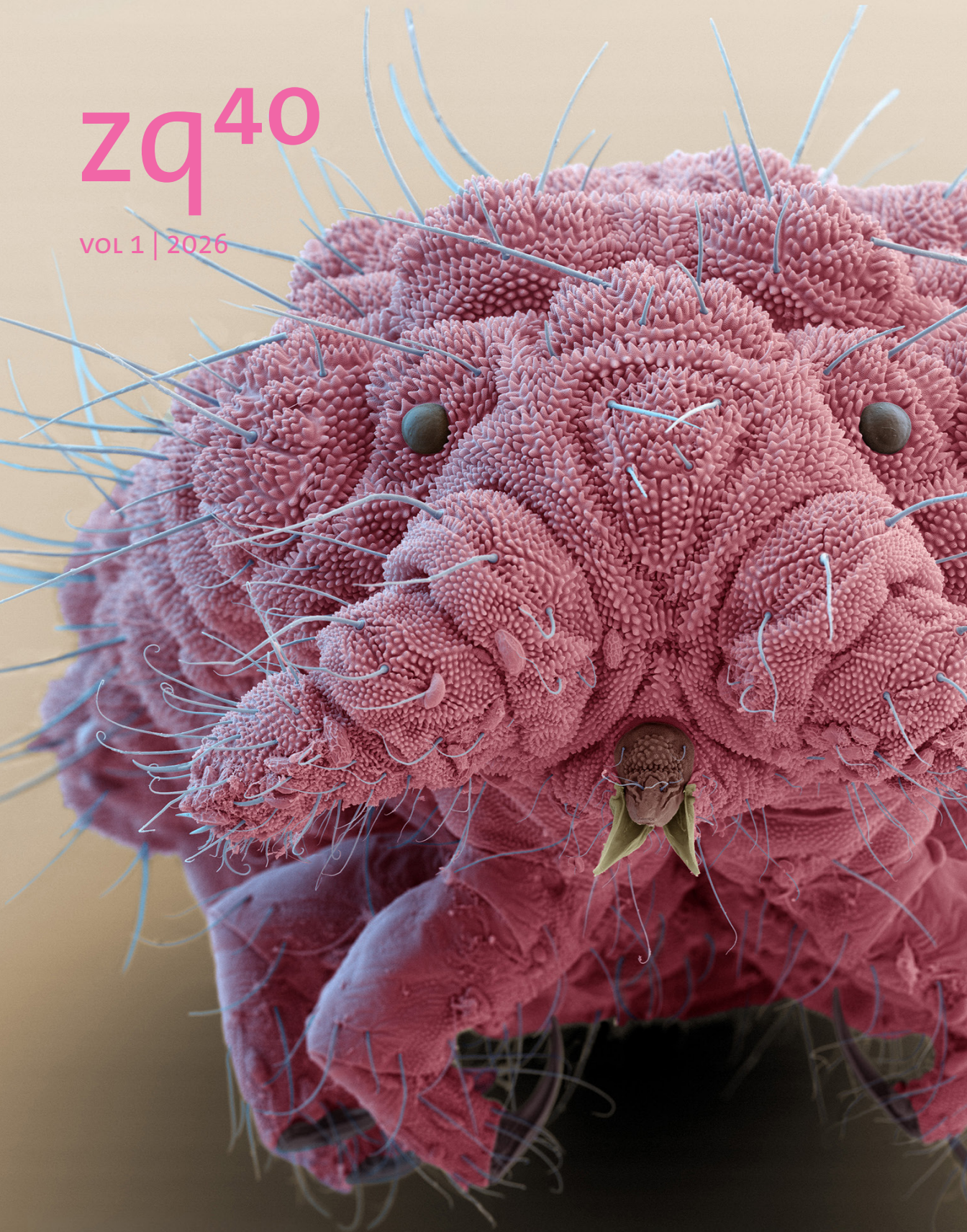
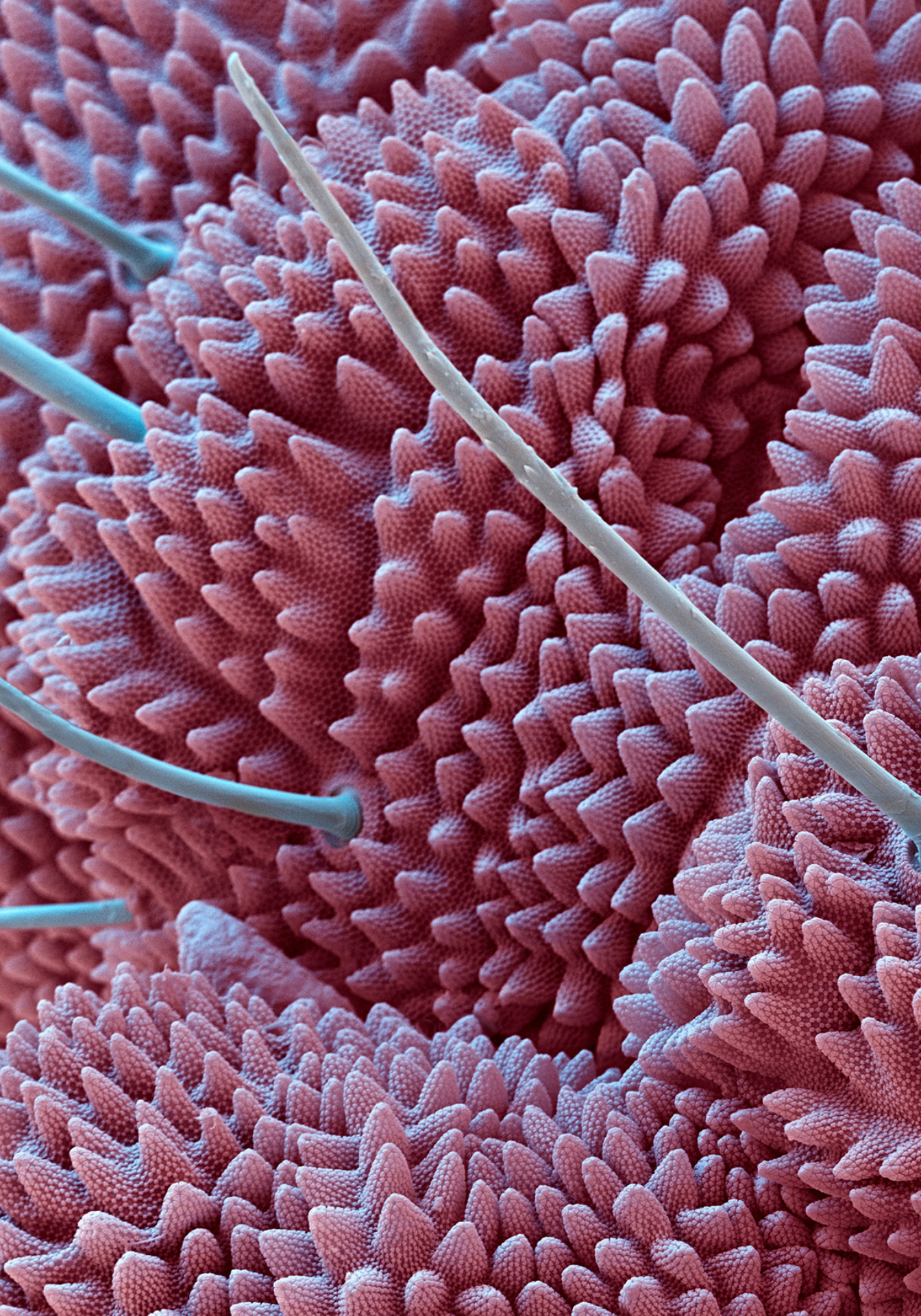
