IJNRD.ORG ISSN : 2456-4184

INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG

An International Open Access, Peer-reviewed, Refereed Journal

BIOLUMINESCENCE : A REVIEW

[1]Dr.Ramneek Kaur ,[2]Mrs Nidhi Narula , [3]Dr.Vaishali Ayachit ,[4]Dr.Sonal Pathak

[1,2,3,4]Assitant Professor

[1]Department of Physics

[1]Mata Gujri Mahila Mahavidyalaya ,Jabalpur,M.P.India

Abstract : Bioluminescence, the natural emission of light by living organisms is seen in many different habitats,particularly in marine environments. Biochemical processes between the enzyme luciferase and luciferin produce this light. Bioluminescence serves a variety of functions in different species, from communication and mating to predator avoidance and prey attraction. Ecological interactions and survival strategies are intricately linked to its functioning. Bioluminescence species are widely distributed in both terrestrial and aquatic habitats .The physics of light emission in these organisms involves energy-efficient processes, with minimal heat loss, making it unique compared to artificial light. At the molecular level, bioluminescence is governed by well-defined genetic and enzymatic pathways, which have become crucial tools in molecular biology and biotechnology. Applications of bioluminescence in modern times range from drug discovery and forensic research to environmental monitoring and medical imaging.Current research continues to explore its genetic regulation, evolutionary origin, and potential uses in synthetic biology. This review presents an integrated overview of the mechanisms, ecological significance, and future potential of bioluminescence highlighting its role as both a natural marvel and a scientific resource.

IndexTerms **- Bioluminescence,chemiluminescence,luciferase ,luciferin**

1. INTRODUCTION:

Bioluminescence (1) is also known as a "cold light" as it appears bluish in colour and generates little heat. It is a natural phenomenon ,which occurs when living organism produces and emits light due to a chemical reaction inside or outside the cell , where the chemical energy is converted into light energy as byproduct .This energy is utilized in most of the reactions. So we can say bioluminescence is a type of chemiluminescence (2), but we use bioluminescence because this reaction is taking place inside a living organism. By doing this, a shining or glittering effect is produced.

Fig .(1) Bioluminescence is a certain type of chemiluminescence

2. PURPOSE OF BIOLUMINESCENCE:

Bioluminescence is a type of communication mechanism observed in bioluminescent mainly marine organisms found in the environment of ocean water including fish, bacteria, jellyfish and algae . It helps some animals attract food for survival in the deep sea (3). Animals can closely control when they light up by managing their chemistry and brain processes depending on their immediate requirements, whether a meal or a mate. They can even choose the intensity and color of the lights.

3. FUNCTIONS OF BIOLUMINESCENCE:

The functions of bioluminescence are as follows:

3.1 Feeding-

Animals can utilize their light to attract prey to them or even to brighten the area around them so they can see their next meal a little better. Examples:
1.Small plankton, like those drawn to the bioluminescence surrounding the beak of the Stauroteuthis octopus, can occasionally be the prey being lured. But bigger creatures might be duped by the light as well.


Fig. (2) Small plankton Stauroteuthis octopuS

2.Whales and squid are drawn to the cookie-cutter shark's luminous bottom, where they are attacked by it after it gets close.

Fig. (3) cookie-cutter shark's

3. A bioluminescent barbel that is dangling from the mouth of the deep-sea anglerfish is lighted by illuminating bacteria.

Fig. (4) Anglerfish (Lophiiformes) use bioluminescent bacteria in it's esca to lure prey. (Luminous Luring/Feeding)

3.2 Defense -

To defend from predators. Example:

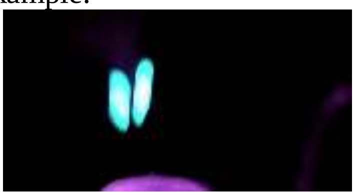

Fig.(5) Squid emits bioluminescent fluid to defend themselves from predators.

