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Ripple Marks
The Story Behind the Story

BY CHERYL LYN DYBAS

Moonstruck
A Celebration of Earth's Moon…From Under the Sea

InOMN, it's called: International Observe the Moon Night. InOMN has become an annual event; it takes place this year on September 22, just before the full moon. Members of the InOMN team include scientists, educators, and moon enthusiasts from government agencies, nonprofit organizations, and businesses throughout the United States and around the world.

Earth's moon, say these lunar followers, has influenced human lives since the dawn of time. International Observe the Moon Night is an opportunity for people to celebrate the moon's beauty and share the experience of watching our nearest neighbor in space. Groups from the National Aeronautics and Space Administration's Lunar Science Institute, to Google's Lunar X Prize, to the European Union's Universe Awareness program, which now includes South Africa, are participating.

While thousands of humans are looking skyward, however, another marking of the moon's appearance is taking place—in streams and rivers, and deep in the sea. This edition of Ripple Marks looks at Earth's natural satellite from waters far beneath.

At First- and Third-Quarter Moon, Grab Your Umbrella

InOMNers may be lucky this year: the gathering is scheduled for a moon close to full. Otherwise, the skies might be obscured with rain clouds, found Randall Cerveny and Bohumil Svoma of Arizona State University and Russell Vose of the National Oceanic and Atmospheric Administration's National Climatic Data Center in Asheville, North Carolina.

In a paper published in *Geophysical Research Letters*, the scientists confirmed the old saying that rain follows the full and new moon. Lunar phases, they discovered, influence rainfall patterns and river flow across the United States, echoing age-old beliefs.

Farmers working their lands believed in a dripping moon that led to rain, depending on whether the moon's crescent was tilted up or down.

A wet moon, also called a Cheshire moon, happens when the "horns" of the crescent, or quarter, moon point straight up, away from the horizon. The Cheshire cat's smile results from the relative angles of the moon's orbit around Earth, and Earth's axial tilt compared to the sun.

As winter approaches in the Northern Hemisphere, the moon's path becomes almost vertical to the horizon. Or so it appears to our eyes. At that time, a quarter moon's horns extend upward. The ancients called it a wet moon: the horns are the edges of a bowl that fills with water. As winter passes, the crescent shape shifts or turns, pouring out the water and causing summer rains. After the bowl empties, it rights itself and dries out.

Is the idea starstruck?

Studies of a link between weather and the moon began to appear in the 1960s; they seemed to lend credence to lunar folklore. Some researchers detected peaks in rainfall at the time of the crescent moon.

Cerveny and colleagues took another look at the question when they happened across a connection between moon phases and stream runoff. The scientists used more than a century of data from stream sites across the United States. They gathered information from almost 11,000 US Geological Survey stations on inland streams; runoff measurements were taken as long ago as 1900. After calculating the moon's phase for each data point, the researchers discovered an increase in stream flow around the quarter moon.

That alone wasn't enough to prove that the moon directly affects rainfall. A previous study had suggested that tides could be raising the water table and leading to higher stream levels.

To demonstrate that there is indeed a silver thread between moon phase and rainfall, Cerveny turned to the US Historical Climatology Network, a database with daily precipitation information for more than 1,200 locations from as far back as 1895.

The adage proved true: rainfall increases in the days around the quarter moon.

"Our results imply that inland precipitation is influenced by lunar tides, which ultimately force the runoff evident in stream gauges," says Cerveny. "These lunar periodicities in rainfall and stream flow may affect flooding and hydro-power generation."

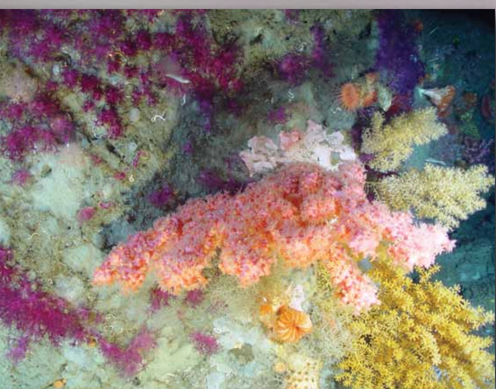
Knowledge of the relationship between moon phase and rainfall may give weather forecasters a better chance of predicting floods. "Flooding might be more likely at the crescent moon than at the full or new moon," says Cerveny.

