Figure 2. Cassava toxicity, testing and processing.
(A) Children with Konzo. This photo was taken during the 1981 epidemic, which was when it was clear that Konzo was related to a monotonous cassava diet (Nzwalo & Cliff, 2011). (B) Bradbury cyanide testing kit using picrate paper. Here: results for different flours purchased at a market in Maputo, Mozambique, plant samples from the Monash University collection, and cassava chips purchased in Melbourne, Australia (photo: R. Gleadow). (C) Women in Mozambique processing dried cassava tubers by pounding. They then mix the flour with water and cook it as a type of bread (photo: R. Miller, Royal Botanic Gardens, Melbourne).

approaches. Farmers prefer to cultivate bitter varieties, as they are perceived to have higher yields and greater tolerance to environmental stress. If bitterness does confer yield benefits, the development of zero-cyanide cassava may not be the best path forward.

What resources are available?

Collections of global cassava varieties are available at CIAT (https://ciat.cgiar.org) and IITA (https://www.iita.org).

Published genomic data for over 200 cassava cultivars are available from https://link.springer.com/article/10.1007/s11103-020-01104-w.

Educational materials in different languages and testing kits are available from the Konzo Prevention Unit: https://biology.anu.edu.au/research/centres-units/konzo-prevention-unit.

Where can I find out more?

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DECLARATION OF INTERESTS

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[1]School of Biological Sciences, Monash University, Clayton, Melbourne, VIC 3800, Australia. [2]Faculdade de Medicina, Universidade Eduardo Mondlane, Maputo, Mozambique.
*E-mail: ros.gleadow@monash.edu

Book review

Six impossible worlds before breakfast

Alex Gomez-Marin

An Immense World: How Animal Senses Reveal the Hidden Realms Around Us
Ed Yong
(Random House; 2022)
ISBN: 978-0-593-13323-1

A foundational challenge in the study of living organisms is the realisation that to share a world is different than to have it in common. The cartoonist Ed Steed has gifted us with one of the most creative, concise, and compelling illustrations of such a quandary: three humans and a tree stand in front of a human skull on a wooden stool; the humans draw the skull, while the tree draws the stool. In other words, we can occupy the same physical *space* with other creatures while inhabiting a different *place*. A forest is a forest, but a forest for a woodpecker has little to do with a forest for a lumberjack.

This obvious but crucial distinction was championed by the Baltic-German zoologist Jakob von Uexküll who, in his delightful 1934 book *A Foray into the Worlds of Animals and Humans*, turned the German word *Umwelt* into a seminal concept for biology and philosophy: the meaningful environment of each living creature.

Consider this: “The tick’s life history provides support for the validity of the biological *versus* the heretofore customary physiological approach. To the physiologist, every living creature is an object that exists in his human world. He investigates the organs of living things and the way they work together, as a technician would examine a strange machine. The biologist, on the other hand, takes into account each individual as a subject, living in a world of its own, of which it is the center”[1]. In his new book, *An Immense World: How Animal Senses Reveal the Hidden Realms Around us*, the Pulitzer Prize-winning science journalist Ed Yong picks up Uexküll’s journey through the worlds of animals in what constitutes a remarkable *tour de force* in sensory

ecology. Yong's previous work, *I Contain Multitudes*, was a stroll through the countless small companions that lie within our bodies. He now pursues the adventure without, describing a myriad animal worlds that lie hidden in plain sight.

The nearly half-a-thousand pages of this literally wonder-full tome teem with an exceptionally long cast of characters: mantises, kangaroos, grasshoppers, manatees, squirrels, moths, owls, vultures, turtles, and so on. Warping the academic flatland of rodents as humans, Yong's book is 'about animals as animals' rather than about 'model organisms'. He entrusts us with an overwhelming diversity, and does so for each creature's sake, celebrating many extraordinary feats in the animal kingdom.