An approaching predator is frequently frightened away by an animal using a bright bioluminescent flare. The predator may become disoriented and startled by the bright signal, which may also make it unclear where its prey is. This strategy is effective in the deep water and can be used to catch everything from tiny Copepods (4) to giant vampire squid. When in danger, the polychaete family's "green bomber" worm and four other worm species with resemblances discharge a bioluminescent "bomb" from their bodies. The commotion could attract burglars if it were used as a burglar alarm.

3.3 Mating

Animals don't only need to look for and attract food; bioluminescence can also play a part to attract partners during mating. Example: Crustacean and worms And to attract prey. Example: Angler fish have light in front of their mouth .

Fig. (6) Glowworms emit a blue-green light that both attracts mates and warns predators to stay away.JOERG HAUKE—GETTY IMAGES

Fig. (7) Fireflies (Photinus Pyralis) use their green glow to attract mates.(Mating)

4. ADAPTATIONS TO SURVIVE IN A DARK ENVIRONMENT LIKE DEPTHS OF THE OCEAN:

4.1 Defensive Adaptations-

Some species luminesce to confuse attackers. Many species of squid, for instance, flash to startle predators, such as fish. With the startled fish caught off guard, the squid tries to quickly escape.Example :The vampire squid exhibits a variation of this defensive behavior. Squid that live near the ocean surface eject dark ink to leave their predators in the dark. But In deep-sea the squid, lacks ink sacs, so the vampire squid ejects sticky bioluminescent mucus, which can confuse, and delay predators, allowing the squid to escape.(5)

4.2 Offensive Adaptations

The angler-fish, which employs bioluminescence to entice prey, may be the most well-known predator to employ this technique. The angler-fish is a large fish with a long, thin, fleshy protrusion on top of its head that is termed a filament. It also has a large mouth with pointed teeth. The ball (known as the esca) on the end of the filament can be lit up by the angler-fish. Smaller fish dive in for a closer look as they are drawn to the area of light by curiosity. It might already be too late by the time the prey notices the angler-fish's massive, black jaws hidden behind the glowing esca. Other fish employ bioluminescence to look for prey, including a species of dragon-fish known as a loose-jaw. Since most fish can only perceive blue light, loose-jaws have evolved to emit red light; as a result, , so loose jaws have an enormous advantage when they light up a surrounding area. They can easily see their prey, but not vice-versa .(5)

4.3 Camouflage-

Counter-illumination can be utilized with bioluminescence to aid with camouflage. Predators hunting for prey from below may find it more difficult to see what they are looking for because photophores on an animal's underside might mimic the faint light coming from the surface . As a result of its prevalence, bioluminescence is playing an important role in the ecology of the ocean. The function of bioluminescence in the oceans is clearly understood with respect to the essentially dark environment below about 200 m. (5)

Fig.(8) Poryfish use bioluminescence to camouflage with surrounding water. (Camouflage/Defense)

4.4 Luminous lure

Fig. (9) Anglerfish (Lophiiformes) use bioluminescent bacteria in it's esca to lure prey. (Luminous Luring/Feeding)

4.5 Communication (in the dark) & Schooling of fish

5. HOW DOES BIOLUMINESCENCE WORK :

The chemical reaction that causes bioluminescence requires two chemicals: luciferin and either luciferase (the terms are derived from the Latin word lucifer light bringer) or photoprotein. Some bioluminescent organisms produce these chemicals themselves, while some are getting it through their food.

Luciferin is a organic molecule of complex substance that actually produces light ,when another molecule (or group of molecules) excites it. In a chemical reaction, luciferin is called the substrate (Substrate: a substance or layer that underlies something, or on which some process occurs, in particular). The bioluminescent colour (e g yellow in fireflies, greenish in lanternfish) is a result of the arrangement of luciferin molecules. Each bioluminescent organism has a unique luciferin and they vary in chemical structure. It can be man made or synthetic, and this synthetic luciferin has a chemical structure of C11H8N2O3S2.

Luciferase is an enzyme or a chemical that helps speed up reaction or accelerate the rate of reaction. The enzyme luciferase catalyses the pigment luciferin .It allows oxygen molecules to bind to luciferin. This reaction is called **oxidation.** Once luciferin binds to oxygen, it produces **oxyluciferin** (equation 1) and emits energy in the form of light. The color and intensity of the ligh**t** vary, depending on –

1. how the luciferin molecules are arranged in an organism and
2. the type of luciferase enzyme.

