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Q & A

Justin Marshall

Justin Marshall is Professor of Neurobiology and Marine Biology at the University of Queensland in Australia within The Queensland Brain Institute. He can be labelled a visual ecologist as he studies comparative eye design and how this is guided by the physics of light. He has co-written a book called "Visual Ecology"*, co-edited a book called* "Sensory Processing in Aquatic Environments"*, is co-editor of a book series in Vision Research and co-authored another book called* "Coral Reefs and Climate Change, the guide for education and awareness"*. As with many marine scientists he worries about the future of the oceans and how best to translate information to non-scientists. He also wonders if anyone reads books these days?*

Did you always want to be a biologist? I have been a marine biologist for as long as I can remember. The neuroscience bit of my life came later but I was fortunate to have marine scientists as parents. To be more accurate, my father was Her Majesty's curator of fish at The British Museum of Natural History and my mother a natural history illustrator. They both had — and as my mother is still going at 94 one continues to have — a strong but gentle influence on my life and chosen direction. They never forced me into it but, as a kid, following them around the beaches and boats of the world, meeting all these cool guys that scuba-dived, had knives strapped to their legs and that got in submarines was just too much, it was obvious, I had to do that too!

One of my early memories is being taken to the Natural History Museum in London to be shown the coelacanth, a 'living fossil' fish found in 1938 and on display in the museum. It was being taken behind scenes for a rest from the eyes of the public so I got to see it close-up in its smelly vat of formalin and, when my Dad was not looking, even poke it a bit. So, at an early age I was hooked by a fish and as we often had smaller deep-sea specimens around the house that my mother painted and drew, ichthyology was just part of life.

My mother was described in one review as "The greatest natural history artist this (last) century" and from her I got a keen sense of form and colour in nature. I do have a bit of an artist's eye, if not the full-blown ability or patience to sit and paint one fish for a whole week. One of my current questions in science is *why are reef fish colourful?* and I have my parents to thank for seeding this early on. I also love parrots and birds of paradise and fiddler crabs and have to face the fact that I am distracted by shiny (or colourful) things. Decoding how animals communicate with colour has become an obsession.

I was lucky at school to have two superb biology teachers, one also named Marshall so my destiny seemed even more sealed. Since then, Mike Land, my DPhil supervisor was and still is a great inspiration. Mike and Mr Marshall both displayed an infectious fascination with beasties and creepy-crawlies and how they work. Mike's thing is optics and animal eyes, so when I started with him at Sussex University I was given a few choices of study animal: spiders, butterflies or these weird crustaceans he had seen once, mantis shrimps.

After a false start or two and a look around my peers (Colin the bat-poo sifter and John on badger anal secretions), I realised mantis shrimp (stomatopods) were for me and the only ones out of Mike's list that lived in the ocean; I was a trained zoologist after all! In particular stomatopods were not to be found in or around the pond near the pub at Sussex University, where several of my contemporaries sourced their study animals, but on The Great Barrier Reef. Stomatopods are truly wonderful animals with, for example, four times the number of colour photoreceptors as humans, and as Australia also has pubs, all was well.

Do you have a scientific hero alive or dead? Aside from Mike Land, who has received enough praise already, I cannot identify one science hero but have categories or sub-cultures of scientists that I have great admiration for and some of whom I have been lucky enough to work with. One

Photograph of painting by Chris Martin.

such sub-culture is the observers of nature — Konrad Lorenz, E.O Wilson and W.H. Longley spring to mind. While Lorenz is famous as one of the founders of the study of ethology (animal behaviour) and Wilson for ants and animal societies, Longley is less well known. Working at the beginning of last century, he heroically humped cameras around in big brass housings to photograph and observe marine fish and all three men deserve praise for doing something that relatively few biologists do now: observe nature.

Unfortunately, in our current "apply or die" scientific culture, there is little funding or support for such work and as a result we are really missing out, both at a personal level and at a cultural level. When I say "I'm a mantis shrimp man" I often get asked what good that does humanity and am proud to say, on one hand "Bugger all — I just love them". On the other hand, I am lucky as our discoveries in stomatopod vision now guide satellite design, optical memory systems for computers and early cancer detection. How did we discover that? Not because we were asked to find a better way to do something useful for humans but because my stomato-colleagues and I are curious about nature.

Wilson's take on life, which boils down to watch an ant and you will feel happy, is in my opinion a vital message in our now self-obsessed screen-driven existence. Hmmm — can you tell I'm over 50! Read E.O Wilson's book called "*Biophilia*" — he explains man's visceral link to nature

much better than I can in these few words.

Other sub-culture influences are the visual ecology and animal colour greats, such as John Lythgoe, Eric Denton and Bill *Mac* McFarland. John's book *The Ecology of Vision* is a constant go-to and I was lucky enough to work with Eric and Mac. Animal vision greats are also important role models for me and Jack Pettigrew (Australia), Simon Laughlin (England), Nick Franceschini (France), Dan Nilsson (Sweden) and Nick Strausfeld (USA) feature large there. So not a single scientific hero but a football team of them and if I had to give a piece of advice to a young(er) scientist it would be hang out with clever guys everywhere as some of it does rub off.

