Letter from the Desk of David Challinor
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I write this letter on a cold night in Washington, D.C. (April 4th); the full moon is so bright that it floods our darkened bedroom. When we consider how long the moon has been illuminating the night sky, it is no wonder so many organisms have synchronized their lives with the waxing and waning moon. This month's letter will consider some remarkable examples of the precision with which the reproductive cycles of some organisms follow the lunar phases.

Marine invertebrates seem particularly susceptible to moonlight, including the Japanese featherstar (*Comanthus japonicus*). This delicate, generally ten-armed starfish both walks on the bottom of the ocean and swims. Featherstars are plankton feeders and spread their arms in a semi-circular disc to capture whatever the night currents bring by them. One of the largest of these creatures has 68 arms, each 12.5 cms (5 in) long, and lives off the Japanese coast at a depth of up to 70 m (230 ft). *Comanthus japonicus* is best known for releasing its gametes (egg or sperm cells) during the first two weeks of October, but only on those nights when the moon is in its first or last quarter phase. All these featherstars spawn during the same two-hour period, even those kept in laboratory aquaria. Still more amazing, a detached arm of one of these featherstars will release its gametes during the same narrow time frame. Scientists do not know precisely what causes such synchronous reproductive activity but suspect that it may be a combination of October's lengthening nights at that latitude (35°to 40° N) and the amount of moonlight that penetrates the water. Yet this marine organism continues its cycle even out of the ocean. As nocturnal feeders, these featherstars understandably could have evolved an extreme sensitivity to moonlight.

Another moon-sensitive marine organism of these waters is the hermaphroditic (having both male and female sex organs) snail *Siphonaria japonica*. These snails congregate at low tide to mate during dawn or dusk in the week before the full moon in May, June and July. Meanwhile, two more southerly species of this snail also mate at low tide, but at midnight during the full moon of the same three months. On the opposite side of the globe, the New England mollusk, *Malampus bidentatus*, congregates on the day before the full or new moon, breeds two days later and lays its eggs two or three days after breeding. These snails are so genetically controlled that they will follow this reproductive cycling even under constant laboratory conditions.

The breeding strategies just described may easily be determined more by tidal conditions than by the intensity of moonlight. Spring tides (no association with the season of the same name) seem to be crucial. They occur when the sun and moon are either aligned together on the same side of the earth or when each is on directly opposite sides, i.e. roughly twice a month at the full moon and the dark of the moon. With gravity of each pulling in tandem, the ocean surface is "pulled up" to its maximum. When the moon is in its first or third quarter, it is at roughly right angles to the sun, so that the solar tide partially cancels the force of the lunar tide. The tidal range is, therefore, more moderate and these tides are known as neap tides. The orbits of the sun and moon are not synchronized, so that along any one tidal shoreline the second high tide in a twenty-four hour solar day comes about an hour earlier than it did on the previous day. Despite the lack of synchrony, the regularity of tidal rhythm has a profound effect on the life cycles of shallow water marine organisms.

As near as scientists can tell, the light from the full moon is thought adequate to trigger the hormone release that initiates the reproductive cycles of shallow water marine invertebrates. Given the remote odds that every full moon would shine on a cloudless night, there evidently only has to be enough of a fully visible full moon to maintain the cycle; once locked in genetically, the cycles operate unimpeded by intermittent deviations such as overcast nights.

The spawning of hundreds of shallow water corals occurs en masse on the fifth day after the spring full moon, which suggests that bright moonlight first initiates reproductive hormone activity. Perhaps the most spectacular moon-timed breeding bacchanal, at least for me, who was lucky enough to watch one, is that of the marine polychaete *Odontosyllis enopla*. These marine worms, which are common in parts of Bermuda, spawn about 55 minutes after sunset on the third night after the full moon in June, July and August. It was an almost mystical experience to look into the meter-deep water while a colleague started counting down to the magic minute mark. At 54 minutes, we saw the first of the three-centimeter-long (about 1 in) adults swim glowingly up from the bottom. Within seconds there was a 2 m diameter circle near the surface of hundreds of pulsating, gyrating worms in a breeding frenzy made all the more remarkable by the steady bioluminous glow of the females and the intermittent flashing of the males.