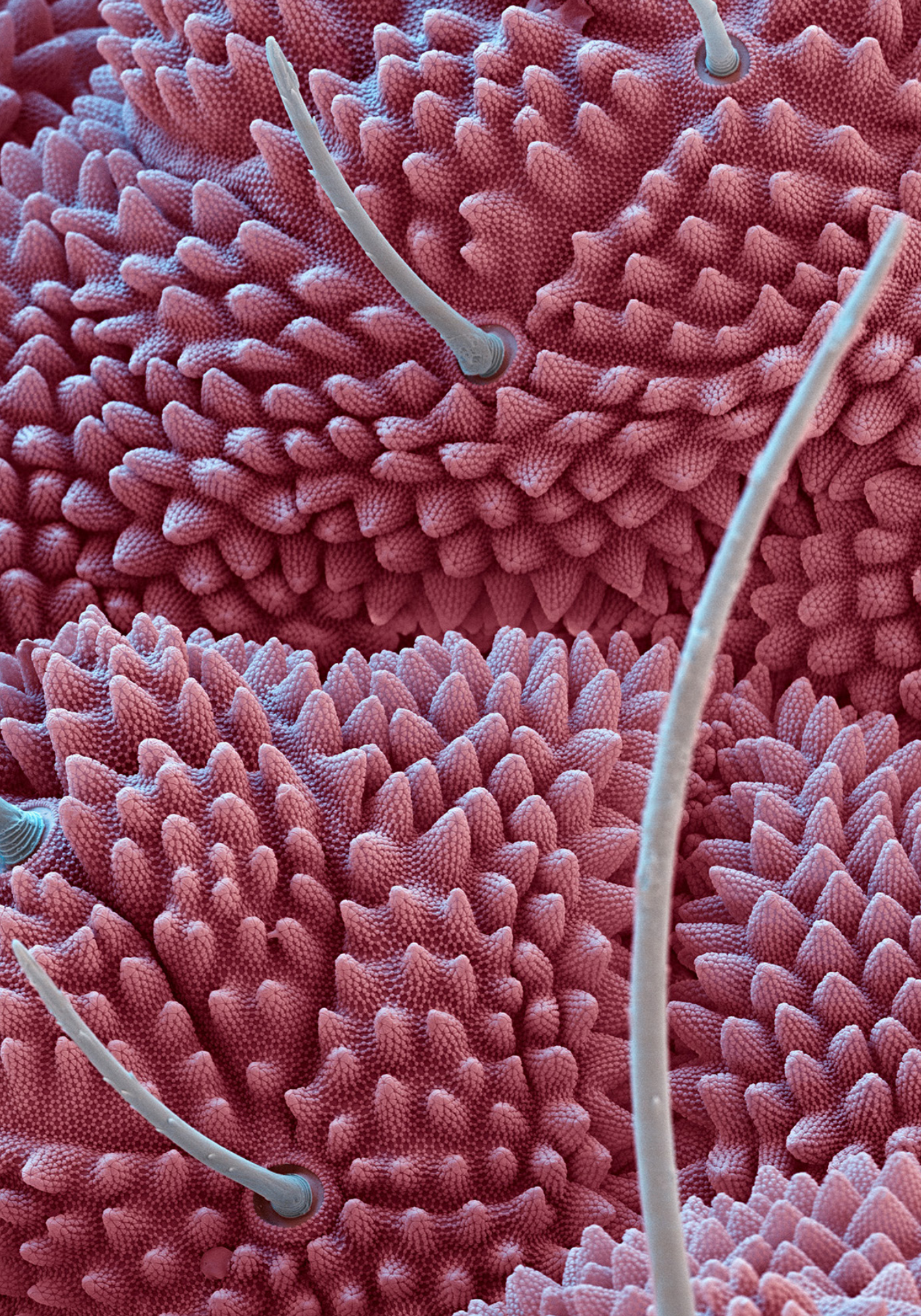


