More Fun Than Fun: Why Do Animals Sport Bright Colours?

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*A lilac-breasted roller (*Coracias caudatus*). Photo: David Clode.*

This article is part of the 'More Fun Than Fun' column by Prof Raghavendra Gadagkar. He will explore interesting research papers or books and, while placing them in context, make them accessible to a wide readership.

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Nature is beautiful, and it is stunningly beautiful when it is colourful. We derive great pleasure in marvelling at the flowers, fruits, insects, spiders, crabs, fishes, frogs, snakes, birds and fellow mammals, for their bright reds, pinks, blues, greens, purples and oranges, and many more colours for which we scarcely have names.

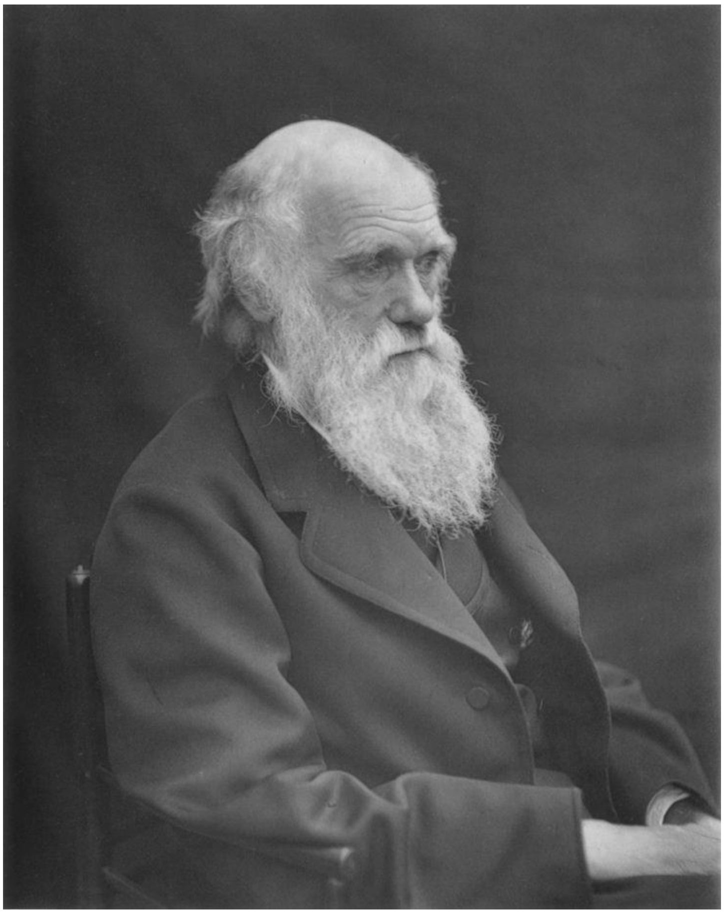
But evolutionary biologists are not content with marvelling at beauty. We want to know *why*. Why should animals and plants be so brightly and diversely coloured? Why should some be red and others blue or green? Why should some use colours to hide while others to advertise? Why should some colourful animals imitate other colourful animals? Why, indeed, should some lack bright colours and be so dull? Robert MacArthur (1930-1972), a well-known founder of evolutionary ecology, said, "Doing science is not such a barrier to feeling or such a dehumanizing influence as it is often made out. It does not take the beauty from nature."

Answers to the questions raised above cannot but add to our appreciation of colourful nature.

The mother of all biology

All biology, however sophisticated and however technology-driven its present-day study, begins with natural history – simple observations and simple experiments in nature made by curious and intrepid wanderers. The biology of colour is no different. We should celebrate at least four famous naturalists who laid the foundation for the modern study of colouration in animals.

Unsurprisingly, the first name is Charles Darwin (1809-1882), who was much concerned with colouration as a mechanism of adaptation and an agent of natural selection, and even more so as the mediator of sexual selection. Darwin paid great attention to the colours he saw, both in nature during his voyage on the *Beagle* as well as in the outcome of his breeding experiments back home. It appears that Darwin anticipated the importance of accurately observing and recording colour. He carried with him the then best available dictionary of colours, Werner's Nomenclature of Colours (1814), which described and defined eleven shades of blue, ten shades of red and eight shades of white.

