ANIMAL VISUAL WORLDS
INTERNATIONAL SYMPOSIUM ON VISUAL ECOLOGY

6-7 March 2018
Instituto de Biociências
Universidade de São Paulo

Organized by
Taran Grant, Almut Kelber, Julián Faivovich & Carola Yovanovich
Tuesday, 06-March | Afternoon, Auditório Geral da Botânica

14.00 | Opening
14.15 | Session I
   Taran Grant - “Questions in amphibian vision”
   Einat Hauzman - “Retinal morphology and evolution of visual pigments in snakes”
15.15 | Coffee break
15.40 | Data-blitz I
   Guido Barbieri - “Photoreceptor types and visual photopigments of Bothrops jararaca and Crotalus durissus terrificus (Serpentes, Viperidae)”
   José Souto Neto - “Hippocampus reidi as a model: visual perception, color change and circadian rhythms”
16.00 | Session I (Cont.)
   Michele Pierotti - “Through a liquid glass to the eye of the beholder: Visual ecology of coral reef fishes isolated by the Isthmus of Panama”
   Daniel Pessoa - “The effect of color and shape cues on the detection and selection of food by marmosets (Callithryx jacchus)”

Wednesday, 07-March | Morning, Auditório Geral da Botânica

09.00 | Session II
   Almut Kelber - “Spatial resolution of bird vision - anatomy and behaviour”
   Gavin Taylor - “The visual worlds of insects, big and small”
10.00 | Data-blitz II
   Luiza Saad - “Plasticity of eye development in eyeless cave planaria”
   Priscila Soares - “Visual Ecology of Brazilian nocturnal bees from different environments; Genus Megalopta (Hymenoptera, Apoidea)”
   Agustín Camacho - “Interactions of morphology, behavior and color on escape success to visually guided predation”
10.30 | Coffee break
11.00 | Session II (Cont.)
   Rodolfo Liporoni - “Light intensity affects crepuscular bees foraging activity in cambuci, a Neotropical Myrtaceae”
   Meire Telles - “Ant navigation in the Amazon forest: preliminary analyses considering the visual parts of the natural environment used by Gigantios destructor (Hymenoptera: Formicidae)”

Wednesday, 07-March | Afternoon, Auditório Geral da Zoologia

14.00 | Session III
   Nadia Cervino - “Diversity in anuran eye structure: preliminary results of an ongoing study”
   Carola Yovanovich - “Turning tiny and shiny: Do retinal specializations in brachycephalic frogs relate to size and diel pattern?”
15.00 | Coffee break
15.30 | Session III (Cont.)
   Maju Viotti - “Behavioural experiments in colour discrimination in Rhinella (Anura: Bufonidae) tadpoles and juveniles: An open project”
   Julián Faivovich - “Fluorescent frogs”
16.30 | Open discussion
Questions in amphibian vision

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Little research has gone into documenting and explaining variation in the visual system of amphibians. The dearth of research on this subject probably owes, in part at least, to a persistent misconception that living amphibians comprise a poorly diversified group intermediate between bony fishes and amniotes, and the understanding that vocalization is the dominant mode of communication in anurans. In this presentation I will draw attention to a number of questions related to vision in amphibians in an effort to convince those present to abandon their current research programs and focus on amphibians.

