



# Bioluminescence in Fishes: Diversity and Functions



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## Introduction

Bioluminescence is an amazing biological phenomenon, which can be found in terrestrial and oceanic environments. Numerous bioluminescent taxa were described from the marine environment [1-2]. Bioluminescence is especially abundant in the deep-sea. The majority of luminescent taxa are invertebrate animals. In contrast to the high diversity in invertebrates, vertebrates lack bioluminescent light organs, with the exception of an amazing diversity in teleosts and some shark species. A recent paper reported that bioluminescence appeared in ray finned fishes in 27 independent evolutionary events [3]. Bioluminescent light is generated in specialized light organs based on an oxidation of a light emitting luciferine in the presence of oxygen and the enzyme luciferase [1,4]. Most of the bioluminescent species produce blue green light in the wavelength range around  $\lambda_{max} \sim 475\text{nm}$  [1]. Luminescence in fishes can be divided into two different types of light production. Fish species with intrinsic bioluminescence show their own luciferase-luciferin system in specialized light organs. Nitric oxide was suggested to modulate adrenaline stimulated light emission in hatchet fishes of the genus *Argyrops* [5].

In case of cartilaginous fishes, luminescence is controlled by the application of melatonin as reported for the pygmy shark *Squaliolus aliae* [6]. Fish species with extrinsic bioluminescence are not able to control their light emission directly. These species host bioluminescent bacterial species in specialized light organs. The bioluminescent bacteria produce a constant light and fishes with extrinsic luminescence use mechanical structures to cover the light organs and produce impressive blink patterns during the night. The flashlight fishes (Anomalopidae) for example use different mechanisms to close their light organs [7]. Numerous studies that describe the anatomy, diversity, function and evolution of bioluminescent light organs in fishes were published in the last 100 years. The objective of this review is to give a short overview about the functions of extrinsic and intrinsic luminescence in fishes.

## Fishes with Intrinsic Bioluminescence

Fish species with intrinsic luminescence use their own luciferase-luciferin system to produce light. Many different

types of light organs and functions of light organs were described. Bioluminescent sharks use ventral photophores to mimic residual light from the water surface and remain unseen by potential predators. This function is called counter illumination. The sharks produce a constant glow and swim up and down in the water to remain unseen and follow a so called «iso luminance depth» [8]. The small deep-sea lantern-shark *Etmopterus spinax* was suggested to use a light organ on the dorsal spine as a visual signal that deters predators in addition to the ventral light organs for counter illumination [9]. The tiny cookie-cutter shark *Isistius brasiliensis* has an unusual feeding behavior.

The small shark bites small round pieces of flesh from pelagic predators like swordfish and tunas. One study suggested that *Isistius brasiliensis* use the ventral photophores to lure pelagic predators instead of the usual function of counterillumination [10]. Lantern fishes (Fam: Myctophidae) show a high diversity and are highly abundant in the mid water column. Lantern fishes have photophores that glow to the sides and downward. In addition lantern fishes show a large photophore that produces strong and short (400ms) light flashes [2,11].

The dragonfishes (Order: Stomiiformes) is an amazing group of bioluminescent fishes. In addition to emitting blue-greenish light, like the most luminescent fish species, dragonfishes produce long wavelength red light. The three dragonfish genera *Malacosteus*, *Pachystomias* and *Aristostomias* show suborbital photophores that emit long wavelength red light and postorbital photophores that glow blue. In addition the genus shows a preorbital photophore that produces red light [12]. The function of red bioluminescence might be related to intraspecific communication [12] and it has been suggested that dragonfish *Malacosteus niger* use red luminescence to see without being seen by other animals [13].

## Fishes with Extrinsic Bioluminescence

Fishes with extrinsic luminescence lack their own luciferase system. They host symbiotic bacterial species in specialized light organs that can either be appendages of the

imentary tract or they show light organs under the eyes (Fam.: Anomalopidae), in a specialized dorsal fin ray (Fam.: Ceratioidei) or light organs at the anterior angle of the lower jaw (Fam.: Monocentridae) [1,4,7,14,15]. Less is known about the transport of symbionts from one generation to the next and about the ontogenetic development of luminescence onset in fishes. The cardinalfish (Fam.: Apogonidae) *Siphamia tubifer* show a ventral light organ and is active during twilight. It has been suggested that *Siphamia* use the light to detect and find zooplankton [16]. The mouth breeding *Siphamia* host the luminescent symbiotic bacterial species *Photobacterium mandapamensis* and one study described that the symbiosis was initiated 8-10 days after the release of the parents mouth [17]. Many deep-sea anglerfishes (Fam.: Ceratioidei) use a luminescent lure at the tip of a modified dorsal fin ray and host symbiotic bacteriae related to the genus *Vibrio*. Angler fishes are generally thought to use the lure to attract prey organisms in the darkness of the deep-sea [18-21]. Prey capture was also suggested for *Gazza minuta* (Fam.: Leiognathidae) display a discrete projected luminescence and it was proposed that *Gazza minuta* attract and locate the fish on which *Gazza minuta* nocturnally feeds. The flashlight fishes (Fam.: Anomalopidae) comprises 6 genera including 9 valid species [22-29]. *Anomalops katoptron*, *Photoblepharon palpebratum* and *Photoblepharon steinitzi* live in relatively shallow waters of coral reefs and feed on zooplankton during the night. Flashlight fishes show enhanced activity during the night. They show bean-shaped light organs under the eyes and host bacteria of the genera *Candidatus Photodesmus* in *Anomalops katoptron* [30] and *Candidatus Photodesmus blepharus* in *Photoblepharon* [31]. Interestingly the related species *Anomalops katoptron* and *Photoblepharon palpebratum/steinitzi* use different mechanisms to close their light organs. *Anomalops* rotate the light organ down and backwards whereas *Photoblepharon* use an eyelid like shutter [7]. Several functions of light organs and blink patterns in flashlight fishes have been proposed [32,33].

