

# Point of View

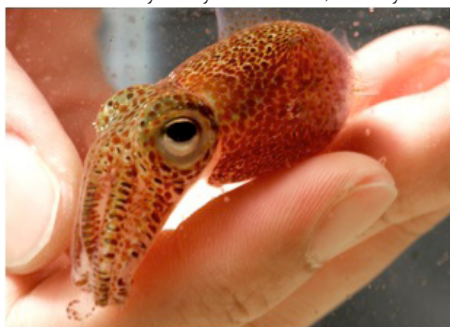
THE EYE RESEARCH INSTITUTE UNIVERSITY OF WISCONSIN-MADISON

## Light from an Inner Eye

Clownfish and sea anemones, remoras and sharks, bees and flowers, ants and aphids, fungi and trees, and mistletoe and live oaks are all examples of visible symbiotic relationships. Symbiosis, in the classical sense, is defined as two dissimilar organisms of different species living together in close association. Yet far more widespread than these observable alliances are the invisible animal-microbial partnerships often essential to human and animal health and survival.

These hidden relationships of hosts and beneficial microbes are a primary focus for Margaret McFall-Ngai, PhD, professor in the department of Medical Microbiology and Immunology and member of the Eye Research Institute. Studying the complex interactions and coevolution of a specific animal host and its bacterial symbiont, she has developed a model system focusing on the relationship between the Hawaiian bobtail squid *Euprymna scolopes* and the luminous bacterium *Vibrio fischeri*. Within this single host/single microbe symbiosis, she seeks to comprehend how evolution has approached the problem of designing tissues that interact with light.

In the bobtail squid, light-interactive tissues include its eyes as well as a photophore (a light-emitting organ) located in the center of its abdominal area. *Vibrio fischeri*, freeliving bacteria within ocean plankton, enter through pores in the squid hatchling's light organ, multiplying rapidly into about a million progeny that begin producing light. The bacteria line the core of the light organ and are surrounded by a layer of thick, silvery



An adult Hawaiian bobtail squid, *Euprymna scolopes*, measures an average of 3cm in total length.

reflector tissue much like the retina of the eye. In addition, the squid's ink sac functions similarly to a human iris and a lens is present, together acting like a dimmer switch to control the level of light emanating from the squid.

By day, the nocturnal squid lies buried in shallow sand flats surrounding Hawaiian coral reefs; by night, as it comes out to forage for food, its projected light helps the squid avoid predators. McFall-Ngai explains, "All of the tissues of the light organ work in concert to produce a behavior in the squid referred to as counterillumination. The squid controls the emission of bacterial luminosity to produce light of the same intensity and wavelength as down-welling moonlight or starlight, thus camouflaging the squid by eliminating its shadow. This 'stealth technology' is typical of many animals inhabiting the homogeneous environment of the ocean water column, where there is no place to hide."

Notable similarities exist between eyes and light organs, and McFall-Ngai has explored the anatomy and biochemistry of both within her squid model. Asking how these two kinds of tissues handle light, whether receiving it as an environmental cue or producing it, she is tracking the biochemical basis of transparency and reflectivity and is discerning

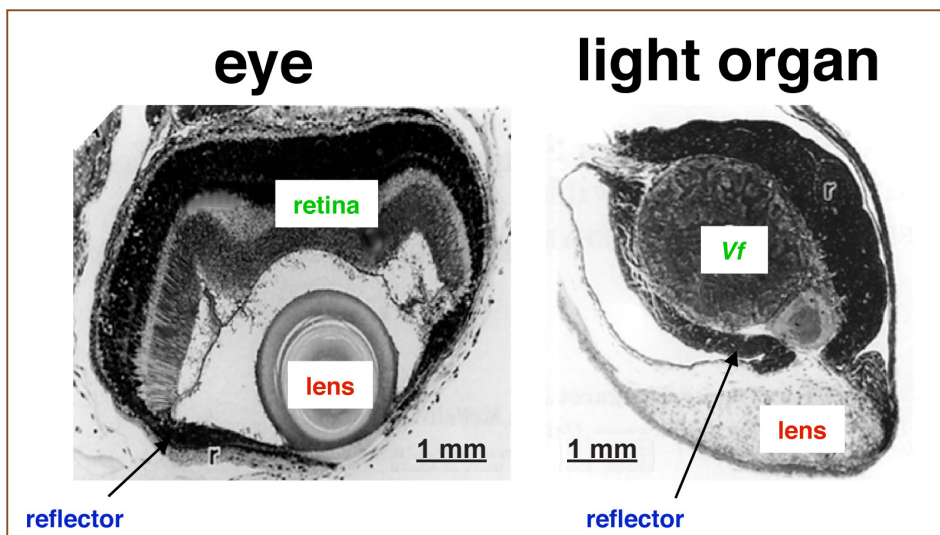


Margaret McFall-Ngai, PhD, stands along the beach at one of her study sites, the Kewalo Marine Laboratory of the University of Hawaii.

adaptations integral to understanding the evolution of vision.

