Why do duckbill platypuses fluoresce under UV light?

In the 19th century, news reached London that there was a mole-like animal with webbed feet and a flat, beaver-like tail. When they first saw preserved skins of these strange-looking creatures, many experts thought the animal was a taxidermy hoax, with a duck's beak sewn to a mole's body.[1] The duckbill platypus, *Ornithorhynchus anatinus,* continues to intrigue the scientific community: Paula Spaeth Anich and colleagues recently stumbled across a museum drawer for monotremes (egg-laying mammals) while investigating fluorescent flying squirrels. They found that platypus fur emitted a cyan glow under UV light. [2]

Molecular basis of biofluorescence

Photoluminescence in biological tissues occurs when shorter-wavelength photons, such as ultraviolet light, are absorbed and reemitted at longer wavelengths by proteins or pigments. The emission of lower energy light (than absorbed light) is known as Stoke's shift, which is responsible for the characteristic of 'glowing in the dark' observed in animals from many phyla. Chemically, fluorescence occurs when an electron is excited to a higher energy state, before some energy is transferred to other quantised stores, such as vibrational modes, and the remaining energy radiates as light when the electron relaxes to its ground state. To emit visible light, a fluorophore must have a HOMO-LUMO gap corresponding to the energy of the visible region. This is often the case for molecules containing conjugated double bonds, such as aromatic rings.[3] To date, fluorescence in mammals is known to be caused by tryptophan and unpigmented keratin fibres, or the accumulation of porphyrin.[4]

According to Travouillon et al. (2023), it is likely that fluorescence is simply a consequence of unpigmented fur in mammals, as the lack of melanin in lighter fur does not conceal fluorescent tryptophan metabolites. In this respect, biofluorescence is merely an artefact of the amount of melanin present. This is dictated by the amount of white fur in the animal, which can be determined by its nocturnal/diurnal activity, feeding guild and locomotion. This is highly probable in platypus, as fluorescence with the highest intensity is emitted from the pale, white fur on its ventral surface. [5]

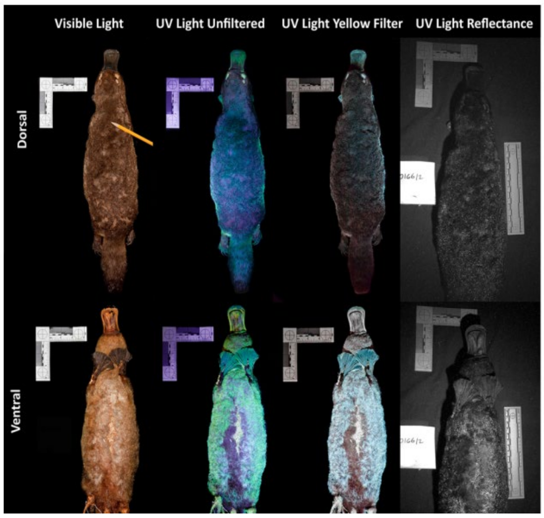

Figure 1: A male platypus (Ornithorhynchus anatinus) museum specimen (FMNH 16612) collected from Tasmania, under visible light and 385–395 nm UV. Cyan-green biofluorescence of ~500 nm seen.

Many mammals' pelages display a distinct reddish UV-PL, caused by the accumulation of ubiquitously expressed porphyrin, a photoluminescent. It is known that porphyrins are associated with all aerobic and anaerobic metabolisms as part of the heme biosynthesis pathway.[6] Although porphyrins are usually excreted through faeces in mammals, their overproduction and tissue accumulation can be malignant, due to the presence of synthase enzymes in fox squirrels (*Sciurus niger*)[7] or free-base porphyrins in springhare species (*Pededitae*)[8]. However, as porphyrins cause a distinct reddish UV-PL, and the fluorescence of platypuses is characterised by their blue-cyan glow, this suggest platypus biofluorescence is not a result of porphyrin accumulation.

