas.2304590120. doi.org/10.1073/pnas.2304590120

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