The stroll begins with a sort of biological *Gedankenexperiment*. In a bemusing vibrant scene, different species go about their businesses in a crowded room: an elephant, a mouse, a rattlesnake, a bumblebee, and a human called Rebecca, amongst other animals. He invites the reader to consider "how Rebecca and the rest of this imaginary menagerie might perceive one another". Dreaming up the modest point of view of a tick on a leaf or a fly on a wall, one can forgo the physicist's conjectural multiverses and the technocrat's promissory metaverses — biology is astonishing.

Yong systematically covers a wide range of animal senses one chapter after another. His voluptuous narrations, however, disclose a dire paradox: in recurrently privileging the physics and chemistry of sensory organs, each animal's *Umwelt* will dissolve into the *Umwelt* of the biologist, too often captured by a mechanistic vision of life. The titanic effort to peep into the sensory bubbles of other species shall then provide at best an insolvent reflection of some of our very abstract explanatory objects as scientists. That's the hex of Yong's blessings: a plea for grasping such alien realms that is based on human-centric accounts, biased towards the favourite explanatory objects of molecular biologists.

Smell and taste go first, highlighting the detection achievements of dogs, bacteria, moths, ants, vultures, elephants, snakes, catfish, mosquitos, and other marvellous creatures. Chemicals and odorant receptors bestow their *Umwelts* (*Umwelten* is the proper plural in German).

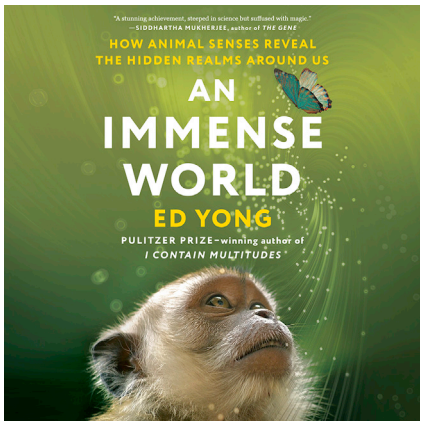
Yong then delves into seeing. We see by smelling light, his poetic prose asserts. Through their eyes, we get to know the lives of jumping spiders, giant squids, scallops, vultures, killer flies, and more. He takes us to dark caves and to the ocean depths. We meet creatures that see at different frequencies. We try to conceive these undertakings via wavelengths and photoreceptors.

Seeing shades of grey would seem good enough. Why evolve the ability to see color? Yong explains how color vision offers constancy so that red at dawn is red at dusk. Beyond monochromats (color-blind animals), nature gave rise to dichromats, trichromats, and even tetrachromats (though not amongst mammals), all the way to the mantis shrimp, which has twelve classes of photoreceptors but poor discrimination abilities. Other creatures enjoy ultraviolet vision. And some animals can sense the polarization of light. Reality surpasses fiction.

The following chapter is about pain, which Yong calls "the unwanted sense". The naked mole-rat is the protagonist here, together with crabs, fish, and lobsters. Neuroscientific data blend with metaphysical commitments: "It's not the case that nociception is a physical process of the body, while pain is a psychological process of the mind. Both *arise from* the firing of neurons" (*my italics*). And yet this should not distract us from the uncomfortable truth that to study animal pain in the lab one must produce it. They certainly suffer, and so do we from 'compassion fatigue'[2].

Yong moves to heat. He narrates the extraordinary ability of camels and squirrels to cope with extreme temperatures. We also learn about snakes' thermal sensitization and thermotaxis in flies. Temperature sensors endowed with 'channels' become, once more, *our* windows to peep and peer into *their* experiences.

The journey gets subtler as Yong addresses the intimacy of touch. Mechanoreceptors are key. He chronicles how manatees, walruses, peacocks, sea otters, and spiders sense currents, textures, and pressures.