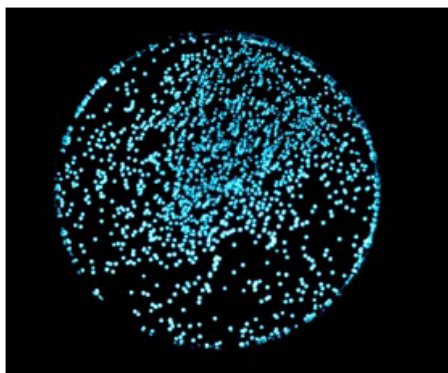
McFall-Ngai is the first researcher to bring biochemical analysis to bear on light organ lens tissue. She discovered that a common protein and enzyme structure underlies the transparent tissues of both light organ and eye lenses. "Though these two classes of lenses are derived from different embryological tissues and have thus evolved independently to perform different functions, their protein composition is remarkably convergent," notes McFall-Ngai. Further biochemical analysis of squid reflective tissues uncovered a distinct family of proteins—named *reflec-tins* by her research group—that self-assemble into stacks of platelets, diffusing light from the photophore via this natural nanoreflector.

After finding that similar proteins were operating in both light organ and



The eye and light organ of *E. scolopes* are composed of functionally analogous tissues. The 'Vf' label in the center of the light organ identifies the portion of the host tissues where the symbiont *Vibrio fischeri* resides.

eye tissues, McFall-Ngai turned to genetic analysis, building a library of all the genes expressed in the squid-vibrio symbiosis. Learning that the squid light organ actually contains the same key visual proteins as those in photoreceptor cells of visual systems, she then set out to determine whether the light organ would also react *physiologically* to light. In the spirit of collaboration fostered by the ERI, McFall-Ngai sought the expertise of fellow ERI member Nansi Colley of Ophthalmology and Visual Sciences. In the Colley lab, electroretinograms (measuring electrical responses of the retina to brief flashes of light) were performed on both eyes and light organs of the squid. Test results clearly demonstrated that the symbiotic light organ could indeed perceive light, in addition to producing and controlling the intensity of light. This observation brings new insight into the bobtail squid's ability

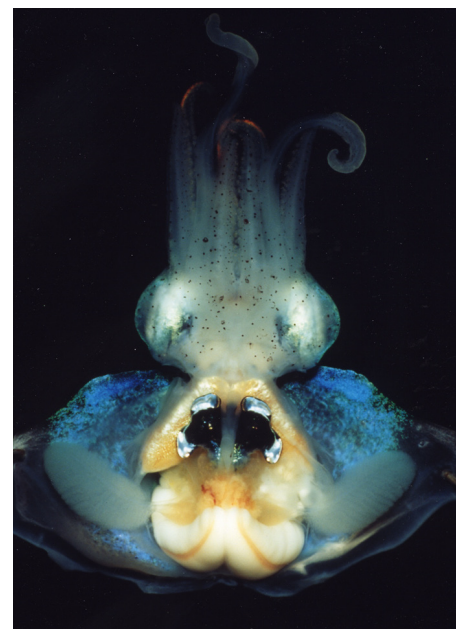


This time lapse photo of the glowing bacteria captures the natural light they emit. Each dot is a colony of 10 million to 100 million cells of *Vibrio fischeri*, which have been cultured on a petri plate.

to control its light output in order to match environmental light conditions.

Significant parallels between eyes and light organs raise speculation that the light organ may have evolved through the assembly of existing visual components in a novel combination or context, a process known as evolutionary tinkering. "With the squid-vibrio model, we have been addressing the broad question of how evolution has solved a problem of biochemical adaptation," summarizes McFall-Ngai. "Our next step is to look at just how deep the developmental convergence is between the eye and the photophore. All embryos are equipped with a set of cells that are 'predestined' to become particular tissues. Are the same genes directing the tissues to become either an eye or a photophore?"

With wide-ranging interests and skills, McFall-Ngai has been able to ask questions and seek answers from unusually broad perspectives. An evolutionary biologist trained in cellular and developmental biology as well as comparative biochemistry, her research falls within multiple fields: comparative animal biology, comparative physiology, vision science, microbiology. All fit under the integrating umbrella of symbiosis, informing her work on the squid-vibrio model and shaping her larger inquiry of evolution. Awarded a Guggenheim Fellowship this year, she will work internationally to promote the study of beneficial animal-bacterial interactions, addressing the role of microbial symbioses



The light organ of the Hawaiian bobtail squid is visible in the center of the animal's abdominal cavity.

in shaping the form and function of the animal immune system.

Findings from twenty years of research exploring anatomy, biochemistry, genetics, and physiology within the squid-vibrio model promise to reveal features that are conserved across the animal kingdom. The retention of these shared features throughout evolution suggests that they are critical for function. As such, our understanding of the biology of this species, which is distantly related to man, may ultimately lead to new strategies for treating human diseases of the eye.



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