Cajal tackles an apparently common complaint from the "newly graduated: 'Everything of major importance in the various areas of science has already been clarified.'" This would not have been of note, except for the fact that the book was first published in 1899! That the same sentiment existed before modern biology, chemistry, and physics were even conceived is truly inspiring. To me, this sentence is a way to peek into the future and keep motivated, knowing that interesting and exciting discoveries are always out there.

How then does one find new ideas? I do not believe that there are hard and fast rules that will guarantee discovery: after all, the list of major advances that followed a chance observation by a prepared mind is a long one. Yet I think there are some things to consider. In Chapter 2 of Cajal's book, he also discusses a trap which he refers to as "undue admiration of authority". Science rewards those who have made discoveries with professorships, prizes, and leadership positions. It is important to realize, however, that those who have acquired these titles do not necessarily have all the answers. Indeed, progress frequently comes not from experts, but from outsiders who approach questions without prior knowledge. There is no better example of this than the molecular biology revolution, heavily influenced by outsider physicists including Delbrück, Gamow, Crick, Benzer, and many others. In my own lab, several exciting advances were initiated by students and postdocs advocating for experiments that I was convinced would never work… Who to consult, then? I have found that older papers, often predating the invention of molecular methods, are a treasure trove of thought-provoking ideas. For example, the Sulston *et al*. paper describing the embryonic cell lineage of *C. elegans* is replete with one-sentence observations and statements, each of which has launched entire research careers. Several of Cajal's hypotheses, over 100 years ago, about the roles of astrocytes in the nervous system were rediscovered independently in recent years and are studied today. Luria and Delbrück's serious contemplation of non-genetic modes of inheritance foreshadowed current interest in epigenetics. When science moves rapidly from one hot topic to the next, some ideas are forgotten. Thus, paradoxically perhaps, digging up long-abandoned ideas is a great way to pursue new and creative research.

Finally, any thoughts on scientific training? The path of most biologists these days is fairly narrowly prescribed: attend graduate school following undergraduate studies, seek a postdoc (usually in a different area of research), apply for faculty positions, and move up the ranks to tenure. I followed this track. But I have learned over the years that the road to discovery can favor those who navigate more unusual paths. And by unusual, I really mean unusual. One colleague whose work I greatly admire was a construction worker before serendipitously deciding to attend graduate school. Another spent many years in industry before turning to academia, and yet another trained for the ballet. I have come to believe that the path is less important than the content. When I first started thinking seriously about science I was in a position where, as my amazing physician wife once remarked about her early training, I didn't know what I didn't know. I was unaware of the existence of entire fields of research. With time, I could say with more confidence that I know what I don't know. These stages of learning have been codified, I believe, in the standard education path, where graduate school provides the first real opportunity to broaden familiarity with the vast science that is out there. Alternative paths inherently imbue their pursuers with the instinct to look well beyond what they are familiar with and may therefore counterintuitively speed up the initial stages of learning. These days I feel there are some things I actually do know, at least in some depth, but these are generally few and far between and this is great, because science is about learning; and how exciting it is that there is so much more left to learn!

DECLARATION OF INTERESTS

The author declares no competing interests.

Laboratory of Developmental Genetics, 810 Weiss Research Building, The Rockefeller University, 1230 York Avenue, New York, NY 10065, USA.
E-mail: shaham@rockefeller.edu

Quick guide

Sea robins

Corey A.H. Allard[1,3], Amy L. Herbert[2,3], David M. Kingsley[2], and Nicholas W. Bellono[1,*]

What are sea robins? Sea robins are an extremely unusual group of fishes with a host of dramatic adaptations suited for life on the sea floor. Sea robins belong to a family of ray-finned fishes called Triglids, which inhabit diverse habitats ranging from shallow salt marshes to deep oceans around the world. Most Triglidae fish are benthic specialists that spend much of their time on the ocean bottom where they hunt in the sand for fish, crustaceans, and other invertebrates. To facilitate their benthic lifestyle, sea robins have evolved a number of bizarre traits, the most iconic of which are their six leg-like appendages (Figure 1).