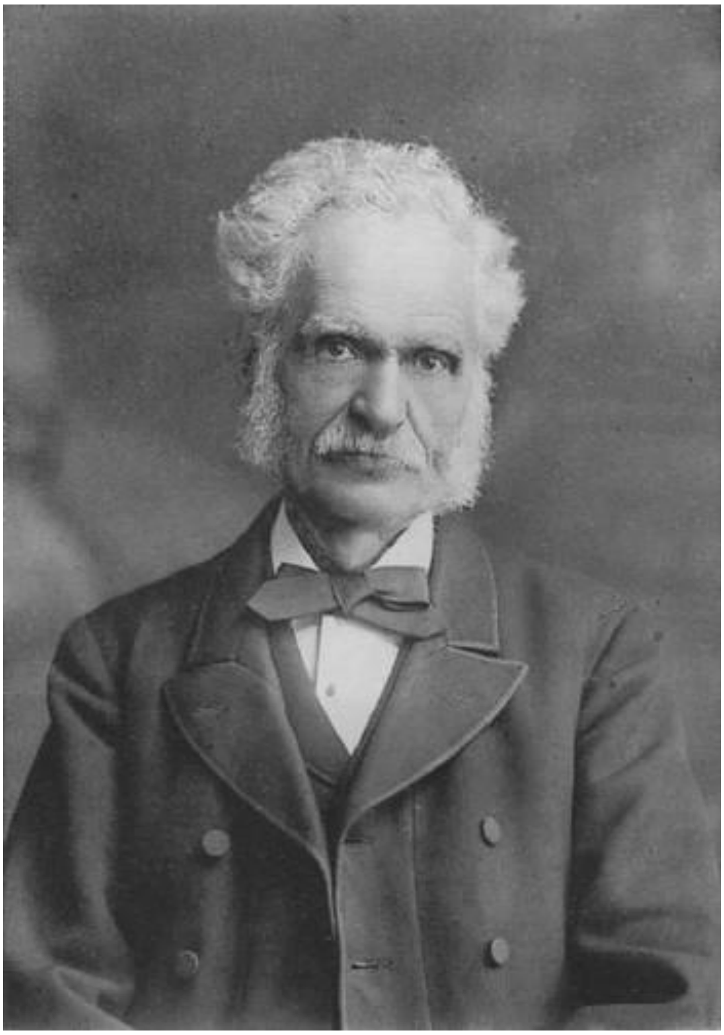


Charles Darwin (1809-1882). Photo: Leonard Darwin, public domain

Animals can use two diametrically opposite strategies to deal with predators: become inconspicuous (cryptic) or develop poisons (toxins or venoms). The problem with poisons is that their action comes *after* the act of predation. So toxic and venomous species must advertise and warn predators, by becoming conspicuous, and a good way to do so is to become colourful. This is called aposematism.

Making toxins and venoms is usually much more expensive than merely becoming colourful, so there is scope for cheating. Some species can be merely colourful, resembling those that are toxic or venomous, thereby getting the same protection without paying the cost of making the toxin or venom.

When a harmless or palatable species resembles a toxic or venomous one, the phenomenon is called Batesian mimicry, in honour of the English naturalist Henry Walter Bates (1825-1892), who first described the phenomenon based on his extensive study of butterflies in the rainforests of the Amazon.



*Henry Walter Bates *1825-1892). Photo: Beetle_Guy, CC BY-NC-ND 2.0*

The German zoologist and naturalist Johann Friedrich Theodor Müller (1821-1897) discovered a variant of the phenomenon of mimicry that involves cooperation rather than cheating. That is, aposematically coloured species mimic each other, thus reinforcing the warning to predators. This has come to be called Müllerian mimicry.

There are many examples of Batesian and Mullerian mimicry among millipedes, butterflies, moths, beetles, ants, bees, wasps, mantids, hoverflies, crabs, cuttlefish, octopuses, spiders, fish, toads, lizards, snakes, birds and mammals, and also in plants (many orchids and some other angiosperm families). We now know that both Batesian and Müllarian mimicry can coexist leading to complex dynamics between the populations of models and mimics – the kind of dynamics best studied with mathematical models.

Johann Friedrich Theodor Müller (1821-1897). Photo: Public domain

I find it remarkable that the naturalist Müller himself provided the first mathematical model of the phenomenon of mimicry, already in the 19th century, which was also perhaps one of the first examples of the use of such models in all of biology. (I also recently discovered that there was much more to Müller than Müllerian mimicry.)

The fourth naturalist in our honour list is Alfred Russell Wallace (1823-1913), the co-discoverer of the principle of natural selection. Wallace was equally obsessed with colour in all that he surveyed. Darwin had an uncanny habit of being correct about most things he said, so it is refreshing to note the few instances where he was not entirely right.