Some organisms have chemicals called **photoprotein**s (equation 2), which combine with luciferin and oxygen. They produce light when they come in contact with calcium ions . Instead, they don't require luciferase to give out light as a byproduct..

luciferase

(1) luciferin + O_2 -----------------------------> oxyluciferin + CO_2 + hv

(2) photoprotein Ca^{2+} ---------------------> protein-coelenteramide + CO_2 + hv

In many cases the bioluminescence intensity is assumed to reflect the velocity of the enzyme-substrate reaction and this intensity is used to analyze the kinetics on the Michaelis-Menten model (equation 1).

As a result of the discovery that oxygen was not kinetically involved in the bioluminescence of aequorin and later of several other similar animals, these proteins were dubbed "photoproteins" (equation 2). Researchers found that the oxygen had already been attached to the luciferin, allowing the photoprotein to operate as a luciferase binding a peroxy-luciferin, a stabilised reaction intermediate.

Frequently, in addition to oxygen, in vitro bioluminescent processes require cofactors, such as-ATP, Mg2+, and Ca2+ for the firefly and photoproteins, respectively (1, 2, 3). Additional proteins involved in creation and regulation in the animal itself (in vivo) include the fatty acid reductase group of enzymes, which creates the bacterial luciferin, a long-chain aldehyde. The bioluminescence systems of dinoflagellates and Sea Pansies both contain luciferin-binding proteins. The well-known Green-fluorescent protein (GFP) in jellyfish and the Lumazine Protein family in various bacterium types are examples of "antenna proteins" that regulate the colour of bioluminescence (3). In contrast to proteins that perform a similar job in photosynthesis, these proteins are referred to be "antenna proteins" since they operate in the opposing manner.

6. THE WIDE DISTRIBUTION OF BIOLUMINESCENCE:

Although they are present at all layers of the biosphere, bioluminescent creatures can only be found below mammals and plants. The occurrence seems to be randomly distributed among genera, and it occasionally occurs in some species of a genus but not others for no apparent reason. Numerous marine creatures, including bacteria, algae, jellyfish, worms, crabs, sea stars, fish, and sharks, exhibit bioluminescence. There are around 1,500 species of luminescent fish alone. Some animals acquire the capacity to glow by ingesting bacteria or other bioluminescent organisms. To name only a few marine species, bioluminescence has been shown in cephalopods, copepods, ostracods, amphipods, euphausids, and many fish. On land, there are a variety of bioluminescent insects, including fireflies, glow-worms, click beetles, and several dipteran species, as well as a variety of luminescent fungi that produce glowing wood. Both marine and terrestrial environments harbour the bioluminescent bacterium. Only in a few instances have the bioluminescence components from the diverse systems been characterised and the general chemistry defined. There are still many luminous species in the deep water that haven't been fully studied.


Fig. (10) Left: The bioluminescent mollusc Pholas dactylus, in the U.K. commonly known as a "Piddock". It has worldwide distribution. Right: Purple jellyfish, common in the Mediterranean and described by Pliny the Elder.

6.1 Anatomic Distribution

The tissue distribution of the components of the bioluminescent system within organisms, has shown variations . The anatomic location of bioluminescence gives clues about the source of synthesis of component , its storage, transport, and the functional role of the luminescence. One of the important organ is the "photophore" i.e. the light producing organ, seen in many luminous fishes and vividly in cephalopods . Photophores are normally built up of complex photogenic (i.e. light emitting)cells. Some of the squid can project luminous clouds from their mouths, and are also having spectacular photophores (light emitting tissue). Bioluminescent reaction components have also been detected in the stomach, secretory organs and liver of some organisms (mostly believed to be there as a result of synthesis or storage)

Fig. (11) A bioluminescent squid from the deep ocean. From the Bioluminescence Web Page.

