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Shedding Light On The Reef

Understanding natural coral reef lighting and how it relates to the reef aquarium.

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While a reefkeeper can be very successful without ever having seen an actual coral reef, the experience of seeing a natural reef can have a profound affect on how he or she views an artificial reef. When observing a coral reef for the first time most hobbyists are struck by how different the light striking the reef appears, and how difficult it is to realistically simulate it in an artificial reef.

Unfortunately, only a small proportion of reefkeepers will ever see a natural reef, let alone a Pacific reef where the animals we keep are collected. So, I write this article for those of you who have not seen a natural reef and who want to better understand the lighting in these areas.

As it travels underwater, light is affected in many ways. It is scattered and absorbed by dissolved and particulate material, so intensity declines. Water also acts as a selective filter, removing colors as the light penetrates deeper water. Light also reacts with the coral reef environment in unpredictable ways, reflecting off organisms, coral rubble and substrate.

Light Duration and Intensity Over Coral Reefs

For the most part, coral reefs are found close to the equator, generally within 15 degrees north or south. While the proximity of most coral reefs to the equator is generally attributed to more favorable conditions found there, the reason corals grow in this area is only indirectly related to temperature or lighting conditions (Johannes 1983). Nevertheless, because most corals grow near the equator, a starting point for understanding coral reef lighting is to examine light found at the equator.

Those of us living north or south of the equator experience longer summer days and shorter winter days as the earth, tilted on its axis, rotates around the sun. The length of day at the equator is constant, so daylight on the natural reef varies by only a few minutes from month to month. Thus, corals are used to days of equal length throughout the year. In this respect, artificial light can more easily simulate conditions found on the natural reef than natural light at a high latitude location, a place far north or south of the equator. Daylight at the equator lasts slightly less than 14 hours.

Anyone who has watched a sunrise knows that sunlight gradually increases as the sun rises above the horizon until it reaches its brightest point, when the sun is directly overhead, and then gradually declines as the sun sets. While the process is obvious, the intensities may surprise most people.

From total darkness, it only takes a few minutes for light to reach levels normally found in a reef tank. Measuring light over a shallow reef off Sulawesi, Indonesia, I found that intensity reached 200 microEinsteins per square meter per second (µE/m2/sec) by 6:30 a.m. This is a light intensity level that exceeds that found on many reef tanks. By 8:00 a.m. light intensity exceeded the intensity found over a tank lighted by 400-watt metal halide bulbs. This raises the question of whether slowly “cycling” lights on gradually is of any value.

On the natural reef, light exceeds that of a typical reef tank in less than an hour. If a hobbyist wants to re-create sunrise on a natural reef, a cycling time well less than an hour would be more realistic than the more typical several hour cycling.Click image to enlarge

Figure 1

As the sun rises, light intensity increases more or less linearly until noontime, where it reaches over 2000 µE/m2/sec on a day without clouds (see Figure 1). This level of intensity is virtually impossible to recreate in a captive system with lighting commonly available to the hobby. A 400-watt metal halide bulb generates 2000 µE/m2/sec within a few inches of the envelope.

Reefkeeping discussions regarding proper lighting for photosynthetic animals often distinguish between “low light” corals and “high light” corals. Provided the terms allude to a coral’s ability to adapt to low light conditions, the distinction is valid. Some corals can successfully adapt to low light conditions better than others. Some hobbyists believe, however, that low-light corals are harmed by too much light.

While there is research that suggests that some corals are harmed by full sun irradiance, the light levels encountered in virtually all reef tanks fall well short of the 2000 µE/m2/sec full sun irradiance the authors are speaking of. The corals normally encountered in the hobby can adapt to conditions found in virtually all brightly lighted (e.g., 400-watt metal halides) reef tanks in the hobby. The Indonesian reef mentioned above was home to a wide range of soft and stony corals from Xenia to Euphyllia ancora, all growing under intensive light.