Tadpoles, treehoppers, and scorpions can also feel surface vibrations through solids and liquids. Hearing would appear less vital than touch or smell. In fact "the first insects were deaf". However, owls, kangaroos and rats master this sense, not to mention bats' prodigious way to employ echoes.

But there is more. Yong reminds us that some fish produce their own electricity to locate and communicate. Using electric fields has several advantages: they spread in all directions, do so virtually instantaneously, and are not distorted by turbulence. As for sensing magnetic fields, very little is known. Kangaroos, birds and whales use it. And turtles should have magnetic 'compasses', yet to be found. Note that organs with openings to the outside, such as nostrils and pupils, would not be required. Being indistinguishable from surrounding tissue, they could be located anywhere within the flesh. Magnetoreception remains the only sanctioned sense without a known sensor.

As Yong's book makes patent, we have more senses than fingers on our hand, not to mention interoception, namely, the ability to feel part of what is going on inside our own body. In turn, through proprioception we sense the location and movement of its parts, distinguishing the actions produced by others on ourselves from our very own. Tickling oneself is vain.

Despite structuring the book in "chapters that revolve around a specific stimulus", Yong emphasizes towards the end that we feel our many senses as a unity. Multisensory integration sews together what we had cut when

describing one sensory modality after another. The unit of *Umwelt* does not dissolve, or perhaps it does. Experience is intrinsic and unitary.

In the final chapter, Yong shifts gears from sensory ecology to political concerns. He concludes the book with a manifesto: "with every creature that vanishes, we lose a way of making sense of the world" and, he adds, "we lose a thread of the rope that sustains us". Urging us to protect threatened "scenescapes", he denounces "sensory pollution", from garbage in parks and chemicals in rivers to lights in forests and sounds in oceans. Indeed, it is not the squirrel that crosses the motorway, it is us who crossed its way. There is a clash of *Umwelts* in our laboratories and in the world. As the American ethnobotanist Terence McKenna put it, if we could feel what we are doing to the Earth, we would stop immediately. But we don't. Why?

We used to have great masters of "tender empiricism". Darwin spent hours eyeballing how plants grow. Von Humboldt drank from the rivers. Goethe tasted the petals of the flowers. Von Uexküll continued the lineage of Romantic *Naturphilosophie*, whose bad and naive scientific press is best understood by grasping its nemesis, namely, the so-called Promethean scientist[3]. In the myth, he steals the fire from the gods and hands it to humanity as technology. In actuality, he goes along Francis Bacon's predicament "to follow and as it were hound nature in her wanderings, and you will be able, when you like, to lead and drive her afterwards to the same place again. (…) Neither ought a man to make scruple of entering and penetrating into these holes and corners, when the inquisition of truth is his sole object"[4].

But what would animals say if we asked the right questions[5]? We may watch a professionally produced animal documentary on TV where a male low pitch voice glosses what a lion and a gazelle think and feel, usually from a dreary Darwinist perspective that casts any event as one more opportunity to confirm that life is all about struggle, competition, and sexual selection. Museums are generally lifeless. And zoos, despite their imperative rebranding as conservation sites, are anachronistic and ethically uneasy. In turn, most of what most city kids know first-hand about animals is based on dogs in parks and fish in bowls. When it comes to neuroscientists, it's mainly about rodents in cages. Given the astounding improvement of automated tools for behavioral tracking, scientists have now dispensed with sitting down and patiently observing what animals do. Experts (believe that they) don't (need to) look anymore. Expertise and experience are taken apart. Avoiding anthropomorphism is our alibi.

But objectivity in biology is a subtle form of anthropomorphism. Uexküll reminds us that all living organisms (including biologists) have a point of view. We are subjects studying other subjects, but we pretend that those subjects are objects (and that we are not there). We are the elephant in the room, both academically and ecologically. Ironically, the species both most absent and present throughout Yong's writing is arguably us. We are hidden in plain sight.