zq40

VOL 1 | 2026







About Zygote Quarterly

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Shoshanah Jacobs
Tom McKeag
Marjan Eggermont

Cover art

Cover: Springschwanz Kopf (Springtail head) 480x2 | pp. 2-3/pp. 86-87:
Springschwanz Haut (Springtail skin)
2800x | Nicole Ottawa and Oliver
Meckes, eye of science©

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ISSN

1927-8314



Diatom. *Asteromphalus* sp. (probably *A. humboldtii*) from a south atlantic ocean deep sea probe. Diatoms are unicellular algae, they are surrounded by a cell wall made of silica. Scanning Electron Microscope, 1400:1
Photo: Nicole Ottawa and Oliver Meckes, eye of science©

Editorial

If there is one theme that runs through this, our fortieth issue of *Zygote Quarterly*, it might be said to be the importance of looking anew. Think how differently a leaf looks when viewed through a simple hand lens. Looking anew, however, as some of our authors remind us, involves more than the use of a novel tool. It requires a deeper understanding of the principles and circumstances that produce the phenomena that we are observing. In the tradition of Science, this can, occasionally, produce a turn of thought or perspective that changes the way we look: an adopted paradigm, as Thomas Kuhn so ably wrote of in *The Structure of Scientific Revolutions*.

Happily, and hopefully, there is a continual turnover and mixing of these ideas within our cultural milieu. Three of our contributors were asked for their perspective on the state of bio-inspired design since the founding of ZQ in “Looking Back/ Looking Forward”. Aubrey Streit Krug of the Land Institute notes that as socio-economic crises intensify, there is an increased interest in the techniques of the “more-than-human world.” She cites the example of the Kernza® perennial grain as a product requiring a different approach to agriculture but offering a rich return. Vytas SunSpiral in “Evolution of Robotics” echoes this

notion, writing of the supplanting of rigid, mechanical robots with flexible and compliant machines. Here different bio-inspired principles are at work when producing elastic, tensile actuators and associated sensors. Pete Foley reminds us in his article “Repositioning Biomimicry” that technology is not enough to equip us to solve our most pressing ecological challenges.

The integration of technology with other approaches will be critical to achieving the “innovation capability” that BID practitioners will need to compete in the global marketplace. Likewise, Michael W. Wright in “Building a BiosVerse Compatible™ Industry”, while reporting on the Biomimetics25 conference, advocates for a focus on impact rather than growth and the need for a strong network and professional cadre.

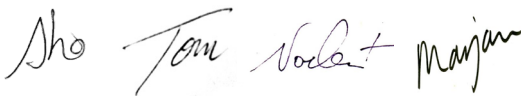
Still, the investigation and application of lessons from nature have been greatly aided by technological advances and dissemination since 2012, when we began reporting in ZQ. Our portfolio features Nicole Ottawa and Oliver Meckes of *eye of science* (<https://www.eyeofscience.de/>) demonstrate this delightfully in their scanning electron microscope images. Inspired by the unknown, they tour us through the too-often hidden world of the very small, from your backyard soil to the frozen Arctic.

Both Richard James MacCowan, in an interview, and Ilse (C.A.) Rovers in “From Hype to Hyphae” share a belief in a constraints-based approach to science translation and bio-inspired applications. Rather than seeking an optimization of an observed phenomenon, for example, Rovers seeks to establish “target values”; when a material, such as the mushrooms she is currently evaluating, can be reliably useful.

Shoshanah Jacobs interviews Douglas Fudge in “Outperforming in the Natural World” and unravels (if you will) the secrets of hagfish slime, and the consideration of scale, time and material properties in the translation of direct observations.

Contributing editor Manuel Quiros and his colleague Oscar Aguado ask “Who Controls Whom? Part II” by exploring the co-evolution of plants and their pollinators. They challenge us to change our relative bearings in viewing this complex dance of adaptation, specialization and signaling.

We hope the viewpoints in this edition might change the way you look at our world. Happy reading! ×



Sho, Tom, Norbert, and Marjan



Mountain landscape UV light as perceived by insects (detail).
Somiedo Pass, Asturias, Spain.
Courtesy of the author O. Aguado.

Thank you

As this is Tom McKeag's last editorial and involvement in *Zygote Quarterly* as editor, we want to take a moment to express our sincere appreciation for his remarkable contributions to the field of bio-inspired design. Tom was one of the three founders of ZQ in 2012. He authored the mission statement published in *ZQ01* (https://zqjournal.org/pdfs/ZQ_issue_01.pdf#page=6), drafted the launch announcement, and identified many of the authors that subsequently contributed articles.

