SASTA OLIPHANT SCIENCE AWARDS

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Science Writing

Year 9-10

Eman Alaboody

Our Lady of the Sacred Heart College

Government of South Australia
Department for Education

SASTA South Australian Science Teachers Association

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Bioluminescence – A Biochemical Phenomenon in Organisms

Our Lady of the Sacred Heart College
Eman Alaboody

Figure 1: Bioluminescent jellyfish.

Introduction

Bioluminescence is considered to be an incredible phenomenon and a type of chemiluminescence in which light is produced or emitted by a chemical reaction within a living organism (National Geographic, n.d). Bioluminescent organisms are predominantly located in the ocean which includes marine species such as fish, jellyfish (Figure 1), and anglerfish (Figure 2) (BYJU'S, n.d). However, some bioluminescent organisms are found on land such as fungi and fireflies (BYJU'S, n.d). Interestingly, over three-quarters of marine species are bioluminescent (Natural World Facts, 2021).

Figure 2: The deep-sea Anglerfish known for its bioluminescent lure.

The Chemical Reaction that Results in Bioluminescence

The biochemical reaction that results in bioluminescence requires specific chemicals known as luciferin and a photoprotein called luciferase (Widder, 2018). Luciferin is a molecule that produces light when it reacts with oxygen, whereas luciferase is an enzyme that assists in speeding up the reaction (Widder, 2018). Many organisms attain the ability of manipulating when they bioluminesce, by regulating their chemistry and brain processes depending on their immediate needs (Tampier, 2017). This self-regulation is useful because different situations will benefit from the variations in which light is expressed (Group Five, 2020). Various types of luciferin exist depending on the animal hosting the reaction (Gianluca Farusi, 2019). Chemically, most bioluminescence is due to oxygenation reactions, which is when oxygen combines with calcium, adenosine triphosphate (ATP) and the chemical luciferin in the presence of luciferase (a bioluminescent enzyme) to produce light (SurferToday, n.d). Organisms that bioluminesce can independently synthesise luciferin (National Geographic, n.d). The bioluminescent colour is determined by the arrangement of luciferin molecules – for instance, yellow in fireflies and green in lanternfish (National Geographic, n.d).

Figure 4: Big South Fork's bioluminescent beach in Tennessee/Kentucky (US) caused by the cluster of dinoflagellates.

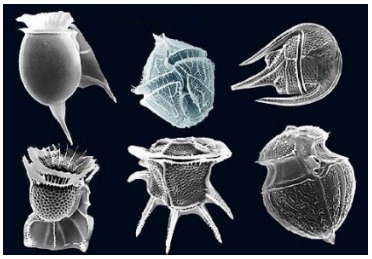

Figure 3: About 90% of dinoflagellate species are planktonic meaning that they float freely in water.

Dinoflagellates

Bioluminescent dinoflagellates that are regarded as algae or microalgae, are a species of plankton (Figure 3), and a common member of the coastal phytoplankton (Britannica, 2017). They are unicellular microscopic marine organisms which are known to thrive in the coastlines of beaches and cause the surface of the ocean to shimmer radiance at night (Figure 4). By day, this clustering algae is visible by its reddish-brown discolouration and is therefore also referred to as red tide (Figure 6) (Group Five, 2020). The red tide is bioluminescent and therefore by nightfall, incredible displays of vibrancy are showcased (Natural World Facts, 2021). Acting as a self-defence mechanism, the purpose of this illumination is to repel predators from consuming the algae (Natural World Facts, 2021). Anything that agitates the algae will cause the targeted group of dinoflagellates to instantaneously bioluminesce, creating a flash of light (SurferToday, n.d). Moreover, the response by the dinoflagellate is similar to a reflex, so if it feels a certain amount of mechanical stress, then it will respond with light (BYJU'S, n.d). Algae is generally sensitive, so

Figure 6: Dinoflagellates clustered during the day time is known as 'red tide'.

Figure 5: Dinoflagellates instantly glow due to the movement of surfers.

the light triggered by virtually any force explains the frequent occurrence of this phenomenon at the shore break, with the constant force of waves crashing and the presence of individuals surfing (Figure 5) (Susan Carty, 2015).

The Bioluminescent Colour of Blue

A common feature that is present in most bioluminescent organisms is the colour of light that they emit. Bioluminescent organisms tend to illuminate blue because blue light travels furthest in water with its intermediate wavelength (Natural World Facts, 2021). Visible lights with very long wavelengths such as red or very short wavelengths are absorbed faster or are filtered out (Bailey, 2018). Other creatures illuminate another colour, a feature that acts to their advantage (Widder, 2018). For instance, the Bloody-Belly Comb Jellyfish (Figure 7) lights up red to ensure invisibility to its predators (National Geographic, n.d). Furthermore, the fact that most marine organisms bioluminesce the colour blue is linked to the vision of deep-sea organisms, many of which do not have colour vision but rather, a single, blue-sensitive, visual pigment (Natural World Facts, 2021). Having eyes that are highly sensitive to blue light is useful for detecting luminous prey as well as potential mates (SurferToday, n.d). This also explains the large eyes found in many deep-sea creatures like the Barreleye (Oxford University Press, 2018). For the Barreleye, this adaptation enables it to absorb as much light as possible (Figure 8) (Oxford University Press, 2018).

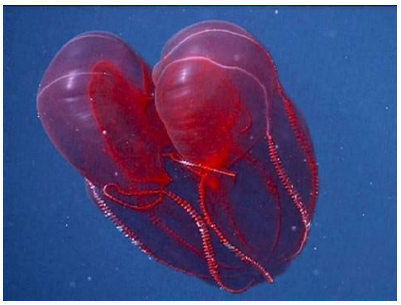

Figure 7: The Bloody-Belly Comb Jellyfish.