Yong proclaims that "this is a book not about superiority but about diversity". The impulse to decenter the human is understandable, as the pendulum swings back from the excesses of exceptionalism. No doubt, humans can be dumb and gorillas smart. Human stupidity is as much of a mystery as our genius. And yet, other animals don't write books about other animals or get annoyed about claims in them. Any plea for all-but-human worlds is prone to self-lampooning. We need to honor both non-human but also human worlds.

A very few pages before the end Yong recalls Uexküll's mention of the *Umwelt* of the astronomer (Uexküll does the same when concluding his seminal book). Indeed, the members of our species inhabit different partially-overlapping universes too. With microscopes and algorithms we can discover and create new worlds. And so, after such a long stroll through the worlds of animals, one wonders why Yong did not walk a few more strides to discuss and contemplate those of humans, acknowledging that even within the sciences there are different provinces, tribes, goals, and values; not to mention the distinctive sensibilities of poets, midwives, and children.

Uexküll's vision has percolated through cybernetics, biosemiotics, neuroscience, and philosophy. However, conceptual credit has remained circumscribed to the footnotes of the life and mind sciences. As his work is being rediscovered at last, it is easy to misinterpret his thought. Concerned with the *modus vivendi* of a humble tick, Uexküll offers a general biological theory. The *Umwelt* is arguably one of the greatest concepts in biology. It is tempting to sell it out for molecular totems. Animal texts then become a pretext for reductionistic subtexts. The explanatory work ceases to be about their subjective lives and becomes about our preferred abstractions.

We then risk bartering meaningful environments (*Umwelts*) for physical surroundings (*Umgebungs*), abdicating inner worlds for sensory receptors. At the end of the day, we may know a great deal about how "an animal reacts to what it senses" in terms of photoreceptors and mechanoreceptors, remaining almost clueless as to how it feels. Prolific with animal tales, Yong's fine pen is skinny on perception–action loops, embodied cognition, subjective experience, and mind writ large[6]. Wonderful stories about sensory organs do not subjectivity make. All inner life is bypassed, even ignored. We also risk failing to appreciate Uexküll's challenge to mainstream thought: *Umwelts* are not mental representations either.

The very title of the book entails a series of profound questions that remain unaddressed. How many worlds fit in a forest, a lake, or a kitchen? If our own perception of reality "is but a tiny slice of" a greater immense world, what is that reality, really? Is there an objective world out there? Uexküll himself writes: "Since the sensory spheres of individual humans are similar in all essentials, the objects in the different *Umwelten* are also similar. This has led people to the premature conclusion that objects by themselves are autonomous realities, having an existence of their own, independent of the subject."

If slivered into sensory bubbles that trap each organism, is such "an immense world" the sum-total of all those tiny bubbles? If so, how to grant it coherence and unity amongst its parts? Are they entangled or extrinsically related? How to square that with their apparent impenetrability and incommensurability? In a word, one

wonders about the fine print of such a small-worlds metaphysics: should one think of them as bridgeable islands, hamstrung monads, layered cakes, braided ropes, flow vortices, musical symphonies? If we are "enclosed within" them, are we locked in? Can we escape or at least expand them? Or are we doomed to at best approach the surface of those other worlds casting our human blankets over them? Too many questions to answer; too tragic to refuse to entertain.

At the end of the day, even if we fail, we must try. Scientific imagination is underrated and shriveled. We need to restore its proper place amongst reason and intuition[7]. Our attempts to conceive such extraordinary worlds are a healthy break from the hype and hope for artificially simulated realities that plague current academe and saturate laypeople's attention. Digital prophets postulate the imminent arrival of the multiverse. Many are already trapped and lost in conversation with chatbots. Some physicists continue to rejoice at untestable parallel universes. Biologists, however, have at their disposal a key to plebeian uncanny worlds, not as wild speculations or technocratic delusions, but as the concrete enacting of embodied life in the natural world.

DECLARATION OF INTERESTS

The author declares no competing interests.

