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## Are our ideas about octopus life too anthropomorphic to help?

Commentary on [Mather](#) on *Octopus Mind*

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**Abstract:** Our understanding of the evolution and ontogeny of the octopus and its behavioral repertoire in its natural habitat remains rudimentary at best. There are many parallels, but also just as many differences from our models of human biology and ontogeny, making anthropocentric generalizations of limited use in explanation.

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Attempting to draw anthropomorphic parallels at times confounds convergent evolution with parallel evolution in discussions of developmental issues (for a general discussion see: Pagán 2019). In her target article, Mather (2019) has not sought to anthropomorphize and is to be commended for highlighting many of the differences in the octopus rather than commonalities. Much of the inherent complexity of the octopus seems to reflect a biological preparedness for environmental variety. I will try to complement her paper by highlighting some of the differences in environment and our limited knowledge of natural ecologies.

Cephalopods are highly complex organisms that appear to have maximised their niche potential within their environment, being found anywhere from the circumpolar seas to the equator and between depths of over 5 km and sea level. We are learning more about their biologies (Kröger, Vinther & Fuchs 2011; Shigeno, Andrews, Ponte & Fiorito 2018). Their central nervous system is uniquely adapted for the control and coordination of eight independent limbs (Levy, Neshet, Zullo & Hochner 2017), allowing them to make rapid and reactive changes in their size, shape, colour and movement in response to their complex environment. This requires alertness in all dimensions.

Mather points out that cephalopods are well-adapted to learning, integrating and coordinating associations and to establishing novel ones within complex and changing environments. Much of their behavioural control relies on independent, parallel, distributed processes, with the vertical lobe providing a central system for learning and retention (Shomrat, Zarrella, Graziano Fiorito & Hochner 2008; Turchetti-Maia, Shomrat & Hochner 2017).

The octopus genome has recently been sequenced (Albertin et al. 2015), and this group appears unique amongst invertebrates in having protocadherin and C2H2 zinc-finger transcription factor families that are enlarged similarly to those in vertebrates. In addition, they make use of the neurotransmitters oxytocin/vasopressin (Kanda, Satake, Kawanda & Minakata 2005) and serotonin (Edsinger & Dölen 2018). Their more limited DNA evolution seems to have been largely substituted for by a conserved and far more extensive process of RNA editing that allows rapid changes to the transcriptome (Liscovitch-Brauer et al. 2017).

Complex behaviours, similar to those in higher primates in the rapidity and flexibility with which they are learnt, that are acquired and modified are reported but differ markedly in the mechanisms through which they are achieved.

Lacking a rigid endo- or exo-skeleton, much of the motion of octopuses is by water propulsion and extension, the contraction and rigidity of their musculature, and their blood circulation. Changes to their colouration and shape are controlled by a combination of neurochemical, electric and hydrostatic processes (Shadwick 1995). Many mechanical systems are now being reverse engineered to emulate some of these remarkable characteristics of “soft robotics” (Walsh & Strano 2019).

Chromatophore systems, through a combination of pigmentation and rapid changes to cell size, enable many cephalopods to use complex changing colour and pattern displays such as chromatic pulses and wave patterns to communicate, match their colour to their background, hunt, and avoid predation (How et al. 2017; Williams et al. 2019). Many can rapidly adopt background patterns and colours to camouflage themselves (Hanlon 2007). Amongst land-based vertebrates, only the more gradual colour change seen in the iridiphore system of the Malagasy panther chameleon produces similar effects (see: Teyssier et al. 2013). The synchronised flashing of fireflies is a simple process of bioluminescent enmeshment that relies on a different mechanism (Ramírez-Ávila, Kurths & Deneubourg 2018).

The cephalopod development, behaviour, and lifespan is strongly affected by their environment. Factors such as barometric pressure, ambient light levels, temperature, and water quality affect their growth, social behavior and longevity. Most of our knowledge of cephalopods comes from experimental work with relatively small, tank-reared specimens. Their behaviour and physiology in their natural habitats are largely unknown. Research has shown multiple paternity in one species and suggests complex genetics and reproductive behaviour (Bo, Zheng, Gao & Li 2016). Most studies have shown that cephalopods are exclusively semelparous (reproduce once in a lifetime); however, there are various reports of iteroparity: in the giant warty squid, *Kondakovia longimana* (Laptikhovsky, Collins & Arkhipkin 2013); vampire squid, *Vampyroteuthis infernalis* (Hoving, Laptikhovsky & Robison 2015); and jumbo squid, *Dosidicus gigas* (Pérez-Palafox et al. 2019).

The lifespan of the octopus in laboratory conditions (at atmospheric pressure and room temperatures) is short (1-2 years), increasing with lower ambient temperature and increasing habitat depth. Polar and deep-sea species typically reach maturity in 3 to 11 years (Schwarz, Piatkowski & Hoving 2018). One deep-sea octopus was recorded by chance at a depth of 1397 m; it had the longest egg-brooding period of any known animal (53 months, see: Robison, Seibel & Drazen 2014). As octopi have been recorded at depths of up to 5145 m (Jahn 1971), our knowledge of their function, reproduction and ageing in natural habitats is scant (Hoving et al. 2014). Those found in the deeper ocean — including *Vulcanoctopus hydrothermalis*, which is reported only in proximity to deep hydrothermal vents — can function in conditions of relative hypoxia (Seibel & Childress 2000). They show remarkable capacities for organ regeneration after damage including for muscle, eyes, cardiac structures and arms (Impradore & Fiorito 2018). Unlike vertebrates, their mitochondria are exclusively interfibrillary, and they have no subsarcolemmal mitochondria. They appear to have evolved metabolic systems using simple carbohydrates and amino acids to maximize the efficiency of oxygen use (Hochachka 1994).

The cephalopod immune system appears to be less well-developed than in vertebrates (Castellanos-Martínez & Gestal 2013). In many molluscs, immune function is associated with bacterial symbiosis (Gerdol et al. 2018). Various octopi also appear to have obligatory

relationships with Dicyemids and Chromidinids, which are found in their kidneys (Furuya, Ota, Kimura & Tsuneki 2004). The role played by these may be saprophytic, commensal, or possibly amensal, but the interrelationships are largely unstudied (Roumbedakis, Drábková, Tymi & di Cristo 2018). Many octopi have interrelationships with specific fauna that they rely on to harvest their den detritus, possibly protecting them from infection (Hartwick & Thorarinsson 1978).

As a final aside, I would note that in humans there is considerable evidence of discrete intra-individual cognitive processes (see for an introduction: Shillcock, Thomas & Bailes 2019), and in this respect, the octopus is far from unique.

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