Wait, what are fish legs? Sea robin 'legs' comprise the first three fin rays (lepidotrichia) of each pectoral fin. In most fish, pectoral fins are webbed to facilitate efficient and effective swimming. Similar to other fish, newly hatched sea robins have webbed fins that they use to swim and hunt throughout the water column. Remarkably, later during ontogeny the first three fin rays begin to separate from the rest of the pectoral fin to result in three individual appendages on each side (Figure 1). Leg development is accompanied by skeletal changes and extensive modification of the musculature and nervous system. Each leg contains two segmented chains of bone (hemitrichia) which slide against one another to bend the leg while sea robins 'walk' along the sea floor. There are no tendons in the legs themselves, and instead all motion is actuated from the base by specialized musculature in the pectoral girdle. Intriguingly, this metamorphosis coincides with a shift from a planktonic lifestyle in the water column to a benthic existence at the bottom of the ocean.

While fish legs may seem strange, they are not unique to sea robins. Indeed, they are also found among other families of fishes that are part of the Scorpaenoidea superfamily that includes

Triglidae. These relatives are also typically benthic, and therefore appear to have also developed legs during adaptation to life at the bottom of the ocean. Remarkably, legs appear to have evolved at least three separate times within the Scorpaenoidea superfamily, suggesting a common selective pressure may underlie this adaptation.

How do sea robins use their legs? Many sea robin species use their legs for 'walking' on the sea floor. Walking locomotion is hypothesized to be more energy efficient than swimming, especially within the turbulent waters of the intertidal zone, and may also help the fish avoid predators in the water column.

Some sea robin species appear to have legs with specialized functions beyond locomotion. Many are known to use their legs to manipulate the substrate by flipping over shells and small rocks in search of concealed prey. Remarkably, certain species are even thought to use their legs to locate prey that is completely buried in sand. These food sources are relatively inaccessible to detection by conventional sensory systems such as sight or olfaction (smell), suggesting that legs may play a critical role in this unique ability. Moreover, divers have observed other fish species following sea robins to steal the food they uncover in an act known as kleptoparasitism. Sea robins' impressive food-finding ability has led scientists to speculate that sea robin legs may represent cryptic sensory structures that 'taste' the substrate to aid in the detection as well as capture of buried prey organisms.

Sea robin legs can taste? In the 1980s, scientists at the Marine Biological Laboratory (Woods Hole, Massachusetts) found that the legs of the Northern Sea Robin are capable of detecting both mechanical forces and prey-related chemicals such as amino acids. These molecules are common ligands for both taste and olfaction in fishes, and are abundant in extracts made from shrimp, squid, and mussels. Curiously, sea robin legs do not appear to house canonical chemosensory cell types like taste buds or olfactory receptor neurons, so the molecular and cellular basis for their interesting sensory abilities remain unknown.

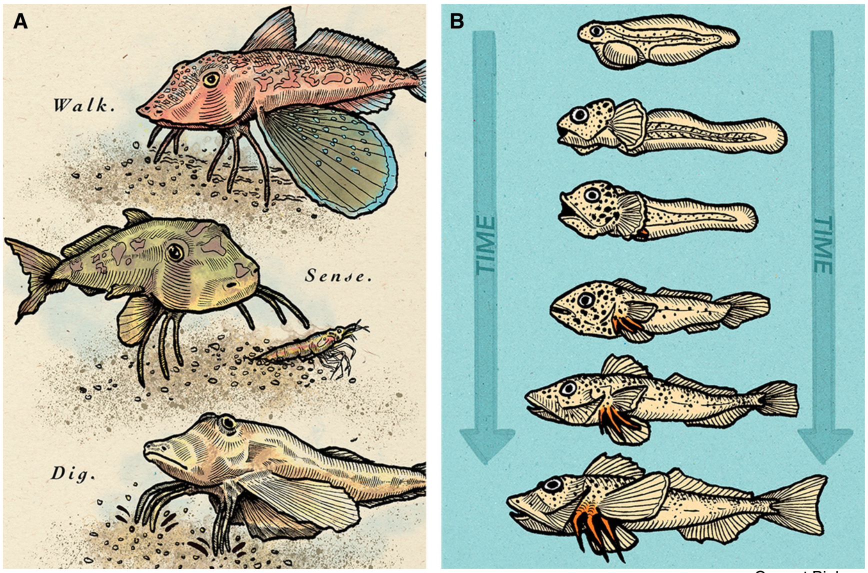

Figure 1. Sea robins are fish with legs.
(A) Sea robins are benthic specialists that have evolved leg-like structures for locomotion, the detection of prey, and digging. (B) Legs separate from the pectoral fin during development. Artwork used with permission from Lily Soucy.