In addition to their spectacular mating ritual, these polychaetes have an interesting life cycle. When not breeding they dwell in sand-coated tubes attached to corals or other firm surfaces. They are nocturnal feeders on various zooplankton. After breeding, the worms shed their bristly swimming arms and return to their tubes. Eggs hatch the morning after spawning and the larvae settle down as adults about four weeks later.

Although lunar-timed reproductive cycles are not uncommon among marine invertebrates, they are rather rare among vertebrates. A fish species in the widespread silverside family has evolved an extraordinarily precise breeding cycle entirely aligned to the lunar tide. Grunion (*Leuresthes tenuis*) are a silverside about 15 cm (6 in) long that live along the shallows of southern California's coast. Large schools assemble to spawn during spring tides at night in June and July. A night or two after the highest spring tide, the fish congregate in huge numbers in the shallows. When the highest point of the tide has been reached, the females bury themselves tail first up to their pectoral fins in the wet sand. The male curves his body around the female to fertilize her eggs while she busily discharges them into the sandy slurry. The female wiggles in the process and is sometimes attended by several males. Each separate spawning takes only 20 to 25 seconds—the time interval between wavelets. When the first wavelet after spawning reaches the female, she frees herself from the sand and, with her suitors, is washed back into the sea. The fertilized eggs, now safely buried about 5 cm (2 in) deep, incubate in the damp sand for two weeks. During that interval the sun and moon will have aligned themselves once more so that at the next nocturnal spring tide, the wavelets again reach the newly hatched eggs and thus enable the fry to escape their wet sand hatchery and begin swimming freely. The arrival of the grunion is so predictable that people come to the spawning beaches with lanterns and buckets to harvest the fish. Once in the ocean, the fry grow rapidly and generally breed the next spring.

Such precisely timed lunar cycles are hard to find in other vertebrates, although there is recent evidence now being further investigated by Dr. Jason Schree of SUNY, Potsdam that lunar cycles have an effect on the dive patterns of different age groups of Galapagos fur seals (*Arctocephalus australis galapagoensis*). Among human cultures, however, lunar cycles have spawned a variety of reactions from myths to the timing of religious events. Farmers swear that crops planted during the waxing moon will grow better than those sown when it is waning. The full moon has long been associated with werewolves, vampires and other monsters, an understandable reaction to the eerie pallor cast on the landscape by beams of the full moon on a clear night. The old-fashioned term "moonstruck" referred to the mentally unbalanced or to the spaced-out behavior of a love-smitten swain. The full moon has impressed humans probably even more than the sun and its light and to this day has retained its mystic quality. Even after the astronauts walked and drove over its surface, our sole natural satellite retains its appeal and charm to all people who bask in its luminescence.

Finally, the lunar cycle determines the date of specific religious events among Christians, Jews and Muslims. Thus in western Christendom (but not eastern) Easter is celebrated on the first Sunday after the first full moon after the vernal equinox. The date for Passover is set by the first full moon after Rosh Hashanah, the beginning of the Jewish year, which starts on the first new moon after the vernal equinox. Islam also operates on a lunar calendar, although Ramadan occurs ten days earlier each year so that that period of diurnal fasting can eventually occur throughout the year. The new (crescent) moon is an important Muslim symbol and appears on flags, on the top of minarets, etc. Likewise, in Bavaria, Germany, statues of the Virgin in village squares always have her standing on a crescent moon. In Sri Lanka, the Buddhist majority ran the country on a lunar calendar at least through the 1960's when the government finally switched to the Gregorian, now universally used in world trade. Why does the moon, rather than the sun, seem to dominate the timing of religious events? I suggest that moon phases in ancient times were easier to distinguish than the minutes-long daily change in the solar cycle, well before people had clocks or the wherewithal to erect Stonehenge-like structures to determine the equinox.

Our moon is so ubiquitous in poetry that a book could be written on the subject. Human love and the moon are inextricably entwined. The moon, I am certain, will continue its appeal and charm to all mankind. Let us rejoice in the pleasure it has bestowed on us all.

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