Seeing Stars: Comparative Features of Visual Systems in Asteroids

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Birk, M.H., M.E. Blicher, and A. Garm 2018. Deep-sea starfish from the Arctic have well-developed eyes in the dark. *Proceedings of the Royal Society B* 285:20172743.

Sigl, R., S. Steibl, and C. Laforsch. 2016. The role of vision for navigation in the crown-of-thorns seastar, *Acanthaster planci*. *Scientific Reports* 6:30834.

Vision in the Class Asteroidea (sea stars) has attracted recent scientific attention as most sea stars possess a compound eye at the end of each arm. These eyes are composed of numerous light sensing units called ommatidia, which are analogous to the multiple facets of the compound arthropod eye. Besides photoreception, little has been proposed regarding the function of asteroid eyes. Rather, sea stars are thought to rely on chemo- and rheotaxis (orientation to chemical and water current cues) for navigation, but new studies have shown that asteroids may also rely on vision.

Sigl et al. (2016) examined the visual quality of the shallow-water crown-of-thorns sea star (*Acanthaster planci*) and whether it relies on vision to locate its coral prey. To address these questions, the authors took thin sections of eyes from *A. planci* to measure the physical characteristics of the eyes and ommatidia. By photographing the thin sections, the authors could measure the angles of light acceptance in the ommatidia in order to mathematically predict visual capabilities such as image resolution and field of view. Mathematical calculations were used to provide some quantitative idea about visual abilities because qualitative descriptions are impossible to obtain (i.e., one cannot perform an eye exam on a sea star).

This study also conducted field experiments to determine the dependence of *A. planci* on vision. Sigl et al. (2016) removed the eyes of some individuals to blind them while they left other individuals non-blinded. The scientists then positioned two individuals from each study group 1.25, 2.5, 5 and 10 meters away from a coral reef structure, released the sea stars, and observed their movements. These methods were used to determine the dependence of *A. planci* on vision because blinded and non-blinded individuals should show no difference in navigational abilities if they did not rely on vision. To control for the effect of eye removal on behavior, Sigl et al. (2016) performed a preliminary experiment that examined the activity of blinded and non-blinded individuals. The experiment showed that individuals from both groups travelled about the same distance, which suggests that eye removal did not affect behavior. However, more controls for the effect of blinding on behavior would have helped validate this claim. Still, the authors also controlled for chemical and water current cues by choosing a reef structure that had a constant and unidirectional flow of water.

Results from the morphological study were striking. Mathematical predictions suggested that *A. planci* sea stars have wide and highly overlapping fields of view in the vertical and horizontal planes. This finding suggests that the animals could 'see' an entire 360° around their bodies, but that they would have a relatively low image resolution (Sigl et al. 2016). Additionally, the field experiments revealed that non-blinded individuals always showed a mean movement toward the reef while blinded individuals almost always showed a mean movement away from the reef (Fig. 1). However, both blinded and non-blinded individuals struggled to or could not find the reef when released from a distance of 10 m, while both groups showed some success in finding the reef when released from 1.25 m (Fig. 1). These results suggest that *A. planci* depends on visual cues over chemical and water current cues to locate coral prey at intermediate distances, but that chemical cues may be more helpful at short distances (Sigl et al. 2016).

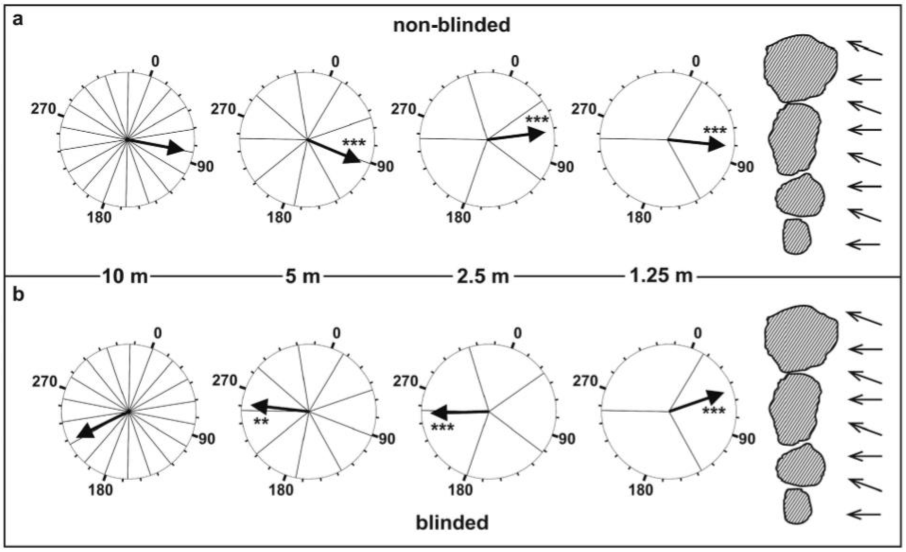

Figure 1. *Mean directional movement of non-blinded (a) and blinded (b) crown-of-thorns sea stars (*Acanthaster planci*) from different starting points 1.25, 2.5, 5 and 10 m from the reef. Arrows in the circles indicate mean directional movement, hatched grey shapes indicate the reef structure, and the arrows to the right of the reef indicate water flow (Sigl et al. 2016).*