While the 2000 µE/m2/sec peak noontime light intensity is an unreachable number, peak intensity is far less important than total integrated irradiance. Integrated irradiance is the total amount of sunshine over the entire day. The total integrated irradiance is the critical determinant of whether corals and other photosynthetic organisms have received enough light to meet their metabolic needs. Integrated irradiance can be calculated by multiplying the intensity of light by the duration of the light.

For a rising and setting sun, the calculation can be difficult, but for a reef tank it is much easier. Reef tanks with artificial lighting have constant lighting, so it is a simple matter to multiply the total intensity of the lights by the length of time the lights are on. For example, if the lights over a reef tank are on 10 hours and generate 200 µE/m2/sec of light, the total integrated irradiance is 200 x 10 x 3600 (the number of seconds in an hour) or 7,200,000 µE/m2/sec. This is normally converted to Einsteins, so the final number is 7.2 E/m2. Equatorial sunlight over coral reefs typically generates over 50 E/m2 on a typical sunny day. This is at the water’s surface, however.

Because light intensity declines underwater, a more important question is what a typical coral receives in daily integrated irradiance. In a study of Pocillopora damicornis, Montipora verrucosa and Porites lobata, scientists found that at 3 meters in somewhat turbid water, a typical sunny day generated a total of 14.4 E/m2 day, while a cloudy day generated 6.2 E/m2 day (Davies 1994). The study found that a sunny day generated sufficient energy to meet the needs of all three corals, but a cloudy day left P. damicornis and P. lobata in an energy-deficient state. This suggests that for the reef tank example shown above, extending the photoperiod would be beneficial. Increasing the photoperiod to 13 hours would increase total integrated irradiance to 9.4 E/m2, a number closer to natural reef conditions.

The sun over the natural reef sweeps across the sky. A coral is not evenly lighted over the entire colony over the course of a day. Portions of a colony will self-shade themselves part of the day, and be in direct sunlight other parts of the day. In contrast, corals in a reef tank receive light from the same direction every hour of every day. This increases the likelihood that captive corals will morph into unusual shapes, as colonies adjust to stationary light. It also increases the likelihood that lower portions of a colony will receive inadequate light. Click image to enlarge

Figure 2

Light intensity at different depths varies according to the clarity of the water. Jerlov (1976) identified a number of different types of water depending on turbidity and degree of light absorption at various wavelengths. Water flowing over a fore reef is generally classified “Oceanic I” or “II” water, some of the clearest water in his categories. In contrast, lagoons can be turbid and absorb much more light. However, even turbid lagoons are brighter than most reef tanks.

While the rate of light fall-off depends on the clarity of the water, generally speaking, light falls off exponentially as one goes deeper in the water. A doubling in the depth of water translates into a reduction of light to only one quarter of the available light. This means light drops off very quickly as one goes deeper in the water. At only 10 meters or 33 feet, light intensity is only 20 percent of surface irradiance (Crossland 1987).

Measuring light levels on the reef adjacent to Bunaken Island, Indonesia, Tom Frakes, Charles Delbeek, Larry Jackson and I found a similar pattern (see Figure 2). The exception was light intensities over sandy substrates. The sensor used was spherical and measured both downward radiance as well as upward reflected irradiance. Thus, as the sensor approached the highly reflective sand, light intensity increased (data not shown). I have also observed the same phenomenon in captive reef tanks. A reef tank with a bright sandy bottom may be brighter at the bottom of the tank than a few inches above it.

Light Quality

One of the most misunderstood aspects of natural coral reef light is the color of light underwater. Photons are the packets of energy that make up the electromagnetic spectrum that includes visible light. The colors we see are, in reality, photons of different wavelengths. As the chart below shows, visible light extends from 400 nanometers (nm) to 700 nm.

Violet 400 to 450 nm
Blue 450 to 500 nm

Green 500 to 550 nm
Yellow 550 to 600 nm
Orange 600 to 650 nm
Red 650 to 700 nm

The wavelengths just below 400 nm are ultraviolet and the wavelengths above 700 nm are infrared.