(a) The light organs assist in predation, i.e. to see or attract prey organisms.

(b) To avoid predators, i.e. evasive swimming behavior coordinated with rapid blinking (blink-and-run pattern).

(c) Intraspecific communication, i.e. school formation, territorial behavior and courtship behavior. *Photoblepharon* live in pairs or small groups between corals and rocks [34,35].

In contrast, *A. katoptron* swim in schools of up to 200 specimens near the water surface [34,35]. Several functions of bioluminescence like communication, feeding behaviour and territorial behaviour were suggested for *Photoblepharon steinitzi* [32]. The split finflash light fish *Anomalops katoptron* use their light organs to illuminate small zooplankton organisms during the night. They display a high frequent blink pattern during

the night and switched to constant glowing in the presence of planktonic prey organisms. The blink pattern of the light organs also follow an exogenous control by the ambient light, i.e. during dim light conditions the light organ is mainly closed [14]. Bioluminescence in fishes is highly diverse and needs further laboratory and field studies to investigate the exact functions of luminescence in fishes especially in deep-sea and coral reef ecosystems.

### Summary

Bioluminescence in fishes is a widespread phenomenon in oceanic environments. Bioluminescence can be found in ray finned fishes and also in some small shark species. Fishes can either display intrinsic bioluminescence, i.e. they have their own luciferin-luciferase system or extrinsic luminescence, i.e. they host symbiotic luminescent bacteriae in specialized light organs. Bioluminescence in fishes has diverse functions and it is used for illuminating prey organisms, attracting prey, communication, counter illumination and territorial behaviour.

### References

1. Widder EA (2010) Bioluminescence in the Ocean: Origins of Biological, Chemical and Ecological Diversity. *Science* 328: 704-708.
2. Haddock SHD, Moline MA, Case JF (2010) Bioluminescence in the Sea. *Annu Rev Mar Sci* 2: 443-493.
3. Davies MP, Sparks JS, Smith WL (2016) Repeated and widespread evolution of bioluminescence in marine fishes. *PLOS ONE* 11(6): e0155154.
4. Wilson T, Hastings JW (2013) *Bioluminescence Living Lights, Lights for Living*. Harvard University Press, Cambridge, Massachusetts, London, England, pp. 12.
5. Krönström J, Holmgren S, Baguet F, Salpietro L, Mallefet J (2005) Nitric oxide in control of luminescence from hatchetfish (*Argyropspectus hemigrammus*) photophores. *J Exp Biol* 208(pt 15): 2951-2961.
6. Claes JM, Ho HC, Mallefet J (2012) Control of luminescence from pygmy shark (*Squaliolus aliae*) photophores. *J Exp Biol* 215(pt 10): 1691-1699.
7. Johnson GD, Rosenblatt RH (1988) Mechanisms of light organ occlusion in flashlight fishes, family Anomalopidae (Teleostei: Beryciformes), and the evolution of the group. *Zoological Journal of Linnean Society* 94(1): 65-96.
8. Claes JM, Nilsson DE, Straube N, Collin SP, Mallefet J (2014) Iso-luminance counterillumination drove bioluminescent shark radiation. *Scientific Reports* 4: 4328.
9. Claes JM, Dean MN, Nilsson DE, Hart NS, Mallefet J (2013) A deepwater fish with 'lightsabers'--dorsal spine-associated luminescence in a counterilluminating lanternshark. *Sci Rep* 3:1308.
10. EA Widder (1998) A predatory use of counterillumination by the squaloid shark, *Isistius brasiliensis*. *Environmental Biology of Fishes* 53: 267-273.
11. Mensinger AF, Case JF (1990) Luminescent properties of deep sea fish. *J Exp Mar Biol Ecol* 144(1): 1-15.
12. Herring PJ, Cope C (2005) Red bioluminescence in fishes: on the suborbital photophores of *Malacosteus*, *Pachystomias* and *Aristostomias*. *Marine Biology* 148(2): 383-394.

