FOXFIRE:

Bioluminescence in the Forest

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People that use forests in fall enjoy a wealth of values. One treat reserved for hunters coming in late, firewood cutters finishing up after dark, and people hiking at night is “foxfire.” Foxfire is a soft glow or light coming from the leaf-covered ground or dead wood. In other parts of the continent this light is called “will-o’-the-wisp” or “faerie fire.”

Cold Fire & Decay

As the weather cools in fall, foxfire is the unusual and eerie lights that haunt the woods. Foxfire can be seen most easily along the ground, in chunks of rotting wood, and on old stumps in moist areas of woodlands. Foxfire is a curiosity, an educational toy for children, and part of folk tales and cultural myths concerning elves, ghosts, and supernatural “cold” fires.

Unfortunately for all the romance and myth surrounding foxfire, its source is fungi rotting wood. The most common luminous fungi in our woods is a tree root rot and wood decayer. The glow of foxfire comes from rapidly growing and healthy fungal cells consuming wood. Kick-back leaf piles and expose pieces of decaying logs to reveal the luminous wood.

Viewing History

Historical information about foxfire goes back a number of millennia. The Greek philosopher Aristotle noted the “cold fire” light. The Roman naturalist Pliny mentions luminous wood in olive groves. In the 1780’s a proposal was made that when wood became rotten, microscopic animals appeared in the wood and they glowed until drying killed them. By 1800 descriptions from rotting mine timbers were showing a relationship between luminescent wood and fungi. In the 1850’s the wood luminescence was confirmed to be fungal-caused and requiring moisture and oxygen. The first half of 20th century was dedicated to publishing lists of species capable of bioluminescence.

Setting out to see foxfire can be difficult, especially where there is plenty of light pollution. Remember that foxfire is a very low intensity -- low energy light. Pick overcast or moonless nights without surrounding artificial lights. Your eyes will need to be fully dark-adjusted for 20-30 minutes. Leave flashlights off and get away from any other types of light reflectance other than star-light. Forget flashlights, fires, candles, watch lights, or other light sources. Passive photo-multiplier binoculars (night scopes) can be helpful. Beware the other denizens of the nighttime forest.

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BL for Short

Bioluminescence (BL) is the emission of light from living things. Most of the lights we use or see come from a high energy density source or a heat source. BL comes from low energy biological systems without significant heat involved. BL light comes from a biochemical reaction at air temperature. Light generated from rotting wood by fungi is bioluminescence.

Bioluminescence is found in many types of living things including bacteria, fungi, algae, invertebrate animals, fish, and insects. More than 30 separate light generation systems using different processes and chemical paths exist across the globe. Many living things generate light, but few are noticed and most are considered rare in our everyday lives. The most common bioluminescence people see are associated with fire-flies and the sparkles in crashing waves at the beach.

Definitions

There are several light related phenomenon which are confused and misidentified.

"Fluorescence" is where energy from an external light is absorbed and immediately released at a longer wavelength (whitening / blueing detergents which convert unseen ultraviolet light into visible light.).

"Phosphorescence" is energy from an external light absorbed and released at a longer wavelength sometime later (glow in the dark children toys).

"Chemiluminescence" is the production of light from a chemical reaction (green-colored emergency light sticks).

"Bioluminescence" is a type of chemiluminescence where light is generated by a chemical reaction inside a living organism.

Reversing Photosynthesis

Bioluminescence is produced by the sudden decay of a high energy molecule to a lower energy form. The difference in the energy levels for this one molecule is one photon of light which escapes. The chemical composition and structure of the special molecule which is energized and decays to produce light, modifies the wavelength of any light generated. Different light wavelengths are used by living things in different environments -- ocean bottom to mountain top.

One way to understand bioluminescence is by comparison with photosynthesis. Bioluminescence is the reverse of photosynthesis. In photosynthesis, a living organism captures light and carbon-dioxide (CO_2) to make organic materials and release oxygen. In bioluminescence, light and carbon-dioxide (CO_2) are released by breaking apart organic materials using oxygen.

BL Two-Step

Fungi generate light in a two step process. Step 1 is loading chemical energy from respiration or photosynthetic processes onto a special molecule. The second step is taking this energized special molecule, called a "luciferin" (meaning fire carrier), and combining it with oxygen in the presence of a special enzyme, called a "luciferase." The result is water, a low energy or energetically decayed luciferin, and a photon of light.