His distinctive editorials introduce each of our issues. Tom has also been a prolific contributor. Of the 285 articles published in *ZQ01-ZQ40*, Tom wrote or contributed 39, from exploring advanced biomimetic prostheses and the development of the Shinkansen bullet train in our first two issues, his tribute to Dr. Steven Vogel in *ZQ15*, a deep dive into mosquitos in *ZQ28*, and the review of Dr. Robert Full's career in *ZQ39*.

During his time at ZQ, Tom also wrote the Biomimicry Column for Greenbiz.com, acted as Executive Director and later Senior Advisor at the Berkeley Center for Green Chemistry, and published his 2023 book *Green chemistry in practice: greener material and chemical innovation through collaboration*. He recently moved from sunny California to Maine, where he is using his

professional training in landscape architecture and town planning to help his coastal town adapt to climate change. Contributing to the Pro-Democracy Movement, he publishes "Viktor Orange: Sociopolitical cartoons by Tom McKeag" at <https://tommc-keag.substack.com/>.

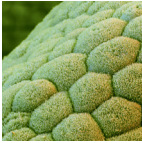
Through his ability to bridge disciplines, connecting biology, design, sustainability, and education, Tom helped ZQ become a rare kind of journal - one that blends scientific rigor with artistic wonder, and that treats curiosity not as a luxury but as a discipline.

Thank you, Tom, for your vision, your generosity, and your enduring influence on the field. We have so thoroughly enjoyed working with you! ×

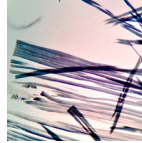


Marjan and Norbert

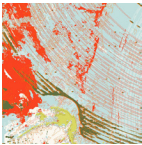
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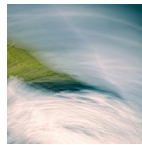
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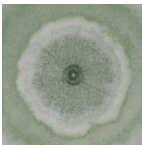
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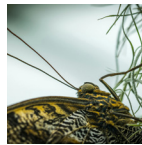
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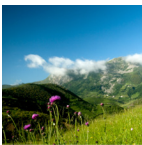
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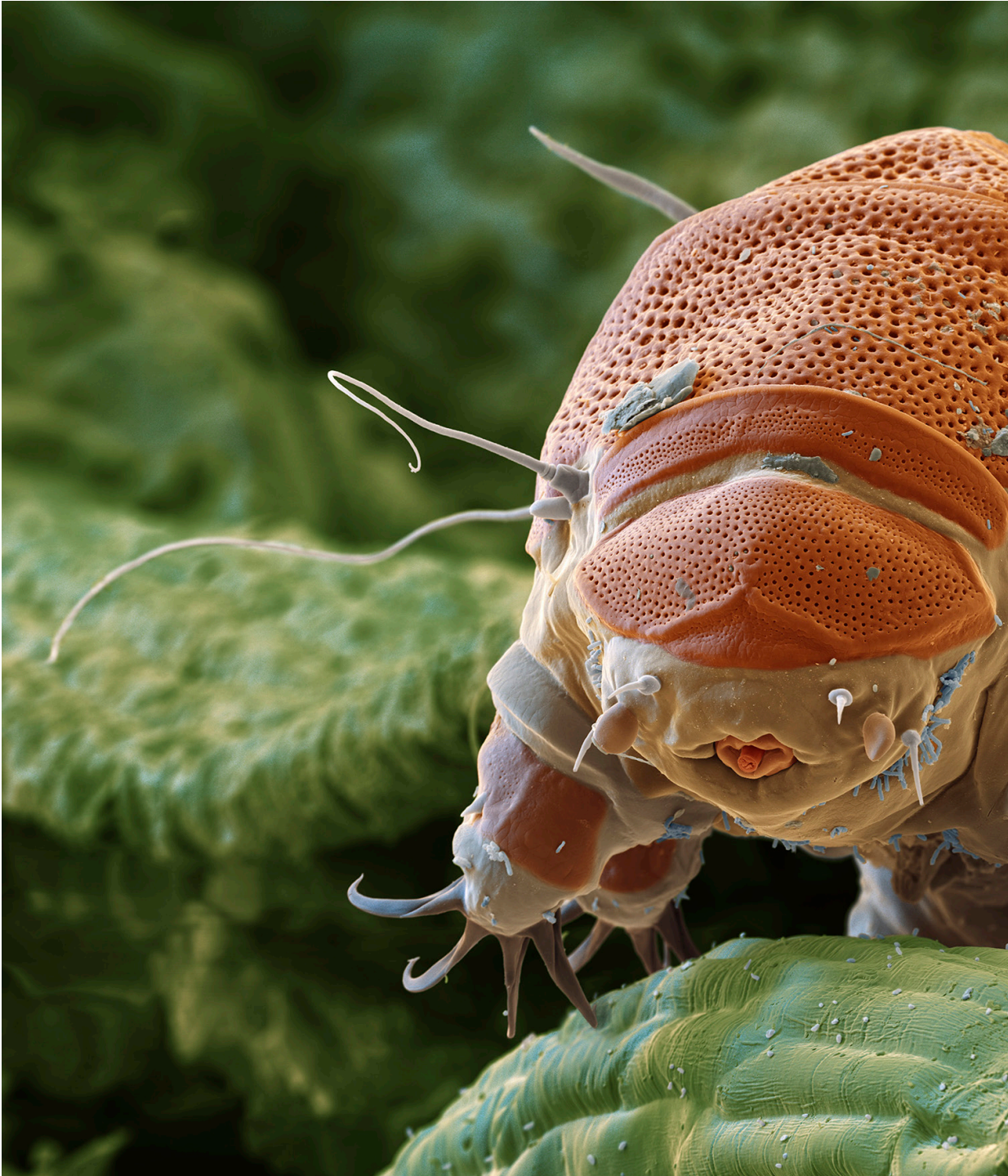
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Echiniscus granulatus. The water bear or tardigrade *Echiniscus granulatus* lives in moss in the Black Forest National Park, Germany. It's a vegetarian and feeds on moss. Scanning Electron Microscope, 1500:1
All photos courtesy of Nicole Ottawa and Oliver Meckes, eye of science©