Retinal Morphology and Evolution of the Visual Pigments in Snakes

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The visual system has developed in different ways during the evolutionary history of vertebrates, based on specific demands of the species. The infraorder Serpentes has a large number of species that are distributed in almost all regions of the world, and its visual system varies according to phylogenetic and ecological aspects, with strong influences from the species’ habitat and daily activity patterns (diurnal, nocturnal or crepuscular). The ecological niches occupied by snakes that inhabit aquatic, terrestrial, arboreal, and fossorial habitats differ in the spectral quality of light, which influences the demands of the visual system and implies strong evolutionary pressure. Remarkable differences are observed in retinal structure, photoreceptor morphology, the spectral sensitivity of the visual pigments, retinal specialization and the spatial resolving power of the eye. Analysis of the density and distribution of cells of the retinal ganglion cell layer (GCL) revealed different types of specialization, horizontal streak, area centralis, or scattered distribution, with higher cell density in different regions, depending on the species. These variations seem to be related to ecological and behavioral features, such as daily activity pattern, habitat and substrate preferentially occupied, hunting strategies and diet. Diurnal snakes that actively forage during the day and feed on fast moving preys tend to have a horizontal streak, while nocturnal species and/or those that feed on slow moving preys seem to have an area centralis or diffuse distribution of cells. Nocturnal species have lower estimated visual acuity, compared to diurnal. A few studies investigated the opsin genes expressed in retinas of species from different families and revealed the expression of three opsin genes in retinas of most species, the rhodopsin gene RH1 and the cone opsin genes SWS1 and LWS. The other two genes, RH2 and SWS2 are not expressed in snake retinas, and it was suggested that their loss occurred in the early history of snakes’ evolution. In all-cone retinas of diurnal Caenophidian snakes
one group of very small single cones expresses the rhodopsin gene RH1, with a blue-shifted absorption peak (from the usual 500 nm to 484 nm). It was suggested that this photoreceptor, a cone-like rod, might contribute to diurnal color vision, compensating for ancestral loss of the middle wavelength sensitive cone.

**Through a liquid glass to the eye of the beholder: Visual ecology of coral reef fishes isolated by the Isthmus of Panama**

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Coral reef fishes represent ideal models for studies examining the effects of ecological selection on sensory systems. Here I take advantage of a unique natural experiment, the uplift of the Isthmus of Panama that ‘placed’ similar genomes, those of sister species isolated on either side of the isthmus, into radically different photic environments: the turbid nutrient-rich waters in the Eastern Pacific or the clear oligotrophic waters in the Caribbean. By characterizing rods and cones visual sensitivities and opsin complement with RNAseq transcriptome sequencing I examine whether the spectral characteristics of these two bodies of water and other ecological factors shaped reef fish visual systems. I present three geminate examples and discuss my findings in relation to the visual ecology of related species in the Great Barrier Reef.

**The effect of color and shape cues on the detection and selection of food by marmosets (Callithrix jacchus)**

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Visual signals may be important sensory tools in the search for and selection of food by primates. According to 19th century proposals, the bright coloration of fruit may have influenced the evolution of color vision in animals. However, information on size, shape and texture has also been cited as important in identifying camouflaged objects in nature. It has been suggested that trichromacy, the color vision found in female Neotropical primates and most humans, favors the detection of conspicuous targets. On the other hand, by exploiting shape cues, dichromacy, the vision observed in male Neotropical primates and human colorblind, benefits the detection of camouflaged targets. The present study sought to evaluate the relative importance of color and shape cues on the detection of food targets by male and female Neotropical primates. The feeding behavior of family groups of Callithrix jacchus was observed when identifying food items of different shapes and colors against a green or green/orange background. Total foraging time and number of captured food targets were recorded. Results showed that males improved, while females decreased, their performances when searching for camouflaged food. Findings corroborate suggestions of a balance...
between advantages and disadvantages of trichromats and dichromats, which would explain the maintenance of the visual polymorphism found in Neotropical primates.

**Spatial resolution of bird vision – anatomy and behaviour**

**Almut Kelber**

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Of all animals, raptors – birds of prey – have the eyes with the highest spatial resolution: wedge-tailed eagles and large vultures see twice as sharp as humans. Many other birds, however, have much lower spatial resolution. Spatial resolution can be estimated from the density of retinal ganglion cells (RGCs) in species without a fovea, and cone densities in foveal animals.

Resolution can also be determined in behavioural experiments, in which the animals are asked to discriminate a grating from a uniform background. Unlike humans, birds have low contrast sensitivity, tested species need \( \approx 10\% \) contrast, while humans can still see <1\% contrast.