Figure 8: The Barreleye fish have large transparent heads and tubular eyes.

Bioluminescence in Marine Life

It is said that life in the deep sea is unique for a reason; the pressure is immense, the waters are cold, and sunlight is not available one kilometre below sea level (Tampier, 2017). Creatures living beyond the twilight zone are forced to spend their lives in an expanse of darkness (BYJU'S, n.d). As there is no sunlight in the deep sea, many organisms have used this feature of bioluminescence to their advantage, in order to communicate with one another, hunt, and confuse predators (Tampier, 2017). Bioluminescence is a widely common feature in many marine organisms (Natural World Facts, 2021). It is a single adaptation uniting vastly different creatures from bacteria and algae to cephalopods and sharks (Jain, 2020). The observation that different organisms have this ability is evidence of convergent evolution, in which bioluminescence has evolved multiple times on at least 40 separate occasions (Natural World Facts, 2021). A highly beneficial and dependent adaptation, this suggests that bioluminescence contributes to the success of organisms by allowing them to communicate, find a mate, and attract prey (Britannica, The Editors of Encyclopaedia , 2021).

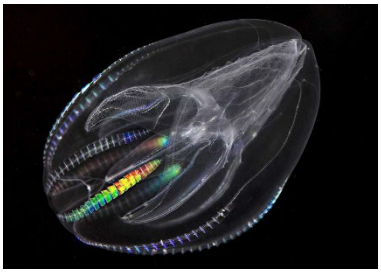

Figure 9: The Comb Jellyfish.

More than half of the ocean's jellyfish and ctenophore species produce bioluminescence in some form (Group Five, 2020). The Comb Jellyfish (Figure 9) moves by beating its shimmering hair-like cilia and can produce light flashes to startle predators (Oxford University Press, 2018). Their relatives, siphonophores release glowing particles into the water to confuse the predator (Undlin, 2018). One particular siphonophore variety known as Erenna Sirena lures its prey by wiggling glowing bioluminescent lures (Figure 10). The spindle-shaped body of the firefly squid is covered in bioluminescent organs called photophores that emit blue-green light (Widder, 2018). In the case of the mentioned cephalopods, they utilise bioluminescence to attract prey such as small fish in the gloomy mesopelagic zone (Gianluca Farusi, 2019).

Figure 10: Erenna Sirena (siphonophore).

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Figure 11: The Bobtail Squid uses counter-illumination as camouflage.

Demonstrating another evolutionary phenomenon, cephalopods (Figure 11) use counter-illumination which is a form of camouflage in which the creature lights up in various intensities to match the ambient light around them (e.g., they glow brighter as they ascend to shallower waters at night) (Natural World Facts, 2021). The colour they emit matches the faint glow of moonlight from the surface, meaning they can blend in with their surroundings whether it is dark or light, and hide from predators (Gianluca Farusi, 2019). In much of the open ocean, concealment is not possible, so animals must use this type of bioluminescence to adapt and be able to hide in the wide open (Natural World Facts, 2021).

Bioluminescence on Terrestrial Land

Figure 13: Fireflies swarming a wildlife park in Australia.

Figure 12: A close-up image of a firefly.

Fireflies produce cold light and have a specific organ that is dedicated to bioluminescence or creating light (Figures 12 & 13). Mostly, a cold light, less than 20% of the light produced in bioluminescence generates thermal radiation or heat (Bailey, 2018). A firefly is known to have a remarkable property where they are able to emit light without radiating much heat (Tech Insider, 2017). It is necessary that firefly organs do not exceed their optimal temperature because this organism will simply not survive the experience of bioluminescence (Tech Insider, 2017). Serving as a form of sexual selection to attract potential mates, male fireflies utilise bioluminescence to seductively entice females (Bailey, 2018).

Figure 14: Fungi bioluminesce in the dark and emit a green light.

Figure 16: Omphalotus Nidiformis (Ghost Fungi).

Out of a total of 120000 species of identified fungi, 100 are known to bioluminesce and are capable of emitting green glowing light (Figure 14). Bioluminescence in fungi is controlled by the circadian rhythm which is regulated by temperature (Widder, 2018). When the temperature drops at sunset, fungi glow to maintain visibility to insects in the dark (Jain, 2020). A group of research scientists in 2015 uncovered why bioluminescent mushrooms grow (Evershed, 2017). The glowing light attracts swarms of insects which is essential, because these organisms allow fungi to disperse their spores (Evershed, 2017). This advantageously propagates the fungi and simultaneously allows mushrooms to reproduce and colonise new areas of the forests so that they can serve as a food source to other organisms (Evershed, 2017). Armillaria Mellea (Figure 15) is the most widespread bioluminescent fungi as it populates forests throughout North America and Asia (Undlin, 2018). Known for its light intensity and bioluminescent properties, the Omphalotus Nidiformis (commonly referred to as the Ghost Fungi) (Figure 16) is found in South Australia and Tasmania (Wikipedia, 2022).

Figure 15: The most widespread species of bioluminescent fungi (Armillaria Mellea).

Conclusion

Bioluminescence occurs in both deep sea and terrestrial organisms (Natural World Facts, 2021). It is an adaptation that is used by many creatures for a variety of reasons such as repelling predators, luring prey, and seducing potential mates (Natural World Facts, 2021). This phenomenon continues to fascinate researchers and has characterised itself as a

never-ending field of study, a source of marvel, and generally an absolute wonder and astonishment in the world of science.

WORD COUNT (excluding all citations and captions): 1413

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