Although there's a statistical link between the lunar cycle and stream flow, the reason remains a mystery.

The moon's orbit could distort the magnetosphere, a region of ionized particles surrounding Earth's magnetic field. That might allow for more particles from space to reach our atmosphere, where they could spark rain showers when they collide with clouds.

Or the lunar orbit may somehow increase the amount of dust from meteors reaching Earth, which might also foster rainfall when it hits clouds. Finally, the moon as it passes overhead could create a pressure bulge that would affect storm systems, Cerveny's pick of the current hypotheses.

All we know, he says, is that the idea of synchronicity between the moon and rainfall isn't lunacy. The crescent moon's Cheshire grin, it turns out, is a good reason for farmers to smile. Rain for their crops will soon fall.



Top to bottom: Spawning of the deepwater sea anemone *Allantactis parasitica* (*Photo credit: Mercier Lab*). A garden of deepwater soft corals (*Photo credit: Fisheries and Oceans Canada*). A large specimen of bubblegum coral *Paragorgia* (*Photo credit: Fisheries and Oceans Canada*). Release of a planula larva by the deep-water coral *Drifa* sp. (*Photo credit: Mercier Lab*)

Moon Phases
Visible In the Deep Sea…?

The moon's phase may affect rainfall and stream flow on Earth's surface, but could it also drive processes far, far below, in the depths of the sea?

Marine scientist Annie Mercier of Memorial University in St. John's, Newfoundland, and colleagues say the answer is yes. They found evidence of lunar periodicity in the reproduction of six deep-sea species. Release of gametes in free-spawning species, and of larvae in brooding species, peaked around the new and full moons respectively, says Mercier.

But how? Can a life form in the abyss "see" the moon?

"The exact nature of the lunar period and its significance in the deep sea remain elusive," states Mercier in a paper published in the *Journal of Biological Rhythms* in February 2011. Co-authors are Zhao Sun and Sandrine Baillon of Memorial University, and Jean-Francois Hamel of the Society for the Exploration and Valuing of the Environment in Portugal Cove-St. Philips, Newfoundland.

Possible explanations, say the scientists, include fluxes in particulate matter floating from the sea's surface to its depths, or cyclic currents—or the ability of deep-sea species to directly perceive the moon's light.

In near-surface environments bathed in moonlight or exposed to the tides (and hence the moon), biological rhythms synchronized with lunar phases have long been known. Lunar reproduction cycles are found in reef corals and fishes. Spawning in many shallow-water tropical and subtropical echinoderms, mollusks, and crustaceans is tuned to the moon's phases.

Deep-sea environments, however, which make up more than 66% of Earth's surface, "are virtually overlooked," says Mercier, "given the difficulties of studying deep-sea organisms in situ and in the laboratory."

With The Deep's dim light and weak tides, "the existence of lunar periodicity hadn't been thought about," she says.

Nonetheless, in the sea urchin *Phormosoma placenta*, spawning in both sexes coincides with the new moon. The deep-sea coral *Gersemia fruticosa* releases its peak number of planulae, or free-swimming larvae, at full moon. Another deep-sea coral, *Drifa*, concentrates its efforts at the waning moon phase. *Flabellum angulare*, a third deep-sea coral, is a new-moon spawner, while the deep-sea anemone *Allantactis parasitica* spawns at the time of the full moon.

There's a scattering of other reports on deep-sea synchronicities with the moon. Peak deposition rates of planktonic foraminifera at 2,700 m down, for example, happen 12.5 days after each full moon. Changes in melatonin release in deep-sea fishes follow tidal oscillations. And growth bands in deep-sea gorgonians linked with lunar periods may result from an influx of sediments that's timed with moon phases.

How widespread lunar reproductive cycles are in the ocean's depths, says Mercier, "is a big question. Moon-related cycles may offer a means of coordinating breeding activities, critical for species that cue to spawning going on around them." Because breeding often coincides with the brightest or darkest nights of the lunar cycle, she says, "timing it to conceal one's offspring may be what's really going on."

In her study, internally brooding corals released larvae at the full moon or during the waning phase; free-spawning species timed gamete release with the new moon. "While these patterns apparently contradict the full-moon mass events in broadcast-spawning shallow-water corals," says Mercier, "they need to be looked at in light of the environmental and predatory pressures of coastal versus deep-sea habitats."