An Indian common mormon (Papilio polytes) mating pair showing sexual colour dimorphism. Photo: Jeevan Jose, Kerala (© 2014 Jee & Rani Nature Photography, CC BY-SA 4.0)§

The life-long butterfly enthusiast, Krushnamegh Kunte, then at the University of Texas, Austin, and now at the National Centre for Biological Sciences, Bengaluru, put Darwin's and Wallace's ideas to the test. He did so by peering at an already published molecular phylogeny (tree of life) of *Papilio* butterflies and found that, at least in this case, Wallace was right. Interestingly, these Papilio butterflies were the centre-stage of the debate between Darwin and Wallace regarding the relative roles of sexual and natural selection. Kunte showed that sexual dimorphism in these butterflies results from females deviating from the ancestral colour patterns to become Batesian mimics of unpalatable species – while the males retained their ancestral colour patterns.

I fell in love with Kunte's paper when I read it in 2008, partly because it gave a thumbs up to Wallace rather than to Darwin (I have an irresistible love for underdogs), and partly because of its cleverness in using an already published molecular phylogeny (these are very expensive to produce) and seeing beyond what others had seen (this costs no money, just a clever mind).

Colour science and colour biology

Today, we have a very sophisticated understanding of the science of colour and the biology of colour. In researching for this article, I read the highly entertaining and uniquely interdisciplinary book, *The Natural History of Colour – The Science Behind What We See and How We See It*, by Rob DeSalle of the American Museum of Natural History and Hans Bacher of the Australian National University. DeSalle and Bacher take us on a romp through the deepest and longest imaginable history of colour, starting with the big bang and ending right up to the role of colour in racial conflict among humans.

The present state of our knowledge of colouration in animals and plants is the product of the combined and collaborative efforts of evolutionary biologists, behavioural ecologists, psychologists, physiologists, geneticists and anthropologists – and even optical physicists and soft-condensed matter physicists. I have been learning with some surprise and considerable satisfaction that this research has many biomimetic and bio-inspired applications in the production of new materials and the development of new technologies in the sports, fashion, military and conservation industries. The biology of colour is now described as "a field that typifies modern research: curiosity-led, technology-driven, multilevel, interdisciplinary and integrative".

That an area of biology has reached such a status is gratifying. But there is one downside. It relegates most people to the role of an awe-struck audience – constraining them to be consumers of knowledge without hope of becoming knowledge producers. I know from personal experience, during my high school and undergraduate days, that this can be depressing to young and aspiring scientists who have access to the knowledge generated by past research but may have no access to modern science infrastructure.

I felt a sense of déjà vu when I read recently that Francis Crick, of the double-helical structure of DNA fame, was worried as a child that everything would have already been discovered by the time he grew up. Now, I know that we need not despair. The natural world is so vast and unexplored that there will always be scope and need for simple, low-cost research driven by ideas rather than technology. I am happy to say this belief of mine is frequently reinforced. The most recent reinforcement came from some beautifully simple experiments on snakes conducted by Ullasa Kodandaramaiah and his student Vivek Philip Cyriac at the Indian Institute of Science, Education and Research, Thiruvananthapuram.

Enchanted by snakes

In an enchanting essay entitled *The Serpent*, the biologist Edward O. Wilson says:

> "Human beings have an innate fear of snakes; more precisely, they have an innate propensity to learn such fear quickly and easily… The images they build out of this peculiar mental set are both powerful and ambivalent, ranging from terror-stricken flight to the experience of power and male sexuality… It pays in elementary survival to be interested in snakes and respond emotionally to their generalised image, to go beyond ordinary caution and fear… It is possible to turn the mind in the opposite direction, to learn to handle snakes without apprehension or even to like them in some special way…"

Vivek and Ullasa seem to provide proof of Wilson's prediction. Vivek told me that he got interested in snakes during his master's course, when he conducted reptile surveys across Kerala's Western Ghats, which in turn prompted him to study snakes for his PhD. Ullasa tells me that he was always interested in reptiles and that when Vivek came and told him of his interest in studying the evolution of snakes, he was immediately intrigued. He adds, "The studies on shield-tail snake colour patterns evolved organically as a result of my long-standing interest in understanding how animals use colour patterns to avoid predation, Vivek's extensive field knowledge of these snakes, and Vivek's novel ideas". Thus, Vivek and Ullasa decided to solve the mystery of why uropeltid snakes are so brightly coloured.