Validation of fluorescence

Biofluorescence is determined mostly using preserved animal taxidermies; the preservation process could affect the degree of fluorescence which is measured. For example, Nummert et al. [9] reported a decrease in fluorescence intensity for preserved compared with live dormice. Borax powder, a common preserving agent, is itself fluorescent with an intensity above 400 arb. units.[10] However, in the platypus, preservation methods of arsenic and borax produced similar quantified fluorescence spectral curves in frozen specimens as live animal pelage, validating that light scatter and preservation are not sources of fluorescence. Platypuses are genuinely fluorescent. [11] [12] This is further supported by the finding of a freshly killed platypus on a road in Australia which glowed under a UV-radiating black light, confirming that both living and preserved platypuses are fluorescent. [13]

Genetic basis of biofluorescence

Assuming biofluorescence is genetic, why would platypuses have the phenotype for biofluorescence? All traits which taxonomic groups exhibit today are due to evolution and inheritance.[14] Populations evolve through a series of mechanisms: allele frequency can change through natural selection or genetic drift acting on new mutations, and the gene pool of a population can be modified by gene flow.[15] In order to determine whether natural selection has driven the evolution of biofluorescence in the platypus, it is necessary to establish if there is an associated survival advantage.

Mechanism of evolution - natural selection

Natural selection is the process of evolution responsible for adaptation: organisms more suited to their environment through genetic mutations are more likely to survive, reproduce and pass on their beneficial alleles. This process causes species to change and diverge over time.

It is reasonable to rule out sexual selection, a mode of natural selection where the selection pressure stems from the desires of the opposite sex, as biofluorescence in platypuses is not a sexually dimorphic trait: the cyan-blue colour displays a similar pattern and intensity in male and female platypuses.[16]

Platypuses navigate their twilit, aquatic environments using mechanoreception and electrostimulation; and hunt prey underwater without vision. They have push-rod mechanoreceptors on their bills to detect pressure and motion, as well as electroreceptors to track the electrical signals produced by muscular contractions of prey. As platypuses already have a range of complex communication mechanisms and hunt without using vision, their ventral fluorescence is unlikely to act as a visual cue or be used for the purpose of intraspecific communication.[17] Scientists therefore hypothesise that the function of biofluorescence is more likely to be interspecific. It is possible that fluorescence has aided platypus survival by providing camouflage to help mask the species from predators, and there are two mechanisms via which fluorescence may achieve this.

The platypus is active at twilight and overnight, and many nocturnal animals appear to have UV-sensitive vision.[18] Biofluorescence may therefore benefit the species, not due to the emission of visible light, but because it absorbs UV and reduces the visibility of platypuses to UV-sensitive predators. For example, owls are platypus predators and detect UV frequencies.[19] Similarly, many nocturnal animals have fluorescence in more body regions than diurnal species, due to its potential protection using camouflage.[20]

Alternatively, Travouillon et al. suggest that biofluorescence can provide camouflage through the effect of counter-illumination, which is the masking of an animal's silhouette with ventral photophores, allowing organisms to hide from predators below by blending in with the light patterns above[21]; as well as countershading, where animals have a coloration gradient on their body, darkening upwards to match the luminescent gradient of the water. [22] The dorsal surface of the animal body is therefore more darkly pigmented than the ventral side. [23] This effect could apply to the semi-aquatic platypus, especially since the pale, white fur on its ventral side fluoresces with the highest intensity, whilst little fluorescence is observed from its dorsal areas with dark fur.[24]

Mechanism of evolution - gene flow and genetic drift
Evolutionary change does not have to be adaptive, and mechanisms such as gene flow and genetic drift could be responsible for biofluorescence in the platypus instead.

Gene flow is the movement of genetic material from one population to another due to migration and can increase the genetic variation of populations.[25] Here, gene flow is unlikely to have occurred due to the low genetic diversity and isolated populations of platypuses. The genetic diversity in some platypus populations is described to be ‘perilously low’ and estimates of heterozygosity detected by microsatellites (HE= 0.032) are among the lowest levels of genetic diversity recorded in a naturally outbreeding vertebrate population. The small population size results in a lack of naturally occurring gene flow.[26]

Due to platypuses’ relatively low genetic diversity, population isolation and hence frequent inbreeding, it is much more likely that acquisition of biofluorescence is due to genetic drift. This is because genetic drift occurs when population size is limited. By random chance, certain alleles increase or decrease in frequency due to "sampling error" in selecting the alleles for the next generation from the gene pool of the current generation. Genetic drift results in a shift away from the Hardy-Weinburg equilibrium and could also cause initially rare alleles to become much more frequent, and even fixed.[27] It can result in increased homozygosity and loss of variation amongst individuals in a population, as well as the founder’s effect, which is seen in the low heterozygosities of platypus populations on Kangaroo Island.[28] Moreover, this could explain why there is no explicit survival advantage to biofluorescence in platypuses as genetic drift does not consider an allele’s benefit to the individual that carries it, and an allele becoming fixed is purely up to chance.