6.2 Geographic Distribution

Bioluminescent organisms such as fireflies and certain fungi can be found on in sea-water is observed in all oceans, particularly densely in bays and coral reefs, where high concentrations of nutrients promote blooms of the responsible organisms. One location in Puerto Rico named the Bioluminescent Bay, is well known for spectacular displays of this dinoflagellate luminescence. "Red Tides" are often blooms of luminescent phytoplankton.

Fig.(12)

7. BIOLUMINESCENT ANIMALS:

Bioluminescence is common in sea dwellers. Jellyfish, starfish, crustaceans, squid, sharks are some of the marine organisms that exhibit bioluminescence. Bioluminescent organisms are present from the surface to the seafloor, near the coast, to open ocean. Many planktons such as dinoflagellates bloom on the surface of the water on getting optimum conditions which make the ocean sparkle at night and shows a reddish-brown colour during the day time .

8. BIOLUMINESCENT ANIMALS:

Bioluminescence is common in sea dwellers. Jellyfish, starfish, crustaceans, squid, sharks are some of the marine organisms that exhibit bioluminescence. Bioluminescent organisms are present from the surface to the seafloor, near the coast, to open ocean. Many planktons such as dinoflagellates bloom on the surface of the water on getting optimum conditions which make the ocean sparkle at night and shows a reddish-brown colour during the day time .

9. EXAMPLES OF BIOLUMINESCENCE:

A large variety of marine entities show bioluminescence wherein the colour that is usually green or blue and in a few cases the red colour is also observed. Apart from marine organisms, bioluminescence is also observed in the land entities, precisely invertebrates such as fireflies, worms, larvae – insects. Bioluminescence is seen in the phylum Ctenophora.

Fig. (13) A brief explanation of the organisms exhibiting bioluminescence is given below:

9.1 Dragonfish – Idiacanthus atlanticus-

The Black Dragonfish is a scaleless fish which appears monstrous and are found inhabiting deep in the sea . They possess special organs, the photophores that are capable of producing light. The organ structures are found in their smallest form along the body whereas larger photophores are located just below the eyes enclosed in a formation that dangles below the barbel. Apart from producing the traditional blue-green colour, they are also capable of producing the red light which helps them find their prey in the dark.

Fig. (14)

9.2 Dinoflagellates –

They are also known as the fire algae . They are a kind of unicellular algae that are found in both freshwater and marine ecosystems. They are capable of bioluminescence as they produce a chemical compound which has the ability to generate light when they undergo proper reactions . The process gets stimulated when dinoflagellates come in contact with any object or other organisms or even water movement through waves. They can also glow with a dip in the temperature. They use the process of bioluminescence as a defensive mechanism against the predators. On lighting up, they produce a glowing blue colour.

Fig.(15)

9.3 Glow-worm

Contrary to its name, glow worms are not worms inherently, instead, they are the larvae of different groups of adult females or insects that have a resemblance to the larvae. The adult forms of these glow-worms lack wings, instead .They exhibit structures on their abdominal and thoracic areas, wherein these organs emit light. They use the bioluminescence process to lure their mates and attract their prey including bugs. They hang suspended to the sticky long fibres they produce where in the prey are entrapped. Glow worms emit light that is toxic enough in order to warn their predators,

Fig. (16)

9.5 Fungi

About 70 species of fungihave been known to be show bioluminescent. They usually emit green light. For example, mushrooms glow in order to attract insects. These insects, upon getting attracted, crawl around them picking up their spores. In fungi, this process is regulated by a circadian clock which is dependent upon temperature. The fungi starts glowing as soon as the sun sets and the temperature drops which, in the dark, are clearly evident to the insects.