The general process description given above is shown in two chemical equations which generate fungal bioluminescence:

Step #1) L + 2NADH ==a=> LH2 + $2NAD^+$ (Energy loading)

Step #2) LH2 + Oxygen ==b=> L + H20 + LIGHT (Oxygen-caused energy decay)

a = oxidase / reductase enzyme
b = luciferase enzyme
LH2 = luciferin molecule

It is not know what molecule acts as the fungal luciferin. From these equations two additional items should be noted. The first is that water (H2O) is generated at the site of light generation. The second item of note is that under extremely low oxygen contents, a surplus of the luciferin (LH2) builds-up. If oxygen is suddenly restored, a “flash” of brighter than normal light is generated.

Many Players

More than 40 species of luminescent fungi have been identified, primarily in the tropics. Most belong to one common group -- white-spored Basidiomycetes. With time, more luminescent fungal species are being discovered and cataloged. Cataloging is difficult. For example, some strains of fungi within the same species have radically different bioluminescent properties or no luminance at all.

Of the luminescent fungi, several species are BL in all part. Some have fruiting body caps that glow only on the underside. Other fungi have glowing mycelial strands in the soil or on rotting organic matter. Fruiting bodies that glow usually do not have glowing mycelium, and fungi with BL mycelium usually have non-glowing fruiting bodies.

Why BL?

The ecological or biological purpose of bioluminescence has been greatly debated. In earlier days, bioluminescence was considered a means to bleed-off excess energy and not generate heat. Another proposal was that bioluminescence helps sponge-up oxygen radicals that could damage tissues. Because of bioluminescence in below-ground tissues, various soil / fungal interactions were proposed. Bioluminescence above ground in fruiting bodies were assumed to attract animal spore disseminators. The true “purpose” of BL in fungi remains unclear.

Local Light

Armillaria mellea and a closely related relative are common root rot and wood decay fungi found across North America, Europe and Asia. Armillaria grows in (and on) old stumps, dead trees, buried roots, and downed logs. The fruiting body of Armillaria is a small golden-colored, stalked mushroom. This fruiting body is not luminescent. Armillaria’s mycelium and rhizomorphs are luminous. The root-like dark rhizomorphs, when they stop growing or when entering a resting period loose luminosity.

The most actively growing and respiring fungal cells generate light. The conditions that allow the fungi to grow fast, allow light to be produced. The most important environmental features surrounding fungal bioluminescence is food supply followed closely by water, oxygen, and temperature.

Food -- The cell wall components and remains of sugars, starch, and proteins in the wood are the desired food-stock of Armillaria. The luminescence can last in one piece of wood for up to 8 weeks until essential resources are consumed. It usually takes at least 4 weeks to build to maximum luminescence.

H2O -- The rotting wood must be kept moist -- too dry and the fungal growth stops -- too wet and the fungal growth is suffocated. Moisture is an important feature of luminescent wood because the process of light generation produces water as a by-product. Luminescent wood feels saturated. If you are collecting luminescent wood, the glowing, rotting pieces of wood need to be kept moist, not soaked. Do not let the wood become dry even for a short time.

O2 -- Oxygen is critical to keep the fungi healthy and growing. Too much water can make oxygen movement more difficult, and light generation will decline and be extinguished. With small pieces of collected luminescent wood, try limiting oxygen and watch as the light fades. You can then quickly let oxygen back to the wood and, under the right conditions, you will be rewarded with a "flash" of light. Do this in complete darkness.

Temperature – The optimum temperature for Armillaria bioluminescence is 77^{o}F (25^{o}C). Light generation is noticeable as low as 34^{o}F (1^{o}C). Light generation declines rapidly and stops above 86^{o}F (30^{o}C).

Miscellaneous – Maximum light is achieved under acid conditions (pH 5.7 - 6.0). Presence of the ammonium form of nitrogen allows for more energy to be released as light. Remember the total respiration energy used in generating bioluminescence is relatively small.

Spectrum

The fungi generates light over a total of 80 nm range which is equivalent to 1/4 the width of the entire visible spectrum (~400 -- 700 nm). Most of the light generated is in a much narrower band. The maximum light output occurs at a wavelength peak of 520-530nm. The 525 peak wavelength is about 40 nm shorter than firefly light and 50 nm longer than luminescence bacteria. Armillaria bioluminescence has a daily light intensity rhythm with maximum intensity around 7:30pm and a minimum intensity around 7:30am. The light intensity rhythm is not affected by total darkness, total light, or changing daily light periods.

The luminous glow is emitted in the bluish-green portion of the spectrum. The color you see in the woods can be slightly different because of the wood and dirt the light is filtered through. Darker, older cell walls and surface layers will change the color of the light showing through. The color you see is also affected by your color vision at night. Color descriptions range from a stark blue to a sickly green.

Conclusions

The specters of the dark autumn woods are products of living things. The processes of life and the recycling of materials involved with foxfire are part of a forest ecosystem. Go out and stalk the secret lights in the woods.