13. Denton EJ, Herring PJ, Widder EA, Latz MF, Case JF (1985) The Roles of Filters in the Photophores of Oceanic Animals and their Relation to Vision in the Oceanic Environment. *Proceedings of the Royal Society B, Biological sciences* 225: 63-97.
14. Hellinger J, Jagers P, Donner M, Sutt F, Mark MD, Senen B, et al. (2017) The Flashlight Fish *Anomalops katoptron* Uses Bioluminescent Light to Detect Prey in the Dark. *PLoS ONE* 12(2): e0170489.
15. Haygood MG, Tebo MB, Neelson KH (1984) Luminous bacteria of a monocentrid fish (*Monocentris japonicus*) and two anomalopid fishes (*Photoblepharon palpebratus* and *Kryptophanaron alfredi*): population sizes and growth within the light organs, and rates of release into the seawater. *Marine Biology* 78(3): 249-254.
16. Dunlap PV, Nakamura M (2011) Functional morphology of the luminescence system of *Siphamia versicolor* (Perciformes: Apogonidae), a bacterially luminous coral reef fish. *Journal of Morphology* 272(8): 897-909.
17. Dunlap PV, Gould AL, Wittenrich ML, Nakamura M (2012) Symbiosis initiation in the bacterially luminous sea urchin cardinal fish *Siphamia versicolor*. *J Fish Biol* 81(4): 1340-1356.
18. Dahlgren U (1928) The bacterial light organ of *Ceratias*. *Science* 68(1751): 65-66.
19. Haygood MG, Distel DL (1993) Bioluminescent symbionts of flashlight fishes and deep-sea anglerfishes form unique lineages related to genus *Vibrio*. *Nature* 363(6425): 154-156.
20. Haygood MG, Prince RC (1993) Light organ symbioses in fishes. *Crit Rev Microbiol* 19(4): 191-216.
21. Munk O (1999) The escal photophore of ceratioids (Pisces; Ceratioidei)-a review of structure and function. *Acta Zool Stockholm* 80(4): 265-284.
22. McFall-NMJ, Dunlap PV (1983) Three new modes of luminescence in the leiognathid fish *Gazza minuta*: Discrete projected luminescence, ventral body flash, and buccal luminescence. *Marine biology* 73(3): 227-237.
23. Boddaert P (1781) Beschreibung zweier merkwürdiger Fische (*Sparus palpebratus* und *Muraena colubrina*). *Neue Nordische Beiträge (Pallas)* 1781: 55-57.
24. Silvester CF, Fowler HW (1926) A new genus and species of phosphorescent fish, *Kryptophanaron alfredi*. *Proc Acad Nat Sci Philadelphia* 78(1926): 245-247.
25. Rosenblatt RH, Montgomery WL (1976) *Kryptophaneron harveyi*, a new anomalopid fish from the eastern tropical Pacific, and the evolution of the Anomalopidae. *Copeia* 1976 (3): 510-515.
26. Rosenblatt RH, Johnson GD (1991) *Parmops coruscans*, a new genus and species of flashlight fish (Beryciformes: Anomalopidae) from the South Pacific. *Proc Biol Soc Wash* 104(2): 328-334.
27. Johnson GD, Seeto J, Rosenblatt RH (2001) *Parmops echinatus*, a new species of flashlight fish (Beryciformes: Anomalopidae) from Fiji. *Proc Biol Soc Wash* 114: 497-500.
28. Baldwin CC, Johnson GD, Paxton JR (1997) *Protoblepharon rosenblatti*, a new genus and species of flashlight fish (Beryciformes: Anomalopidae) from the tropical South Pacific, with comments on anomalopid phylogeny. *Proc Biol Soc Wash* 110(3): 373-383.
29. Ho HC, Johnson GD (2012) *Protoblepharon mccoskeri*, a new flashlight fish from eastern Taiwan (Teleostei: Anomalopidae). *Zootaxa* 3479: 77-87.
30. Hendry TA, Dunlap PV (2011) The uncultured luminous symbiont of *Anomalops katoptron* (Beryciformes: Anomalopidae) represents a new bacterial genus. *Mol Phylogenet Evol* 61(3): 834-843.
31. Hendry TA, Dunlap PV (2014) Phylogenetic divergence between the obligate luminous symbionts of flashlight fishes demonstrates specificity of bacteria to host genera. *Environ Microbiol Rep* 6(4): 331-338.
32. Morin JG, Harrington A, Neelson K, Krieger N, Baldwin TO, et al. (1975) Light for all reasons: versatility in the behavioural repertoire of the flashlight fish. *Science* 190(4209): 74-76.
33. McCosker JE (1977) Flashlight fishes. *Sci Am* 236(3): 106-112.
34. Steche O (1909) Die Leuchtorgane von *Anomalops katoptron* und *Photoblepharon palpebratus*, zwei Oberflächenfischen aus dem Malaiischen Archipel. Ein Beitrag zur Morphologie und Physiologie der Leuchtorgane der Fische. *Z Wiss Zool* 93: 349-408.
35. Haneda Y, Tsuji FI (1971) Light production in the luminous fishes *Photoblepharon* and *Anomalops* from the Banda Islands. *Science* 173(3992): 143-145.



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