Could you introduce the key aims of your research on how reef fish analyse and perceive their visual environment?

My primary objective is to develop a better understanding of visual behaviour, processing and cognition through behavioural techniques using a fish model system that has not been modified by selective breeding or genetic manipulation. I am interested to find out how visual processing and cognition may differ in animals lacking a cortex, from what we know about ‘higher vertebrates’ including humans, who have that extra processing power.

Many visual tasks are assumed to require a cortex, such as object recognition and face perception. Despite extensive research we still don’t know how these tasks are achieved in the human brain, but various theories are discussed in the literature. By testing some of these hypotheses on ‘simple’ vertebrates, I aim to establish if the underlying processes really do require a cortex or whether there is a general underlying mechanism that is conserved across the animal kingdom.

Can you discuss your research into the ability of fish larvae to find a reef, and the significance of this to your work in the wider context?

Larvae spend several weeks in the relatively featureless pelagic environment and must find a reef for settlement and further development. In contrast to earlier assumptions, fish larvae are able to influence where they are going (they don’t just drift with the currents) and can swim in an orientated (non-random) way. At present, we don’t know how they do this, and my job in the collaboration is to look at the possibility of visual cues, such as a solar compass or polarisation patterns playing a role in this behaviour.

Why have you decided to focus on the role of ultraviolet (UV) radiation in the aquatic environment?

Within this overarching aim, my research is also focused on the role of UV radiation in the aquatic environment. On the one side, UV is used for visual communication, while on the other it is well known to cause cell damage. There appears to be a delicate balance between the positive and negative effects of UV and part of our focus is to characterise this balance under current conditions. UV radiation is increasing due to a range of climate change-related effects and many species of amphibians are disappearing as a direct consequence. Our goal is to investigate how the balance between negative and positive consequences of UV radiation for fish is affected by changes in UV levels.

Your research has involved the development of necessary software for image capture, extraction and manipulation of reef fish UV facial patterns. How was this software developed and what is the potential for its wider application?

I was fortunate that Rainer Obergussberger, who was studying image analysis in Germany at the time, joined my lab to carry out the work for his Master’s thesis. He developed the software Fishface, which we now use to extract the patterns. He also developed software that allows us to morph between any pair of faces, so that we can create new faces that lie between the two original images. He now has his own image analysis company in Germany (Senswork).

What have been some of your most noteworthy research collaborations?

There are two key collaborations, which have both received funding from the Australian Research Council (ARC). First, I am collaborating with Jeff Leis (Australian Museum, Sydney) and Claire Paris (Florida, USA) on larval fish orientation. Together we have spent the last three years investigating the sensory abilities of reef fish in various settings, including the laboratory, as well as in a drifting in situ chamber (DISC) developed by Claire Paris in the open water. We are currently analysing data and writing papers summarising our findings. Jeff Leis has been a great mentor to me since we first met during my PhD. His thorough, systematic and logical approach to research in general and in particular to the interpretation of results has shaped my own way of thinking and helped me be a better scientist.

Second, I am currently part of a research collaboration with Matthias Franz (Konstanz, Germany), Redouan Bshary (Switzerland) and Guy Wallis (Brisbane, Australia). We combine a unique set of skills (computer vision, image analysis, animal behaviour, psychophysics and object recognition), which are required by our recent (also ARC-funded) project: ‘Pattern recognition in animals and machines: using machine learning to reveal cues central to the identification of individuals’.

UV vision in fish

Using the damselfish as a model system, dedicated neuroethologist Dr Ulrike Siebeck is investigating how animals analyse and perceive their visual environment．
THE WAY IN which animals process their visual environment and, conversely, how their environment has channelled their evolutionary development, remains a fascinating yet poorly understood process. One starting point has been the attempt to unravel how basic characteristics such as colouration or patterns can shape an animal’s behaviour. For example, the ability for certain species to see in ultraviolet (UV) light, as well as recognise patterns that reflect UV light, has become an emerging topic of interest.

Unlike the human eye, which features a lens that blocks UV light, in some animals UV is able to reach the retina, converting the light into nerve signals that are then visually processed by the brain. In birds, for example, the ability to perceive UV light has been studied in relation to its effects on behaviour such as mate selection and species communication – a discovery that inspired visual neuroethologist Dr Ulrike Siebeck, who is based at the University of Queensland, Australia, to take up her own research project: “When I was looking for a PhD that would combine my love of all things underwater with my background in vision and animal physiology, papers were being published on the discovery of UV markings on bird plumage,” she acknowledges. “I was intrigued by the fact that researchers had, up to that point, overlooked the possibility that birds might use UV colours for mate choice etc., because they had been using their own visual system to assess animal colouration.”

PLenty OF FISH

Using the knowledge she gleaned from other studies about bird plumage, while adhering to her passion for the marine environment, Siebeck turned her attention to the UV sensitive photoreceptors found in fish and their ability to communicate using UV signals. Her first task was to narrow her search; because there were thousands of potential fish species to investigate, Siebeck needed to screen their visual abilities before embarking on any time-consuming behavioural experiments. It was her PhD advisor, Professor Justin Marshall, who directed her studies toward the different physical components that make up a fish’s eye – ocular media including the cornea, lens and vitreous humour – to test whether they prevent UV from reaching the retina. “I used a spectroradiometer – a machine that measures the spectrum or wavelength composition of the light – to determine the spectral properties of the light passed through the ocular media of different species of fish,” she explains.