The uropeltids are a small group of primitive, non-venomous, burrowing snakes, endemic to India and Sri Lanka. Although they have a somewhat drab backside, they usually have a bright and contrasting yellow or red underside, which is displayed to predators by turning upside down and twitching the body. Brightly coloured non-venomous snakes are well-known to mimic the colouration of highly venomous coral snakes in North America – an exceptionally well-studied system of Batesian mimicry. It had therefore been assumed that our uropeltids must be Batesian mimics of our local venomous coral snakes, or perhaps of some local poisonous centipedes.

Top: Ullasa Kodandaramaiah's students in the field. Bottom-left: Coloured clay models before being placed in the transects. Photo: Ullasa Kodandaramaiah. Bottom-right: Ullasa. Photo: Subhash Rajpurohit.

Vivek and Ullasa however, proposed a radically different possibility. They postulated that the uropeltids don't mimic venomous snakes or poisonous centipedes. Instead, they provide an honest signal of their own undesirability. But why should they be undesirable to predators? Uropeltids have an unusual body structure, perhaps adapted to their burrowing habit: a narrow head (with which they dig) and a short, distinctive tail that is covered with hard scales and looks like a head, complete with false eyespots. Hence the name 'shield-tail snakes' and the term cephalic mimicry.

When attacked, they hide their true heads under their coiled bodies and display their tails. This makes it hard to capture them, and takes a very long time for the predators to subdue and eat them if at all they succeed (20-40 minutes as compared to 2-4 minutes for other similarly sized snakes). Uropeltids are often preyed upon by terrestrial birds such as jungle fowls, peafowls, domestic chickens, Guinea fowls and turkey, which may also feed instead on, grains, various arthropods, amphibians, lizards and snakes. Vivek and Ullasa postulated that uropeltids use their colourful undersides to signal their undesirability due to these long handling times.

Then they set about getting evidence for or against their hypothesis. First, they asked whether their bright colours indeed protect uropeltids from predators. To find out, they prepared 1,000 model snakes using non-toxic, brown-coloured clay and painted them with colours resembling uropeltid snakes. They placed the model snakes in different habitats where the snakes are usually to be found. After some 86 hours, they recovered as many models as they could locate, and looked for evidence of predation marks on them, made most likely by birds such as jungle fowl. They found clear evidence that model snakes that were brightly coloured to resemble the real snakes had fewer predation marks relative to models without bright colours. Bright colouration was indeed protective.

In a final, and clinching, experiment, they tested the idea that predators learn to associate the bright colours with increased handling times. We might expect predators to avoid prey with long handling times if other prey with shorter handling times are available. To test whether predators can learn to associate these colours with handling times, Vivek and Ullasa made model snakes with similar colours but with long and short handling times. There is a rather interesting story behind this, which Vivek narrated to me in an email:

> "The idea for the captive chicken experiment testing if birds can learn handling time came by accident when a student, C.S. Jayasooryan, made chapatis [Indian bread] for dinner during our field visits. The chapatis were so hard that it took really long to finish dinner. This incident got me thinking that the cephalic mimicry in uropeltid snakes could increase handling time of the snakes and that the bright colouration could be advertising longer handling times. This eventually led to the experiment where we manipulated handling time using baked and unbaked chapati dough to test if birds can associate their colour with handling times and avoid prey with long handling time."

First, Vivek and Ullasa gave captive chicks the opportunity to learn. They offered one set of chicks with model snakes made from baked as well as unbaked dough – but presented on brown paper, so that there was no way to distinguish between them beforehand. They verified that chicks took significantly longer time to handle (measured as the time from the first attack till the model was completely eaten) the models made from baked dough compared to the models made from unbaked dough. When given a choice later, these chicks did not display any preference for baked versus unbaked models, suggesting that they had not learnt how to distinguish between them.

Next, they presented baked models on yellow paper and unbaked models on brown paper to another set of chicks. When tested later, these chicks preferentially attacked the unbaked models on brown paper and avoided the baked models on yellow paper, suggesting that they had learnt that the yellow paper contains food that is difficult to handle. The title of their paper says it all: 'Don't waste your time: predators avoid prey with conspicuous colours that signal long handling time'.

I wholeheartedly admire and applaud the modern, technology-driven biology – but it warms my heart to know that there is still a lot that we can do merely with love for nature, bright ideas and some dough, baked and otherwise.

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