Inheritance from phylogeny
However, fluorescence in mammals has recently been discovered to be much more common than previously thought. Biofluorescence is a characteristic that may have arisen from random mutations in the ancestors of platypus, and may have become a vestigial trait. It is most likely to have been inherited as biofluorescence is extremely common amongst mammals and appears across almost all clades of the mammalian phylogeny in all habitats globally, present in over half of all mammalian families and representing all of the major mammalian lineages; placental mammals, marsupials and monotremes.[29] Platypuses belong to the order of monotremes, which along with marsupials and eutherians diverged from the therian mammal lineage ~150 Myr ago. The only other species of monotremes are the four species of echidnas.[30] As marsupials and all monotremes (e.g. *Tachyglossus aculeatus*) also display biofluorescence, this suggests that the characteristic in platypuses is an ancestral mammalian trait – a dominant phenotype given its homogeneity – passed on from the therian lineage.

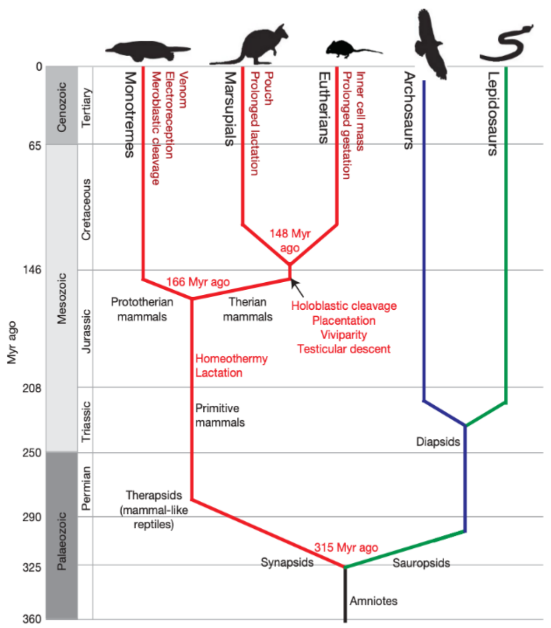

Figure 2: Platypus (Ornithorhynchus anatinus) phylogeny

Conclusion
Why do platypuses fluoresce under UV light? There are two aspects to this - the molecular and evolutionary basis. It is certain that platypuses fluoresce due to evidence in roadkills, and similar spectral curves across frozen and preserved animals. From the known causes of fluorescence, tryptophan and unpigmented keratin fibres are most likely due to platypuses' distinct blue-cyan glow.

It is most likely that platypuses inherited the trait of biofluorescence from phylogeny due to supporting evidence of its prevalence in close lineages. Hence, the widespread prevalence of this trait also reasons that it is unlikely that biofluorescence evolved in platypuses due to random mutations, gene flow or genetic drift. There is also very weak evidence for the suspected survival advantage of the trait - protection against predators; actual field-based research will be essential to reach a conclusion.

It is worth noting that this conclusion is drawn from an extremely small sample size, limiting our ability to draw conclusions about the ecological function of this trait. It would be beneficial to further investigate the molecular basis of this trait, using fluorescence spectroscopy, extraction of biofluorescent compounds using thin-layer chromatography, as well as liquid chromatography to identify specific fluorophores. This is necessary for further insight into the genetic basis of the trait, and which genes or pathways lead to the production of fluorophores. Observing fluorescence in newborn platypus will also provide more information about whether biofluorescence could be related to diet or any metabolic function of developed platypuses. Assuming inheritance is the main cause of biofluorescence in platypuses, analysing when the trait was introduced into the genes of early mammals using phylogeny analysis may also be useful to determine a reason.

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Finally, fluorescence is found in a wide variety of organisms, from frogs to corals, from catsharks to jellyfish. Yet in most cases, it fails to exhibit any clear adaptive significance.[31] So why do we always expect to find a purpose? Would a lack of function in any way diminish the delight in learning about the platypus' unexpected fluorescence? This was an argument Darwin himself was faced with after the acceptance of natural selection. He was captivated by the question of why orchids come in so many shapes, sizes and arrangements, in other words, investigating the existence of analogous features, when they were all meant to accomplish the same thing: fertilisation.[32] By tracing instead the history of the orchid structures across related species, the cumulative effect of successive "chance" variations became evident.[33] Perhaps – echoing Darwin – the platypus' startling trait has no ultimate "why" at all, besides history and happenstance.

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