For now, however, what happens in The Deep stays in The Deep.

Sunset Sonata

Corals, The Moon, and "The Blue Pulse"

Shallow-dwelling corals also spawn on cue; they, too, may be timing the event to the phase of the moon. Coral reefs release eggs and sperm all at once for one, or at most a few, consecutive summer nights after sunset on the evenings after a full moon.

What's the signal that says "go"?

Scientist Alison Sweeney of the University of Pennsylvania wondered whether corals' spawning events might happen not only on a certain day, but at a certain time. Could they be synchronized with fluctuations in the light spectrum at twilight?

"There are dramatic—and physiologically relevant—changes in both skylight color and intensity during evening twilight," says Sweeney. "The path length of direct sunlight through the atmosphere increases, and skylight becomes increasingly blue-shifted."

The twilight spectrum is deep blue before the moon rises, but after moonrise becomes more red. During the first half of the lunar month, the moon is already in the sky at sunset and the twilight spectrum is therefore red-shifted. But at full moon, when the moon is just below the horizon at sunset, there's a brief period before moonrise when the spectrum of skylight is a deep twilight blue.

Sweeney thought that corals and other reef species could be using this "pure twilight" to synchronize spawning, but only if the spectrum of light in the ocean followed the same pattern as that of skylight.

By measuring the light spectrum in the sea near a tropical coral reef over a six-day period around the full moon, she found that the twilight spectrum shifted depending on whether the moon had risen. A team of researchers measured twilight irradiance on August 3, 4, 6, 7, 8, and 9, 2009, and observed a "significant effect of lunar elevation on underwater irradiance on the evenings around the full moon," says Sweeney. "The twilight spectrum was deep blue just after sunset, but gained red wavelengths as soon as the moon rose. The length of the blue twilight period increased each evening as the moon rose later and later."

She calls it "the blue pulse."

The scientists also monitored elkhorn coral spawning. The corals spawned simultaneously between 21:30 h and 21:50 h on the third and fourth nights after a full moon.

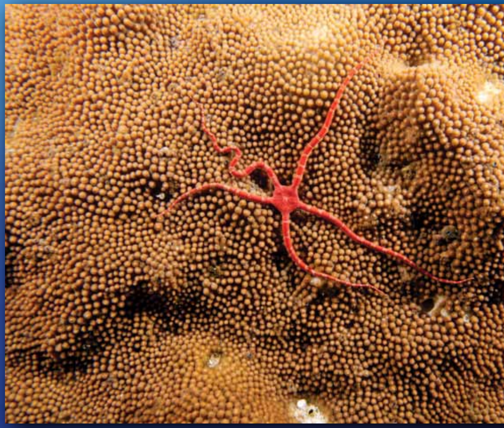
The researchers published their results in the February 2011 issue of *The Journal of Experimental Biology*. Co-authors are Charles Boch and Daniel Morse of the University of California at Santa Barbara, and Sonke Johnsen of Duke University.

"Somewhat counterintuitively," they wrote, "no eyes are required to detect these spectral changes. In fact, eyes probably reduce the ability of an organism to perceive low-intensity changes such as these. A broad, unobstructed sheet of photoreceptive tissue like that present in corals (and sea urchins) would actually be the optimal detector design for observing this spectrum."

What happens on nights when the moon hides behind clouds? Sweeney says that corals are capable of detecting changes in light even on overcast evenings.

Artificial light may also affect corals. It's red-shifted compared with both moonlight and sunlight, "and may therefore alter twilight spectral dynamics," she says. "With many of the world's coral reefs located in attractive travel destinations and densely populated coastal cities, it's important to investigate the effects of artificial light on corals' spawning."

What's next on the horizon? Sweeney is testing the effects of skylight spectra on spawning to find out for sure: are corals-in-love moonstruck?



(TOP) *Montastraea franksi*, a star coral, with gamete bundles "set" in the coral polyps' mouths just before they are released. The ruby brittle star (*Ophioderma rubicundum*) is probably waiting to catch some of the bundles for food. (MIDDLE) The same star coral a few moments later as the gamete bundles start to float upward. (BOTTOM) *Montastraea faveolata*, another star coral, releases its gamete bundles. *Photos courtesy of Schmahl/FGBNMS; http://flowergarden.noaa.gov/education/coralspawning.html*

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