Portfolio
eye of science
Nicole Ottawa and Oliver
Meckes

eye of science

Nicole Ottawa and Oliver Meckes

Could you tell us about how you are inspired by nature?

How can one not be inspired by nature? There are such endless harmonic forms, patterns, and colors. In the microscopic world, the deeper you go, the less color is visible. But the details you discover can be breathtaking. And you won't stop wondering. Recognizing so many details in even the smallest creature makes one think about a higher being who created all this around us. This awakens reverence for nature / creation.



Oliver Meckes and Nicole Ottawa
Photo: Sigwart-photo.de

Can you tell us about 'eye of science'? What kind of techniques do you use for your work?

The main tool that we use to create more than 80% of our images is a scanning electron microscope. This offers magnifications from 20 to 100,000 times using an electron beam, which is fine enough to image large molecules. But electrons can't detect colors. Hence, the basic image of a SEM is always black-and white. The next obstacle is that the electrons can't move in air, so the microscope works in vacuum which places very special demands on the sample: it has to be absolutely dry and electrically conductive. A biological sample normally never is. So, before any imaging, extensive preparation must be done to view the sample, involving fixing, drying in alcohol and CO₂, coating with gold or other precious metal and mounting in specimen holders. All this may take several days. SEM imaging is the smallest part and takes a few hours. We then invest many more hours of work to color the images as accurately as possible using Photoshop.

The other part is light microscopy, where we mostly use stacking techniques, as in the image of a slime mold, and polarized light when generating images of thin sections of stones and minerals. Just for fun, Oliver is also doing advanced macro and



Slime mold. This *Trichia botrytis* species found in forest soil has fully matured fruiting bodies. Extreme macro photography, stacking from 54 single images. Magnification 80:1

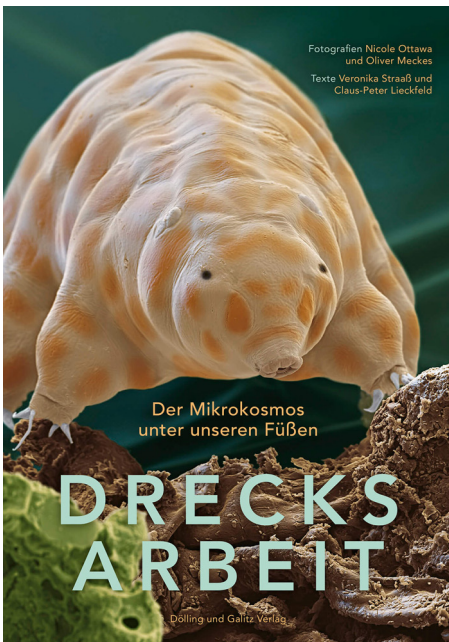
eye of science

Nicole Ottawa and Oliver Meckes

fluorescent imaging, as well as underwater photography.

Who/what inspires you creatively? What do you 'feed' on the most?

Working in the biological or medical field, from time to time you encounter undiscovered territory. Very often, we are not looking for something in particular, but it is rarely boring. The thin section of a stone in polarized light might appear as an artwork of Miró, even a leaf of moss hides fantastic forms or patterns. It's the "unknown" we feed on most.



Dirty Work: The microcosm under our feet

What are you working on right now? Any exciting projects you want to tell us about?

We finished a big story about life in soil recently, which resulted in the book *Drecksarbeit* and a touring exhibition. Currently, we are working with Arctic plankton.

What is the last book you enjoyed?

Oliver: Wolfram Fleischhauer's *Das Meer (The Ocean)*, a thriller about the exploitation of the oceans and the mafia-like structures behind it. An underground environmental organization wants to stop these companies by using unconventional methods.

Nicole: Giulia Enders' *Gut: the inside story of our body's most underrated organ*, about the microbiome inside us, and why we should take care of it. And *The Dawn of Everything: A New History of Humanity* by David Graeber and David Wengrow. I just started reading, but it has really grabbed me!

What's your favourite motto or quotation?