A CANDIDATE FOR FURTHER INVESTIGATION

Through her studies of UV vision, Siebeck has accumulated data on almost 400 species of fish, half of which she discovered to have UV blocking ocular media. “The next step was to identify a good candidate species for further studies on communication and visual ability,” she explained. “Communication involves signals being sent between at least two parties – in this case UV signals. So I needed fish with UV patterns and UV transparent ocular media.”

SIEbeck spent time swimming with a mirror that she placed in the habitats of various fish species. Her goal was to investigate the way in which the fish responded to their own reflection. Some species were territorial and reacted by attacking the perceived intruder in the mirror. Eventually, the best candidate was identified as Pomacentrus amboinensis – a damselfish from the Western Pacific that has UV transparent ocular media and individually different UV markings. It is also territorial, hardy and quick to adapt to new environments such as aquaria.

EXPERIMENTAL STAGE

With her candidate species chosen, Siebeck went on to conduct behavioural experiments, the first of which set out to define whether the Damselfish could discriminate between same species fish both with and without UV patterns. “To check this, I had a set-up with a single P. amboinensis male in a large aquarium. I then exposed this male to two other males (intruders) which were contained in plastic tubes,” she details. “The trick was that one tube allowed UV to pass through (UV+) while the other one did not (UV-).” Siebeck observed that the territory owner would attack the UV+ fish significantly more than the UV- species, thus suggesting that spectral difference plays an important part in triggering animal behaviour.

Next, Siebeck set out to prove her second hypothesis: that UV+ fish would be recognised as conspecific, competing for the same territory or food. This led her to carry out tests with another fish species that presented the same colour and shape, but distinguishable UV patterns. Pomacentrus moluccensis turned out to be the ideal candidate. Her results showed that the territory owner was not able to differentiate between the two intruder species when their UV patterns were not visible, thus concluding they use UV patterns for species discrimination.

Further examination of the species’ facial recognition, whereby Siebeck trained fish to identify UV patterns, enabled the team to prove that fish could indeed discriminate between the facial patterns of their own species and that of other species. “Interestingly, it was the shape information that rather than the spectral information, was used to solve the task,” she added. “This also meant that we could use black and white patterns for further analysis, which makes life much easier for us as scientists because we cannot see the UV patterns ourselves! Since then we discovered that the fish are highly sensitive to slight changes in the facial patterns, which makes them ideal candidates to study the features used for visual processing.”

A team of researchers based at the University of Queensland, Australia, is studying the visual perception and neuroethology of reef fish, with the end goal of improving understanding of animal behaviour and evolution.
VISUAL PERCEPTION AND NEUROETHOLOGY OF REEF FISH

OBJECTIVE
To develop a better understanding of visual behaviour, processing and cognition through behavioural techniques and using a fish model system.

KEY COLLABORATORS
Jeff Leis, Australian Museum, Sydney, Australia
Matthias Franz, HTWG, Konstanz, Germany
Redouan Bshary, Université de Neuchâtel, Switzerland
Guy Wallis, The University of Queensland, Brisbane, Australia

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ULRIKE E SIEBECK moved to Australia for her PhD on the visual ecology of reef fishes following an undergraduate degree in Biology in Germany, completed in 1998. Since 2005, she has been building her laboratory for visual neuroethology at The University of Queensland. She has also been working with the Catlin Seaview Survey project as Senior Research officer since 2014.

SIGNIFICANT FINDINGS
• UV is used by damselfish as a high-fidelity ‘secret communication channel’ hidden from predators
• Individually distinct UV markings in damselfish code for species and individual identity
• Ambon damselfish can rapidly learn visual discrimination tasks such as those used in the primate literature. This establishes them as model organisms for the behavioural investigation of visual processing and cognition
• Ambon damselfish process colour and luminance information in separate channels, similar to what has been found for the human visual system

NEXT STEPS
Fish cognition – having established the best paradigms for testing fish, the team is now looking at testing image invariance and face recognition in fish.

Fish visual processing (species discrimination) – the researchers are currently running a suite of behavioural experiments designed to characterise the ability of fish to discriminate various natural and artificial patterns. The results will be fed into machine learning algorithms to help isolate candidate features that the fish are using for discrimination.

Larval fish orientation in the pelagic environment – the group is in the analysis stage of this project and is hoping to come up with a model explaining the cues used to help larval fish find a reef to settle on.

UV – having completed a suite of experiments characterising the ability of damselfish to see in the UV (spatial and temporal resolution, threshold sensitivity, acuity, etc.), the team is keen to use this information to develop a model on how a fish see other fish in the UV.

Many reef fish display elaborate colour patterns, which contain ‘secret’ signals, invisible to UV blind creatures like humans and many fish predators.