Many hobbyists believe that light at the depth most corals grow is blue. In my opinion, this misguided belief has fueled the demand for high color temperature “blue” metal halide and fluorescent lighting for reef tanks. Water is blue and photographs of coral reefs often feature wide expanses of deep blue water, but other colors are present at depth. Water absorbs longer wavelength light to a greater degree than short wavelength light. In other words, the first wavelengths absorbed are infrared and red wavelengths. As one descends a little further, the slightly shorter wavelengths of orange light is absorbed at the same time ultraviolet light is absorbed. As one descends further in the water, yellow light is attenuated and finally violet is absorbed. As one approaches 30 meters or 100 feet, the only light that remains is between 450 nm and 550 nm (Dustin 1982). Note that both blue and green remain and that both shorter and longer wavelength light is attenuated.

It is an inaccurate generalization to suggest that only blue remains. It is more accurate to describe the light field underwater as lacking red, rather than consisting only of blue. This can be seen graphically in Figure 3. Even at 30 feet, most of the visible spectrum is still present, with only red light over 600 nm significantly attenuated.

While some of the corals collected for the reef hobby have habitats that extend below 30 feet, virtually all coral species collected are found in shallow depths, often only a few feet below low tide. This means that most corals imported have adapted to living in virtually full-spectrum light. This is also true of Tridacna clams and anemones collected for reefkeeping. These organisms are collected from shallow, full-spectrum light environments. Therefore, the hobby’s focus on blue light is more a reflection of current hobby fashion rather than clear evidence that corals need blue light. At the same time, studies have shown that corals can adapt to predominantly blue light (Kinzie et al. 1984, Kinzie and Hunter 1987), so a hobbyist has a great deal of flexibility in choosing lighting, as long as sufficient intensity is provided.Click image to enlarge

Figure 3

Ultraviolet Light

Ultraviolet (UV) light has been the focus of a great deal of coral research in the past few years. It has been linked to coral bleaching in the wild, and is generally considered harmful to corals and other invertebrates (Lesser et al. 1990). In spite of what I find to be the well documented harm UV causes corals, some segments of the hobby continue to speculate about the value of UV light over a reef tank. The speculation is based on the belief that ultraviolet light enhances the color of certain stony corals. Pigments of red, pink, blue and green are thought to be a coral’s “sunscreen,” which protects it from damage from ultraviolet light.

I believe the assumptions are wrong on a number of counts. First, corals do possess pigments that protect them from UV. The pigments, however, are clear, much like sunscreen used by people is clear (Banaszak and Trench 1995). Furthermore, the green, blue, pink and red pigments normally associated with UV protection by the hobby have nothing to do with UV (Dove et al. 1995).

The link between pigment and UV is easy to understand. With few exceptions, the most colorful corals are found near the surface of the water where high levels of UV light are present. Deeper water corals are typically brown even when nearby corals of the same species closer to the surface are colorful. Based on these observations, it was assumed that UV light produced more colorful corals.

Because research has ruled out UV, other conditions must account for the difference. As pointed out above, light intensity drops rapidly as one descends in the water. Corals near the surface receive considerably more light than deeper water corals. The higher intensity of light near the surface may be providing greater energy to corals giving them the necessary excess energy to produce pigments. Unfortunately, research has not yet proven a link between light intensity and pigmentation, so the matter remains open to speculation. In the meantime, hobbyists who find bright colors in their stony corals fading should consider light intensity as the most likely culprit.

In the reef tank, excessive UV can have deleterious effects on both reef inhabitants and the reef hobbyist. Metal halide and fluorescent bulbs used in the hobby provide protection from excessive UV light. In addition, hobbyists should use common sense around reef tank lighting. Do not operate double-ended metal halide bulbs without protective UV filtering glass, and metal halide bulbs should be discarded should the outer envelope become cracked or broken.

Properly lighting the reef tank involves a number of decisions and sorting through multiple options. Using the natural reef as a reference point, a hobbyist is better prepared to design a lighting system that meets the needs of the tank's inhabitants.