Always expect the unexpected. The world is full of wonders. x

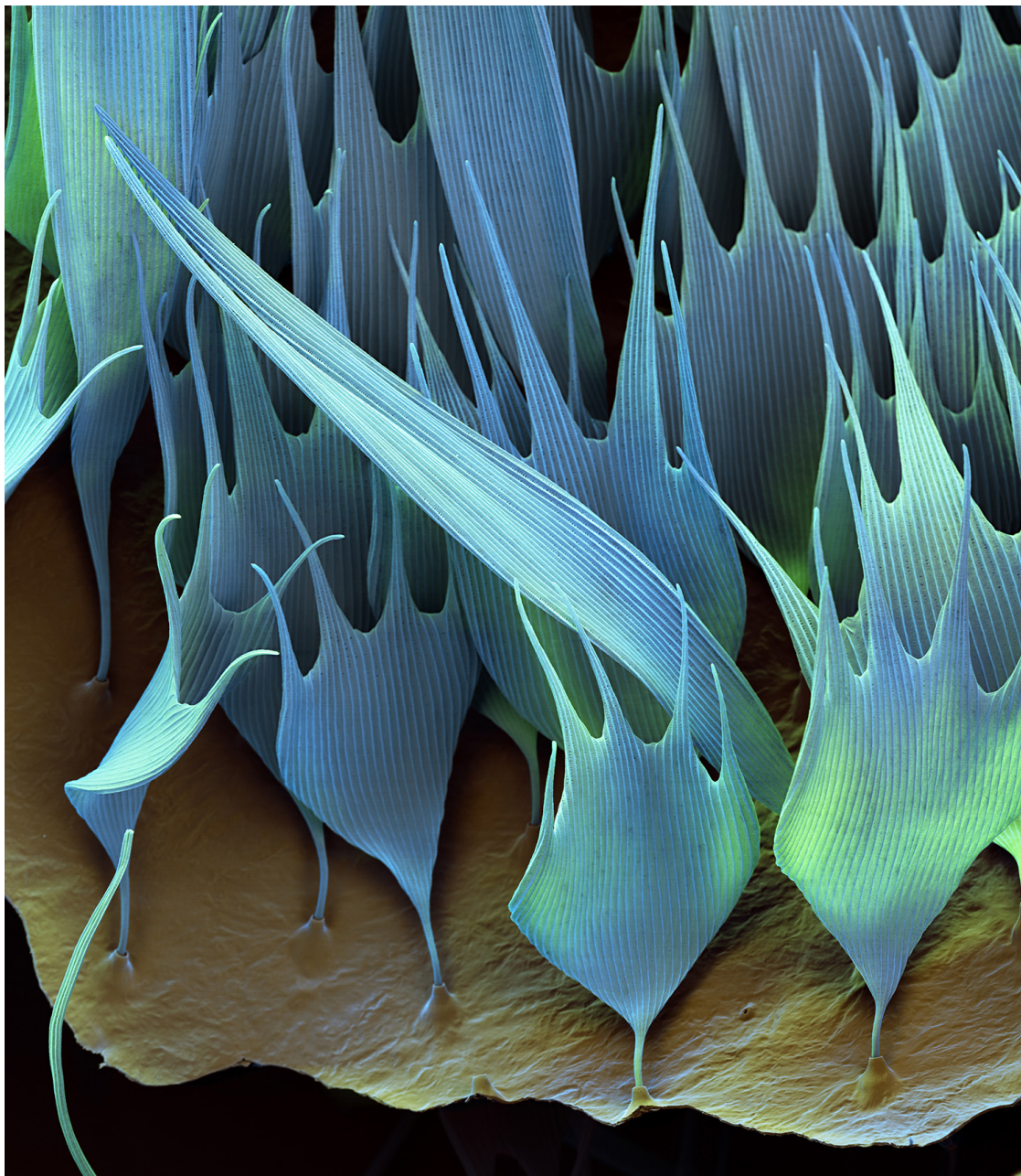
For more please see:
<https://www.eyeofscience.de>