A later study by Birk et al. (2018) investigated the presence of eyes and quality of vision in 13 deep-water sea star species. They collected deep-sea asteroid species by trawl in the Arctic Ocean and removed eyes from some individuals to mathematically predict visual quality. Birk et al. (2018) also kept alive some individuals of each species to observe their behaviors and any presence of bioluminescence because it is the only source of light in the aphotic zone.

Morphological results from Birk et al. (2018) revealed that 12 of the 13 deep-sea species had well developed eyes (Fig. 2) and that several species would have similar fields of view and image resolutions compared to *A. planci*. However, the authors also found that *Novodinia americana* would have the highest image resolution of all the species studied, despite the fact that it was only found in the aphotic zone. Further, the only physical eye parameter that correlated with depth was pupil size. Since a larger pupil allows in more light but produces a fuzzier image, this finding suggests that deep-water species may sacrifice image resolution for higher sensitivity at lower depths. Results from the behavioral studies in Birk et al. (2018) also showed for the first time that *Diplopteraster multipes* often had its stomach extended out of the mouth along the substrate, and that two species exhibited distinguishable bioluminescence; *D. multipes* produced short flashes while *N. americana* could continually glow. The authors hypothesized that these bioluminescent species, which live exclusively in the aphotic zone, depend on vision to locate bioluminescent bacterial mats on which to feed (as in the case of *D. multipes* because it extends its belly along the seafloor) and possibly for intraspecific communication (in the case of *N. americana*, which sustains a bioluminescent glow).

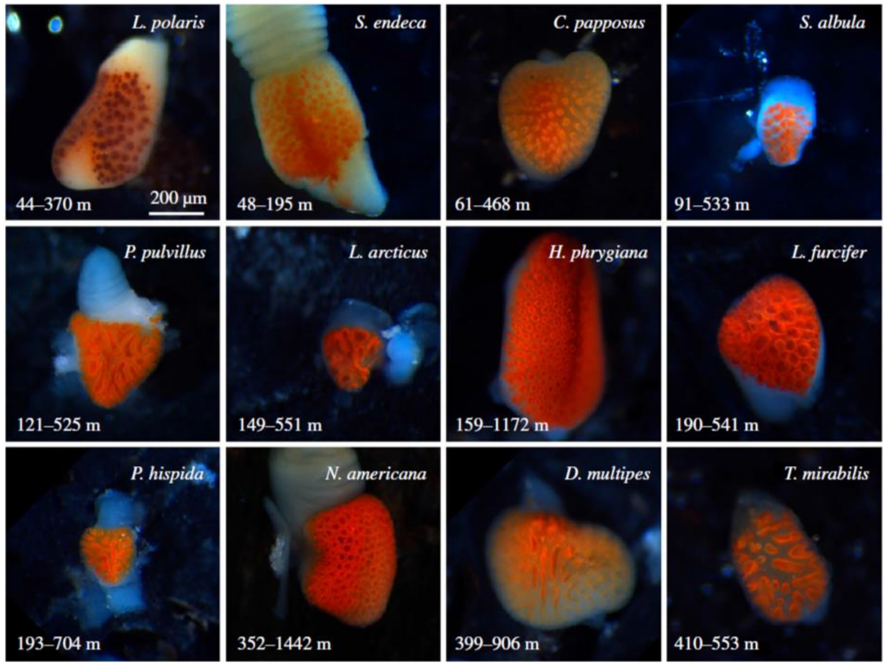

Figure 2. *The compound eyes of deep-water sea star species. Note the small orange units, ommatidia, comprising each eye and differences in number, shape and dispersal of ommatidia (Birk et al. 2018).*

Together, these papers indicate that members of Class Asteroidea do possess well-developed vision and that some species may rely on such vision. Sigl et al. (2016) demonstrated that *A. planci* depends on vision for reef navigation and prey location, while Birk et al. (2018) suggested that vision may play a role in prey location and/or intraspecific communication in some deep-water species. However, the studies did not propose other uses for asteroid vision such as mate location and predator surveillance, and future work should be aimed at addressing these gaps. Further, the discovery of bioluminescence and high-quality vision in aphotic zone species encourages future work that involves *in situ* observations to test Birk et al.'s (2018) hypotheses about the species' behaviors. Though these studies shed light on sea star sensing, much work is yet left to be done to better illuminate the story of asteroid vision.