Similar to humans, birds can resolve higher spatial frequencies if patterns have achromatic contrast – contrast for the bird double cones – compared to patterns with only chromatic contrast. Budgerigars, for instance, can resolve 10 cycles/degree visual angle with high achromatic contrast, but only around 5 cycles/degree with purely chromatic contrast. Harris's hawks have a similar spatial resolution to humans (40 – 60 cycles/degree) for achromatic gratings, but a higher resolution for chromatic (red-green) gratings.

Interestingly, in both species of bird, we find a much lower spatial resolution when testing the optomotor response. Budgerigars follow movements of large-field stimuli with head rotations, interspersed by fast set-back saccades, only if the patterns have spatial frequencies lower than 2 cycles/degree. In Harris's hawks, the threshold is slightly higher, with 3 cycles/degree. In summary, we can conclude that in birds – and likely other animals – the spatial resolution limit is not a single property of a visual system, but related to specific behavioural contexts that engage different visual pathways.

**The visual worlds of insects, big and small**

**Gavin Taylor**

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Spatial vision provides essential information to meet the sensory demands of many insects and allows them to perceive images of the objects their environment. Focusing light through a lens and transducing it in a photoreceptor are the first stages of vision, and the dimensions of such optical structures across an eye determines its optical resolution and sensitivity. Many studies have described insect compound eyes based on characterizing a limited portion of their structure in 2D, such as from a histological slice or a flattened corneal replica. However, to understand how
in an insect full visual world, it is necessary to describe its entire eye in 3D. To provide this information, I utilized microtomography to image the full 3D structure of compound eyes and visualize the gross structure of the cornea and retina, as well as the fine structure of the corneal facet lenses. This technique allows the corneal visual field and resolution to be calculated, as well as dimensions influencing sensitivity, such as the retinal thickness. Importantly, all measurements can be expressed in common world referenced coordinates, which allows for easy comparisons between insects, even if their underlying eye morphology varies. Ultimately, this information will be used to simulate how an insect would view its environment.

Light intensity affects crepuscular bees foraging activity in cambuci, a Neotropical Myrtaceae

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Some bees have developed a nocturnal habit and fly in dim-light conditions during the dusk, dawn and night. These bees can pollinate economically relevant plant species, such as cambuci (Campomanesia phaea, Myrtaceae) in Brazil. We aimed to investigate how light intensity affects flower visitation of cambuci by nocturnal and crepuscular bees. We counted visits minute by minute along 30 nights/twilight in 33 cambuci trees from a commercial orchard, measuring in the same time the following environmental variables: light intensity, temperature, air relative humidity, wind speed and flower availability. Light intensity is the only variable that explained nocturnal bees flower visitation in cambuci, which peaks at intermediate light intensities. Our results highlight how nocturnal bees rely on light to explore cambuci resources and suggest that the bees light-dependent foraging activity is not always linear, as postulated by previous theoretic models. This is the first step to understand general factors that might influence nocturnal bees activity and brings concerns about possible negative effects of light pollution at night for cambuci-crepuscular bees interaction.

Ant navigation in the Amazon forest: preliminary analyses considering the visual parts of the natural environment used by Gigantiops destructor (Hymenoptera: Formicidae)

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Desert ants are the major model in navigation studies. However, desert environments are poor in horizontal visual cues, generally providing celestial information that help during navigation. Few studies have investigated how ants that inhabit visually noisy environments, such as forests, navigate, especially when considering tropical areas. In
such environments, horizontal and canopy cues have been demonstrated to be important for navigation of ants nesting in trees (Paraponera clavata and Odontomachus hastatus), but for ants nesting on the ground, there is a gap of knowledge regarding their basic orientation mechanisms. *Gigantiops destructor* (Formicinae) forages within a complex environment: The Amazon forest. This species has characteristics that make it an interesting research model in visual orientation. They inhabit partially sunny areas within the forest and are solitary diurnal foragers. In addition, they present the largest eyes of any ant species and do not use pheromones or scent marks. So, what information does *Gigantiops destructor* extract from the visual scene on the way back home? The purpose of this project is to answer this basic and yet open question. So far, what we can say is that panoramic views – and probably skylines - guides the homing behaviour of zero vector individuals.