How do legs connect to the nervous system? Sea robins have a specialized nervous system that appears to reflect the critical role sensory legs play in predation. Sensory information is relayed from each leg to the central nervous system by a large, branched nerve which emanates from a massively enlarged spinal ganglia. Within the spinal cord, these ganglia form synapses with neurons located in six extra macroscopic spinal lobes (one per leg) which are not found in legless fishes. While the exact function of these unique lobes is unknown, they are thought to underlie integration and processing of sensory information received by the legs.

What can we learn by studying sea robins? A longstanding goal in biology is to understand the origins of novel traits. Sea robins represent a particularly clear example of an organism that has specialized for an environmental niche by evolving new organs. Legs and their accompanying neural hardware allow these fishes to thrive in their benthic environment and may enable them to access resources unavailable to competitors. Sea robins also possess a host of other unique traits, including expanded pectoral fins that allow them to soar like a bird under the water, armor plating on their heads and bodies, dramatic variations in coloration and pigment patterning, and specialized sonic muscles that beat against their swim bladder to generate croaking sounds that may be used for communication. Furthermore, there is dramatic phenotypic diversity among closely related sea robin species, including considerable variation in leg morphology which may reflect specific uses, such as digging versus locomotion.

Sea robins are therefore ideally positioned to become a powerful comparative model for illuminating general principles that drive the evolution of biological novelty. Such efforts will be facilitated by technological advances that are making research featuring unconventional model organisms increasingly feasible, including new sequencing technologies, bioinformatic resources, and genomic editing. Critically, two readily available and non-threatened species of sea robins can be crossed, cultured, and maintained in the laboratory. These species are therefore strong candidates to develop as model systems complete with experimental and bioinformatic resources. Furthermore, as genome sequencing extends to many new organisms, comparing the genomes of species with and without legs will lead to insights into conserved evolutionary and developmental processes. By expanding our biological studies to unusual and specialist organisms like sea robins, we can uncover and compare new biology that is critical for understanding the full spectrum of development, physiology and evolution across the tree of life.

Where can I find out more?

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DECLARATION OF INTERESTS

The authors declare no competing interests.

[1]Department of Molecular and Cellular Biology, Harvard University, Cambridge, MA 02138, USA. [2]Department of Developmental Biology and Howard Hughes Medical Institute, Stanford University School of Medicine, Stanford, CA 94305, USA. [3]These authors contributed equally.
*E-mail: nbellono@harvard.edu

Letter

In Indonesia and beyond nature conservation needs independent science

William F. Laurance[1,*], Abdil Mughis Mudhoffir[2,3], Wulan Pusparini[4], Erik Meijaard[5], and Jayden E. Engert[1]

Biodiversity conservation is a crisis discipline[1] requiring frequent evaluation of potential interventions to reduce environmental threats. To have a chance of success, past conservation activities need to be assessed, to better understand how alternative approaches affect conservation outcomes. Yet, many governments and corporations have a vested interest in environmental debates, and promote information supporting their views, with some even suppressing relevant evidence[1,2]. Worryingly, such actions may be undermining science as an independent guide to policymaking and conservation management.

The megadiverse nation of Indonesia harbors the largest expanses of tropical rainforest in Southeast Asia (Figure 1), with nearly unrivaled numbers of critically endangered species. Despite facing environmental challenges from much-needed socioeconomic development, Indonesia has recently achieved admirable reductions in deforestation rates and fire occurrence[3]. However, its efforts to cast itself in a positive light environmentally are coming at a cost.

In September 2022, five leading conservation scientists — three of whom had worked in Indonesia for

Figure 1. Imperiled species and environmental threats in Southeast Asia.
(A) Bornean orangutan (*Pongo pygmaeus*; photo © YAY Media AS/Alamy). (B) Sunda clouded leopard (*Neofelis diardi*; photo © Ch'ien Lee/Minden Pictures/Alamy). (C) Bulldozer clearing a logging road in central Kalimantan, Indonesia. (D) Great hornbill (*Buceros bicornis*; photo © Scenics & Science/Alamy).