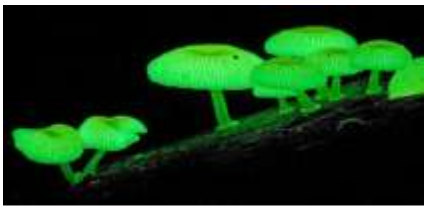

Fig. (17) This Mycena lampadis is one of about 80 species of mushrooms that have the ability to glow.GETTY IMAGES

9.6 Fireflies

Fireflies are having light-generating structures which are located in their abdomens. Light is generated when the chemical luciferin reacts with oxygen in the presence of energy i.e. ATP. The enzyme luciferase is responsible for the bioluminescence . It serves few purposes such as, in adult fire-flies, bioluminescence is used to lure mates and attract prey. The light pattern that flashes is helpful in identifying different members belonging to the same species, and also to differentiate between male and female fireflies. In the larvae version of the firefly, it is used as a warning to the predators so as to not consume them as they possess toxic elements. Some other fireflies have the ability to sync their light emission to a process which is called as simultaneous bioluminescence.

Fig.(18) Fireflies are bioluminescent. They produce their own light through a chemical reaction in their abdomens.TREVOR WILLIAMS—GETTY IMAGES

A lot is still unknown about how these organisms use bioluminescence . An abrupt "turning on" of the lights could frequently scare off potential prey. Many forms of bioluminescence are challenging to see in visible light. Hence , it is difficult to easily acquire their samples for scientific study.

10. LIGHT EMISSION'S PHYSICS-RELATED CHARACTERISTICS:

Bio-luminescent organisms are found all over world-wide. For example the so-called "phosphorescence" (A specific type of photo-luminescence related to fluorescence) (Photo-luminescence: light emission from any form of matter after the absorption of photons (electromagnetic radiation)) .Examples: The sparkle of fireflies on a summer night is produced as a result of a chemical reaction in their glowing abdomens.

Light emission from bioluminescence results from a chemical reaction that gives a large amount of energy which, instead of being released as heat as in a normal chemical reaction, is channeled to populate the product molecule in its excited electronic state(energy is stored). This excited state is the same produced in that molecule by the absorption of radiation, so that the spectral distribution of the bioluminescence is often the same as that of the product fluorescence (Fluorescence is different from bioluminescence. Florescence happens in the presence of stimulating light or other electromagnetic radiation, that is absorbed and then emits light by a substance over extended periods of time. It is a form of luminescence.). The color of the bioluminescence however, is sometimes "tuned" by the protein environment of the product excited state, a property evolved to suit the function of the light emission, that is for communication, defense against predation, etc(6).(Lee, 2015) Organisms can optimize their use of bioluminescence. In ocean water, higher frequencies are required to achieve maximum transmission because electromagnetic radiation dissipates easier in the water. This is why radio waves travel easier through space than through water. To optimize their use of bioluminescence, animals must tune their light output with the use of proteins (Refer to the chemistry section at the top), making it possible for bioluminescent organisms to somewhat adapt to their environment.

Visible radiation corresponds to light in the wavelength range of 400-700 nm (Fig.19). Bioluminescence spectra are broad bands with widths at half-height around 60-100 nm. The bioluminescence maximum of most marine species falls within the range of 450-510 nm (7), whereas terrestrial organisms have predominantly a yellow-green bioluminescence colour. Reasons for these variations is that -in ocean water, blue to green (400-500 nm the higher side of frequency) luminescence achieves maximum transmission, while terrestrial species have their maximum visual sensitivity for yellow light (lower frequency). The visual pigments of most marine organisms are most sensitive in the blue-green region.