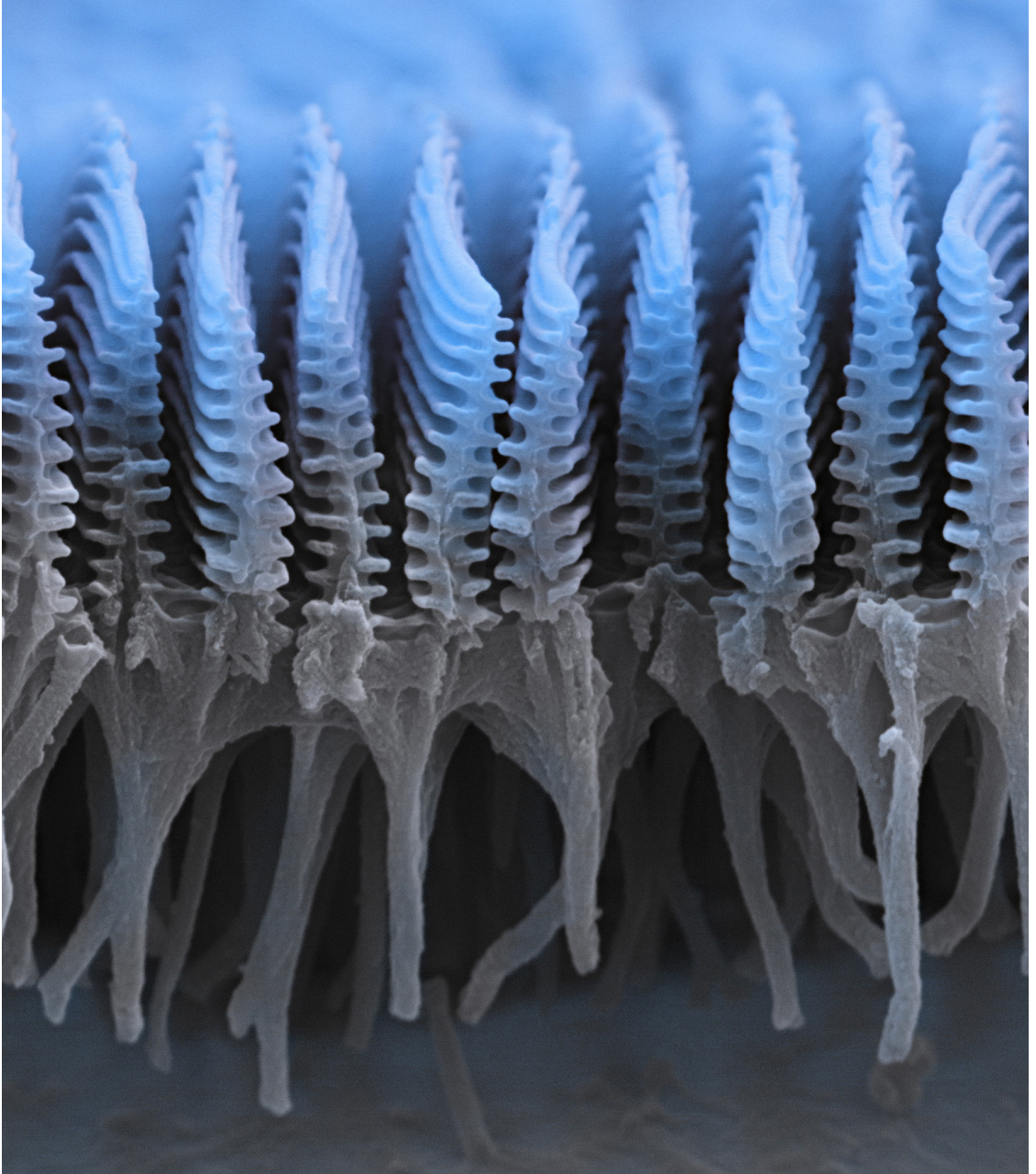
Gneiss. This rock is a common and widely distributed type of metamorphic rock. For microscopic analyses the stone is thin sectioned and polished to $30\mu\text{m}$. Polarized light gives information of its mineral content. Light microscope, 27:1