Outside of *scientist* in the strict sense, Sir David Attenborough is a one-man inspiration for me and I am lucky enough to have worked with him on a couple of documentary series. Although with no formal scientific training, he is by trade another great observer of life and of course a fascinated and engaging communicator of what he sees. Being able to explain science and the natural world clearly and involving everyone in it is a constant goal for me. I must admit that when I sit and write a scientific paper, I sometimes run the Attenborough voice through my head and pretend to be David. Guess I should buy one of those blue safari shirts.

What is your favourite discovery? You should be able to guess by now, mantis shrimp vision. A larger-than-life African princess and my long-term colleague Tom Cronin have helped this along. The African princess by visiting my aquarium room at Sussex while wearing a psychedelic kaftan of many colours. As she walked through the door, all the stomatopods leapt to the front of the aquaria and waved their appendages. Being a highly-trained observer — maybe they see colour, I thought — quite a radical step for a small-brained crustacean. Shortly afterwards, as my brain developed, I discovered the basis of their colour sense and was shipped off to Tom's lab in Baltimore as he had a useful machine and was the crustacean vision man and an all-round nice guy. Thirty years later, along with Roy Caldwell, the man who knows more about stomatopods than anyone, we are still working together unlocking the secrets of stomatopod vision which include not just complex colour vision but a sense of polarised light and even circularly polarised light that places them in a class of their own. Four hundred million years ago one of them got hold of an optics text book and now they are a physics lesson on a stick.

How does the push towards more applied science affect your work? I have touched on this a bit already and from my experience with stomatopods, it is clear to me that science discovery should not be driven by an application end-goal. I just love getting out in nature and rolling around in it. But as a terminal techno-nerd I also embrace bio-inspired engineering and the lessons we can take from nature's trial and error tinkering, evolution. I am best at the front-end of the innovation process, am happy to pass on ideas to others that may exploit what I discover for human benefit and hope to remain slightly involved in that process up to a point. Guess I'll never get rich?

The largest change I have had to make is in the way grant proposals for funding are written as, with dwindling resources for scientific research, the 'apply or die' culture I mentioned earlier is the reality in many sectors. This is a great shame, especially for the new eager (OK to be poor) naturalists coming through the system and is in part my fault. The push to apply comes essentially from a system ignorant in what actually underpins innovation and application, and that ignorance has come from a lack of clear communication from science to the public. Until recently one of the government bodies funding my work classified it as 'non-directed research'; well, that made me feel good. Never mind governments, they will do what we tell them to win votes, the conversation between science and the public, who after all pay for the science we do, needs a shake-down.

My own attempt at doing better in this space is CoralWatch, a citizen-science venture where untrained folks from school kids to tourists engage in gathering data (www.coralwatch.org). I started CoralWatch as reefs were bleaching more regularly and we needed an army of volunteers to help monitor. The Great Barrier Reef is undergoing this stress-response now: a loss of symbiotic algae when water remains unseasonably warm. Over the last twenty seven years this huge Australian nature icon has lost 50% of its coral cover and after this season may drop below that. At the time, I thought we were being most useful in helping to collect data on coral reefs to feed this back to science. Now I realise that at least as important is the engagement process and fostering a relationship of trust between science and society. Apparently Benjamin Franklin did not say "*Tell me and I forget, teach me and I remember, involve me and I learn*" but this is our CoralWatch mantra and I think a good guide to get effective funding for science back on the agenda in general. It does take time away from research, but I strongly believe that most, if not all, scientists should have a blue safari shirt in their cupboard.

Social media and science: good or bad? I have a smart-phone and other smart-hardware but don't engage in Facebook, Twitter or Snapchat personally. However, professionally I do all of the above and think it vital to interact with social media in order to communicate wonderful scientific discoveries. CoralWatch has thousands of friends, but I really don't care what they had for breakfast. Maybe that is the mark of a 50+ year-old person, but there are clearly dangers in spending too much time desperately tweeting and finding 'friends' that might like to see your rather limp discovery. Like applied versus blue-sky science there is a good compromise here and I don't think we have found it yet.

As I write, it is orientation week here on campus and I am saddened and amused by the zombie-smart-phoners shuffling around campus bumping into each other, not talking. I am also amazed at the excited student talking to his family by SKYPE as they sit on a beach in California. Smart devices both destroy and create communication in personal life, and this is being mirrored through scientific institutions. We don't have books on campus any more — I hate that! I can

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sit at my desk and pull down almost any contemporary paper even before it is printed — I love that!