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Instituto de Neurociencias de Alicante, CSIC-UMH, 03550 Sant Joan d'Alacant, Spain.
E-mail: agomezmarin@gmail.com
Twitter: @behaviOrganisms

Primer

Plesiosaurs

P. Martin Sander[1,2]

In the early 19th century, long before the discovery of the dinosaurs, scientists and the public alike were faced with the realization that strange beasts, wholly extinct, were once populating Earth's ancient oceans. In no small part, this realization was through the discovery of the first plesiosaurs (and ichthyosaurs) along the Dorset coast of England in the seaside town of Lyme Regis. There was this large marine reptile resembling a large sea turtle, but with four evenly shaped flippers and looking as though a large snake had been pulled through its carapace. It was soon to be named scientifically *Plesiosaurus*, in reference to its greater similarity to living reptiles than the *Ichthyosaurus* (Figure 1). While the *Ichthyosaurus* was relatively easily understood as a fish-shaped reptile descended from land-living ancestors, the *Plesiosaurus* was beyond comprehension, even though incomplete skeletons had been unearthed already in the early 18th century. Plesiosaurs seemed so alien that the first complete skeleton, discovered by the famed Mary Anning a little more than 200 years ago (Figure 1A), was considered a fake by the leading anatomist of the day, the Baron Georges Cuvier in Paris. Only study of the original specimen convinced him of the authenticity of this animal but reinforced his seminal insight that there is extinction.

What intrigued Cuvier most, and still offers a challenge to evolutionary developmental biologists today, was the incredibly long neck (Figure 1A), consisting of over 40 (or more) vertebrae, almost twice as many as any other tetrapod. The tail, by contrast, was short, unlike in most other reptiles. This combination of a short tail and an unreasonably long neck precipitated another famous episode in the history of paleontology some decades later. Reconstructing the most long-necked of plesiosaurs, an elasmosaur, American paleontologist and zoologist Edward Drinker Cope had mounted its skull on the tip of its tail (Figure 1C). Apparently, he too could not cope with the notion of an animal having over 70 neck vertebrae. When this error was repeatedly noted in public by his competitor Othniel Charles Marsh, the 'bone wars' ensued, which later played out in the race over dinosaur discoveries in the Wild West.

Returning to the first plesiosaur skeleton, the flippers presented a puzzle as well. Their anatomy is not very different from the front limbs of whales and sea turtles, but the hind flippers, which are absent in whales and small in sea turtles, look very much like the front flippers (Figure 2). In fact, on occasion, front flippers have been mixed up with hind flippers in mounted skeletons in museums, in the tradition of Cope. The similarity in shape of fore- and hindlimbs is also a unique feature among tetrapods, suggesting that all limbs served exactly the same function.

Popular interest in the sea monsters from Lyme Regis was such that, in 1830, it led to an artistic visualization of plesiosaurs as living animals, the beginnings of paleoart. The genre started with a bang, as a loose-leaf lithograph entitled *Duria Antiquior* (a more ancient Dorset; Figure 1B). This iconic depiction of a plesiosaur attacked by an ichthyosaur surrounded by a marine menagerie in an Early Jurassic sea is the archetype of many such illustrations, immortalized by Jules Verne in his *Journey to the Center of the Earth* from 1864 (Figure 1D). Paleoart, even in its earliest version, derives its scientific relevance by visualizing paleobiological hypotheses, albeit more or less well supported and often only implicitly. However, such visualizations sometimes inspire real-life scientific questions such as: How exactly did plesiosaurs use their four equally shaped flippers in locomotion, or why was the plesiosaur neck so incredibly long, and how flexible was it? These questions are at the center of much modern plesiosaur research and lend importance to the study of unique but extinct *Bauplans* such as that of plesiosaurs for our understanding of evolution.

A tale of three extinctions

Often called 'the mother of all extinctions', the end-Permian mass