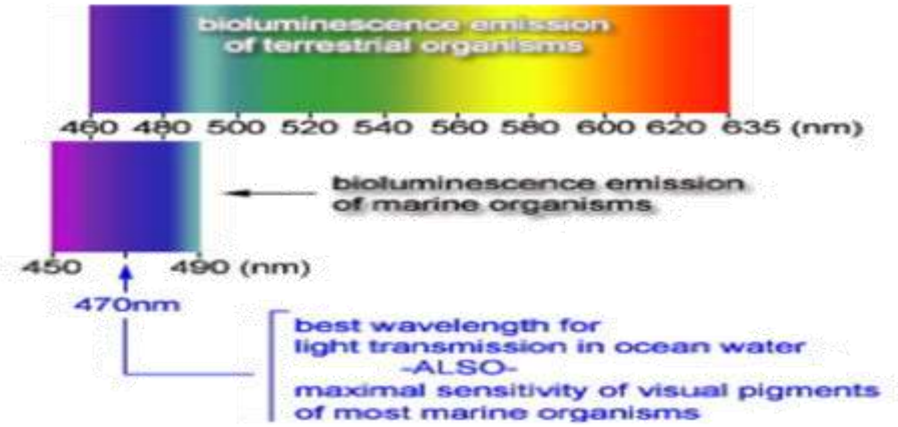

Fig. (19) The end-product of bioluminescence is visible light. The visible part of the spectrum is 400-700 nm, and the emission maxima of most luminous marine organisms falls within the range of 450-490 nm.

The bioluminescent bacteria for example, exhibit a range of *in vivo* bioluminescence spectral maxima 470-542 nm, much larger than for the *in vitro* reaction with different bacterial luciferases. The shortest in vivo wavelength maximum, 470 nm appears to be characteristic for species belonging to the genus *Photobacterium*.

11. BIOLUMINESCENT LIGHT:

Depending on the environment and organism that it is produced in, bioluminescent light can take on a wide variety of appearances. For example , the blue-green region of the visible light spectrum is where the majority of marine bioluminescence is exhibited. In the deep sea, these hues are easier to see. Furthermore, the majority of marine species are exclusively sensitive to blue-green hues. They cannot physiologically process the violet, red, or yellow colours . The majority of land species glow in blue-green. However, several glow in the yellow spectrum, such as fireflies and *Quantula striata*, a tropical species from Southeast Asia that is the only land snail known to show bioluminesce.

Most species can only glow in one colour. The most well-known of these is perhaps the so-called railway worm, which is really a beetle larva. The railway worm's body shines green, while its head glows red. The bioluminescence is expressed differently by several luciferases. Some living things continuously produce light. For example, several fungal species found in rotting wood produce a steady glow known as foxfire. However, the majority of creatures flash for between a fraction of a second and ten seconds using their light organs. These flashes can appear in particular places, like the dots on a squid. Other flashes can fully illuminate the organism.

12. EFFECTS OF BIOLUMINESCENCE AND MOLECULAR BIOLOGY:

Cloning distinct bioluminescent system parts has ushered in significant developments in biological science. A calcium-dependent photoprotein called *aequorin* was cloned in 1985 from the jellyfish *Aequorea victoria* (8, 9). As the intensity of its luminescence varies with calcium concentration, aequorin has proven effective in the monitoring of cell calcium. In 1985 (10), firefly luciferase was cloned. This bioluminescence system is frequently used as a highly sensitive method for ATP assessment, such as to find microbial contamination in water systems ,food materials, etc. Since ATP is a substance found in living beings, this assay can detect the presence of organisms that might be harmful or cause spoiling. Numerous other luciferases have also been cloned, including those from bacteria, *Renilla reniformis*, and *Vibrio harveyi* (11).

Fig. (20) Jellyfish are known for their ability to glow. We photographed these at Mote Marine Center in Sarasota

13. MODERN BIOLUMINESCENCE APPLICATIONS:

According to the 2008 Nobel Prize in Chemistry, the "Green-Fluorescent Protein" or GFP is the most well-known protein in biology. In 1994, different organisms began expressing GFP after it had been cloned in 1992 (12). As more and more applications of GFP have been made since then, the number of scholarly citations has gone into the thousands. In instance, GFP is now well known for being a top-notch protein or gene tag. A protein of interest can be fused to GFP and its fluorescence tracked inside a cell to analyse the location and behaviour of the protein**.** With its exceptional structural stability and capacity to produce fluorescence *in situ* without the need for an external substrate addition, GFP makes a great instrument for researching cellular and subcellular processes (13).The market for quick and efficient diagnostic tests based on bioluminescence is continually changing. For instance, the marine bacteria *Vibrio fischeri* that emits bioluminescence is used in "Microtox" to analyse the toxicity and water quality. The respiration mechanism is hampered when this organism is exposed to a toxin, which reduces the bioluminescent intensity**.**

There are several "fun" applications and concepts, such the potential for bright Christmas Trees and walkways in addition to luminous wine and beer. Using light sticks for night concerts and directing planes to their gate positions are just a couple of commonplace uses for this pervasive phenomenon known as luminescence.