**Diversity in anuran eye structure: preliminary results of an ongoing study**

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The eyes of anuran amphibians are among their most striking external morphological features. The great diversity in eye size, iris coloration, and pupil morphology contrasts radically with existing knowledge about the internal morphology of the eyes, and the evolution in external morphology during the evolutionary history of the anurans. While there is an extensive record of non-systematized observations on external morphology of eyes in anurans, information on the internal structure of the eye is limited almost exclusively to studies on ultrastructure or physiology of the retina. The latter, on which all generalizations about the structure of the eye in anurans are based, were done in the best of cases (that is, assuming that the reported information is comparable for all species) in only 11 species of seven families of anurans. Although this may be a fact to be considered, actually the eyes of the anurans were never studied in a comparative context.

In this talk we will show preliminary results on the study of the diversity of ocular morphology in exemplars of some anuran families such as Alsodidae, Phyllomedusidae, Hylidae, Leptodactylidae, Bufonidae, Batrachylidae, Telmatobiidae, Microhylidae, among others, with special focus on the retinal morphology.

**Turning tiny and shiny: Do retinal specializations in brachycephalid frogs relate to size and diel pattern?**

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Amphibians have played a fundamental role in shaping our understanding of vertebrate visual physiology and yet, despite the presence of unique features such as two spectrally different kinds of rod photoreceptors, the potential diversity of visual systems across the wide range of life habits and anatomical phenotypes within the amphibian phy-
logenetic tree has been heavily subsampled. Our current work is focused in exploring this variability in Brachycephalidae, a relatively small clade with representatives that can be either diurnal or nocturnal, aposematic or cryptic, small-sized or miniaturized. We are studying the composition of the retina at the topographical and ultrastructural level using light and transmission electron microscopy. Our samples show clear regional differences in the photoreceptors population and the topography of retinal layers that could influence sensitivity and resolution. We will discuss the potential functional significance of these specializations and the patterns that are emerging from this comparison, and how future studies should be approached to gain a better understanding of the visual abilities linked to these retinal features.

**Behavioural experiments in colour discrimination in Rhinella (Anura: Bufonidae) tadpoles and juveniles: An open project**

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In Amphibia, one may say that anurans have gone through strikingly more intense ecological and phylogenetic diversification when in contrast to those described in salamanders or caecilians. Therefore, it is no surprise that anuran larvae reflects this diversity and differs to a great extent from other life stages and logically, these differences influence in the behavior and response to environmental stimuli.

With that in mind, it can be interesting to extrapolate in to the visual aspect: recent studies have found that blue sensitive cones are lost during metamorphosis in some salamanders and, although it hasn’t been documented in anurans yet, there have been studies regarding different spectral sensitivity between tadpoles and adults. How these morphological and physiological changes translate into behavioural aspects, specifically regarding color discrimination, has yet to be understood.

It is known that tadpoles can discern colors and learn to reproduce specific trainings. Consequently, some comparisons can be made, such as: can we observe these abilities in the following development phases? And if so, why? In this presentation it will be discussed behavioural experiment ideas as to test similar hypothesis, its strategic details and probable resulting questions.

**Fluorescent frogs**

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Fluorescence, the emission of light in a longer wavelength after direct excitation by light absorption of the emitting molecule, is poorly studied in vertebrates, particularly in tetrapods. In this talk I will recount the steps leading to the recent discovery of fluorescence in a neotropical treefrog, *Boana punctata*, and will discuss its chemical basis, its inferred biological relevance, and the putative taxonomic distribution of fluorescence in anurans.