Fast communication, like media releases on an exciting discovery, often gets stuff wrong. Sorry media, but it is true and my advice to students and mentees is: if the media get 50% right that is pretty good. Media, do better, we can ignore you and do it ourselves these days. But as the old saying goes, even bad publicity is good and at least your thing got beyond the four walls of the laboratory. It is important not to worry about too many decimal places as a scientist, while by nature we need to stick to as accurate a picture as possible. Like any good marriage, there is a compromise but it may hurt finding it.

Social media should never be allowed to pass judgment on anything more than "did you like what I had for breakfast?" and should not, in my opinion, be viewed as a peer review process. In the Victorian era of science there was a magazine published called "*Science Gossip*" which contained observations from the Reverend Tottington-Bassett on the number of toads in his garden that year. Fascinating stuff! Scientific journals, like *Current Biology*, only allow words and ideas in print after an exhaustive and exhausting review process involving much hair-tearing and trying to get it right. More often than not, the work is rejected. A problem social media has introduced is that the innocent bystanders to the scientific process no longer distinguish "*Science Gossip*" from "*Current Biology*". It is a challenge for both science and society to find this balance again using the new and exciting tools at our disposal.

For me, the answer lies in both reading books and keeping up to date with gizmos. Importantly the fast stuff, social media, needs to be taken as a first indication of the 50% truth and as a spark to getting out the peer reviewed stuff. Get interested, buy a book online, especially if it is one of mine.

Sensory Neurobiology Group, Queensland Brain Institute, University of Queensland, St Lucia, Brisbane, Queensland 4072, Australia.
E-mail: Justin.Marshall@uq.edu.au

Quick guide

Shelterin

Isabelle Schmutz and Titia de Lange*

What is shelterin and what does it do? Shelterin is a six-subunit protein complex (comprising TRF1, TRF2, POT1, TPP1, TIN2 and Rap1) that associates specifically with mammalian telomeres and allows cells to distinguish the natural ends of chromosomes from sites of DNA damage. Shelterin binds telomeres through TRF1 and TRF2, which interact with the double-stranded telomeric DNA, whereas the POT1 proteins (POT1a and POT1b in the mouse) associate with single-stranded (ss) telomeric DNA. POT1 is linked to TRF1 and TRF2 via an interaction between the POT1-binding protein TPP1 and TIN2, which binds both TRF1 and TRF2. The sixth shelterin subunit, Rap1, interacts solely with TRF2 (Figure 1A). All these factors are constitutively and ubiquitously expressed and the complex is highly abundant, potentially covering all telomeric DNA. In addition to the terminal telomeric repeats, shelterin proteins are found at certain interstitial telomeric sequences. Rap1 binding is also detected in the vicinity of several genes that are differentially regulated when Rap1 is lost. This suggests an additional role for Rap1 as a transcriptional co-regulator.

Shelterin function is crucial for telomere maintenance and genome integrity. Knockout experiments in mouse cells have revealed that shelterin protects telomeres from DNA damage signaling and DNA repair and also promotes the semi-conservative replication of the telomeric DNA. Moreover, shelterin regulates the telomerase-mediated maintenance of the telomeric DNA.

Do the different shelterin subunits work together or individually? The protein–protein interactions between the different shelterin components are critical for its stable association with telomeric DNA. However, with regard to how shelterin represses the various aspects of the DNA damage response, there is substantial division of labor amongst the different subunits. The TRF2 subunit is required for repression of the ATM-dependent DNA damage signaling pathway as well as classical non-homologous end joining (c-NHEJ). On the other hand, the ATR kinase signaling pathway is repressed by POT1. The repression of homologous recombination requires the concerted action of POT1 and Rap1. POT1 and TRF2 act independently to repress two different 5' end resection pathways at telomere termini. Finally, the TRF1 subunit of shelterin has a specialized role in promoting the semi-conservative replication of telomeres.

The regulation of telomerase-mediated telomere maintenance by shelterin appears to be complex and the molecular details have not been fully elucidated. Current models propose that the shelterin subunits POT1 and TPP1 play key roles in the regulation of telomerase action at individual telomeres. TPP1 is required for the recruitment of telomerase and thus acts as a positive regulator of telomere maintenance. However, telomerase is also negatively regulated by shelterin so that telomeres do not become inappropriately long and telomere length homeostasis is achieved. This negative regulation involves both TPP1 and POT1 but the molecular details of this interesting aspect of telomere biology are far from clear.

How does shelterin inhibit DNA damage signaling and repair? The mechanisms underlying the repression of DNA damage signaling and repair are not fully understood. One important mechanism involves the sequestration of the DNA ends into so-called t-loop structures (Figure 1B). T-loops are formed and/or maintained by TRF2. They are created by strand invasion of the single-stranded 3' overhang at the end of the telomere somewhere into the duplex telomeric DNA. These lariat structures provide an architectural solution to many aspects of end protection because they sequester the DNA end and make it inaccessible to DNA-end-binding proteins whose binding may initiate downstream DNA damage signaling and DNA repair. T-loop formation by TRF2 can explain