14. PEOPLE AND BIOLUMINESCENCE:

To better understand how people may use bioluminescence to make life simpler and safer, biologists and engineers are researching the substances and environmental factors involved in the phenomenon. GFP, for example, is a useful "reporter gene." Biologists link substances (genes) called reporter genes to other genes they are researching. GFP reporter genes can be quickly recognised and quantified, typically through their fluorescence. This enables researchers to track and keep track of the activity of the gene under study, whether it is expressed in a cell or engages in chemical interactions. Other applications are more novel. For example, bioluminescent trees could help in illuminating metropolitan streets and highways. As a result the demand for electricity would go down. When they need water or other nutrients or when they were ready to be harvested, bioluminescent plants and crops may glow. Costs for farmers and businesses would go down as a result.

15. CURRENT RESEARCH:

The use of bioluminescent algae in architecture is being researched by scientists. These algae have the potential to be used as an eco-friendly, long-lasting light source due to their ability to produce light. Utilising them can reduce the need for fossil fuel-powered electricity and contribute to environmental protection. Additionally, designers of human-computer interactions are attempting to research and comprehend how organic beings can enhance digital communication. Scientists can investigate how bioluminescent algae process information and interact with their environment because they are like little, independent computers that produce light. made.

REFERENCES:

1. Haddock, S.H.D., Moline, M.A., and Case, J.F. (2010), Bioluminescence in the Sea. Annu. Rev. Mar. Sci. 2:443–493.
2. Campbell, A. K.(1988). Chemiluminescence: principles and applications in biology and medicine. (VCH/Horwood, Chichester).
3. Shimomura, O. (2006). Bioluminescence: Chemical Principles and Methods. (World Scientific, Singapore).
4. Campbell, A. K., and Herring, P. J. (1990). Imidazolopyrazine bioluminescence in copepods and other marine organisms. Mar. Biol. 104: 219-225
5. Bioluminescence in the Ocean - CIMI School. (2014, December 18). Retrieved May 17, 2015, from http://cimioutdoored.org/bioluminescence-ocean/

6. BASIC BIOLUMINESCENCE. (n.d.).Retrieved May17, 2015, fromhttp://www.photobiology.info/LeeBasicBiolum.html
7. Herring, P.J. (1983). The spectral characteristics of luminous marine organisms. Proc. Roy. Soc. Lond. B. 220: 183-217.

8. Inouye, S., Noguchi, M., Sakaki, Y., Takagi, Y., Miyata, T., Iwanaga, S., Miyata, T., and Tsuji, F.I. (1985). Cloning and sequence analysis of cDNA for the luminescent protein aequorin. Proc. Natl. Acad. Sci. USA. 82: 3154-3158.
9. Prasher, D., McCann, R.O., and Cormier, M.J. (1985). Cloning and expression of the cDNA coding for aequorin, a bioluminescent calcium-binding protein. Biochem. Biophys. Res. Commun. 126:1259-1268.
10. De Wet, J. R., Wood, K. V., Helsinki, D. R., and DeLuca, M. (1985). Cloning of firefly luciferase cDNA and the expression of active luciferase in Escherichia coli. Proc. Natl. Acad. Sci. USA. 82:7870-7873.
11. Viviani, V. R., Bechara, E.J., and Ohmiya. Y. (1999). Cloning, sequence analysis, and expression of active Phrixothrix railroad-worms luciferases: relationship between bioluminescence spectra and primary structures.: Biochemistry 38: 8271-8279.
12. Prasher, D. C., Eckenrode, V. K., Ward, W.W., Prendergast, F. G., and Cormier, M. J. (1992). Primary structure of the Aequorea victoria green-fluorescent protein. Gene 111: 229-233.
13. Zimmer, M. (2010) Green fluorescent protein: a molecular microscope, on Photobiological Sciences Online (KC Smith, ed.). American Society for Photobiology, http://www.photobiology.info/.