eye of science

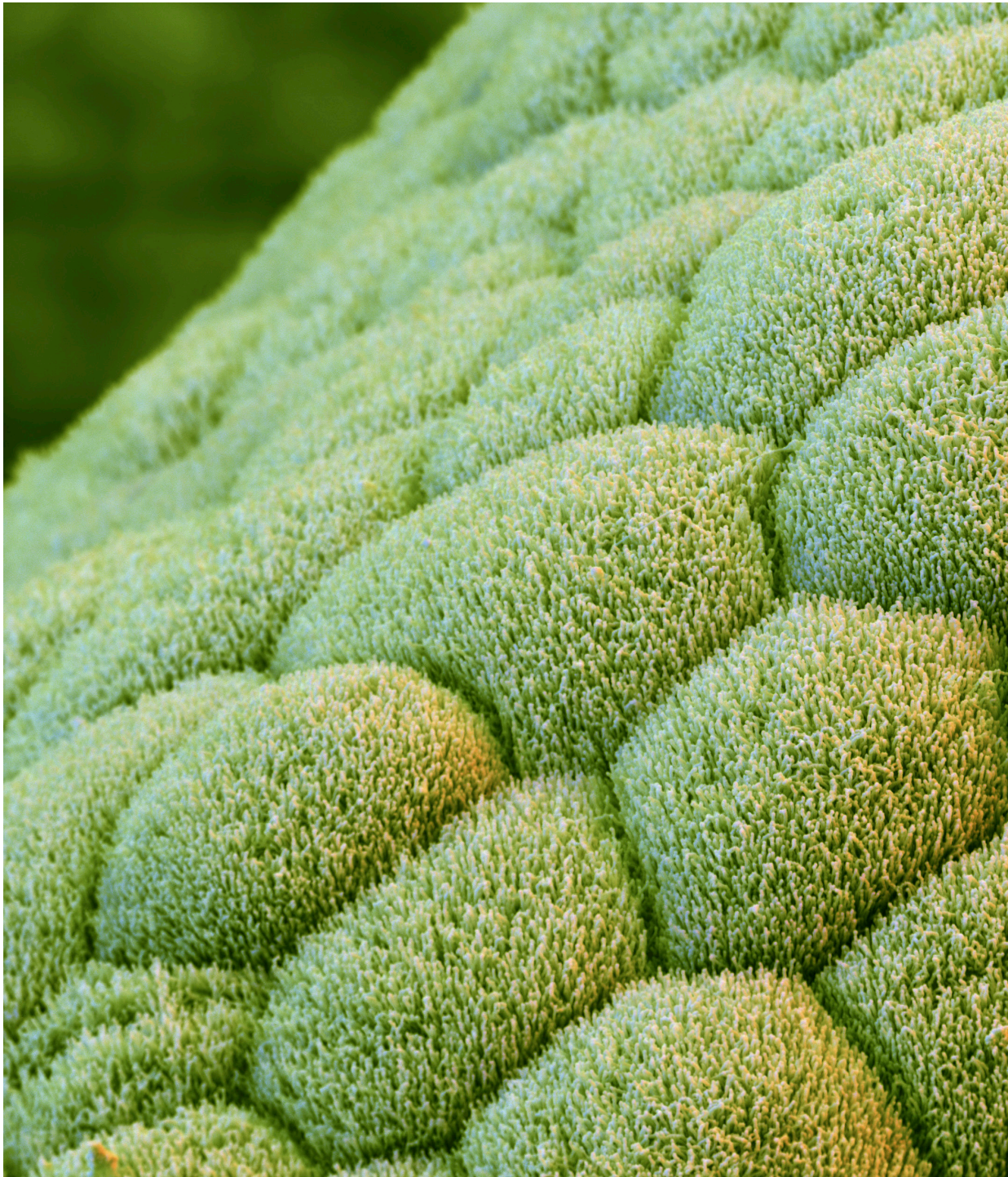
Nicole Ottawa and Oliver Meckes



Bombyx mori. A fragment of a wing of the silk moth *Bombyx mori* with attached scales. Scanning Electron Microscope, 520:1



Morpho peleides. The scales of this butterfly (here sectioned) have ridges whose stepped structure causes the interference that creates the metallic shimmer and shine on its wings. Scanning Electron Microscope, 28,000:1



Gallenblase (Gall bladder). Surface of a gall bladder with microvilli. Each hexagon represents a cell. Scanning Electron Microscope, 8000:1

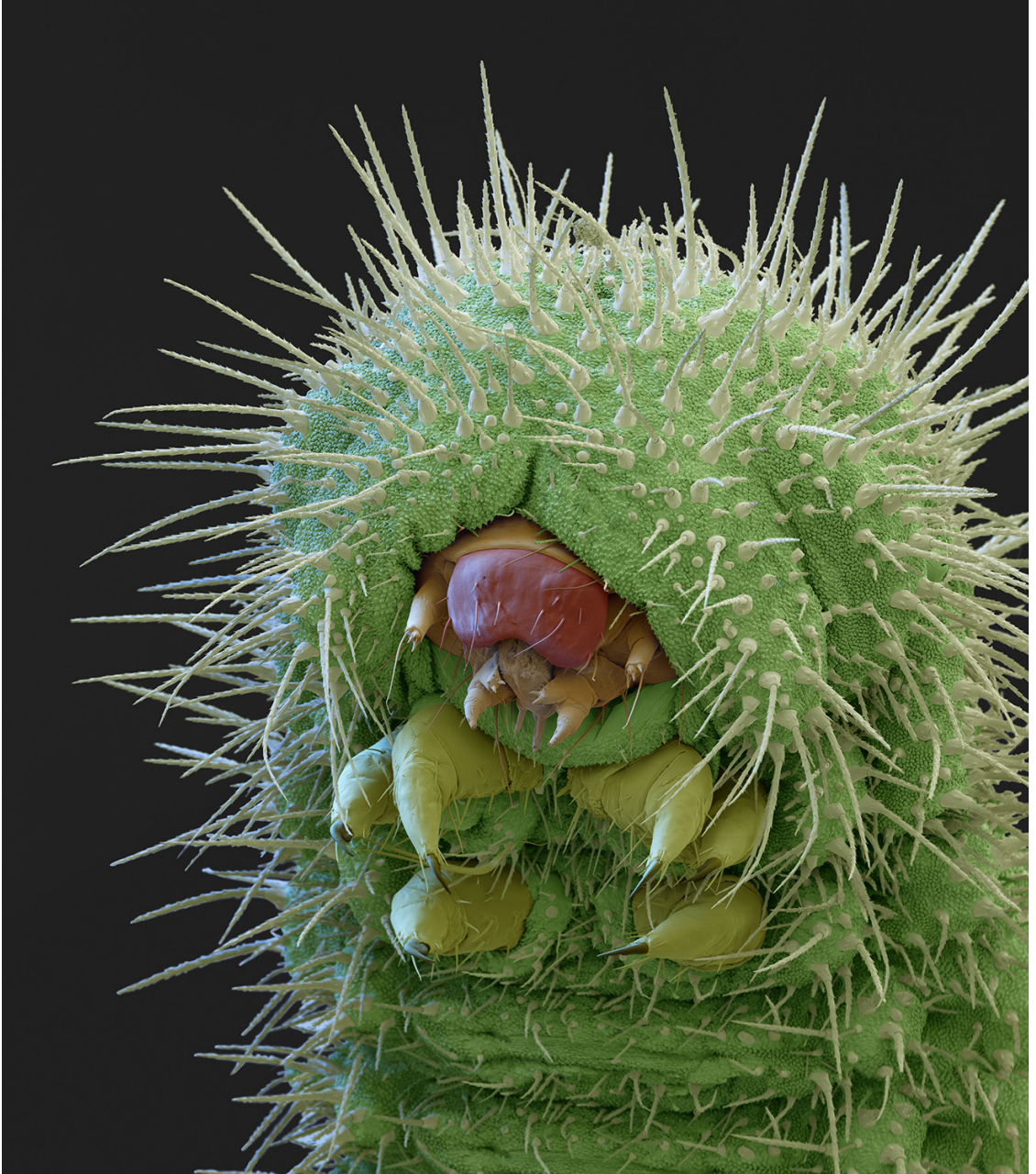


eye of science

Nicole Ottawa and Oliver Meckes



Polyommatus sp. Adult. The common blue butterfly feed on nectar from the flowers of restharrow and bird's-foot-trefoil where they also lay their eggs. Scanning Electron Microscope, 50:1



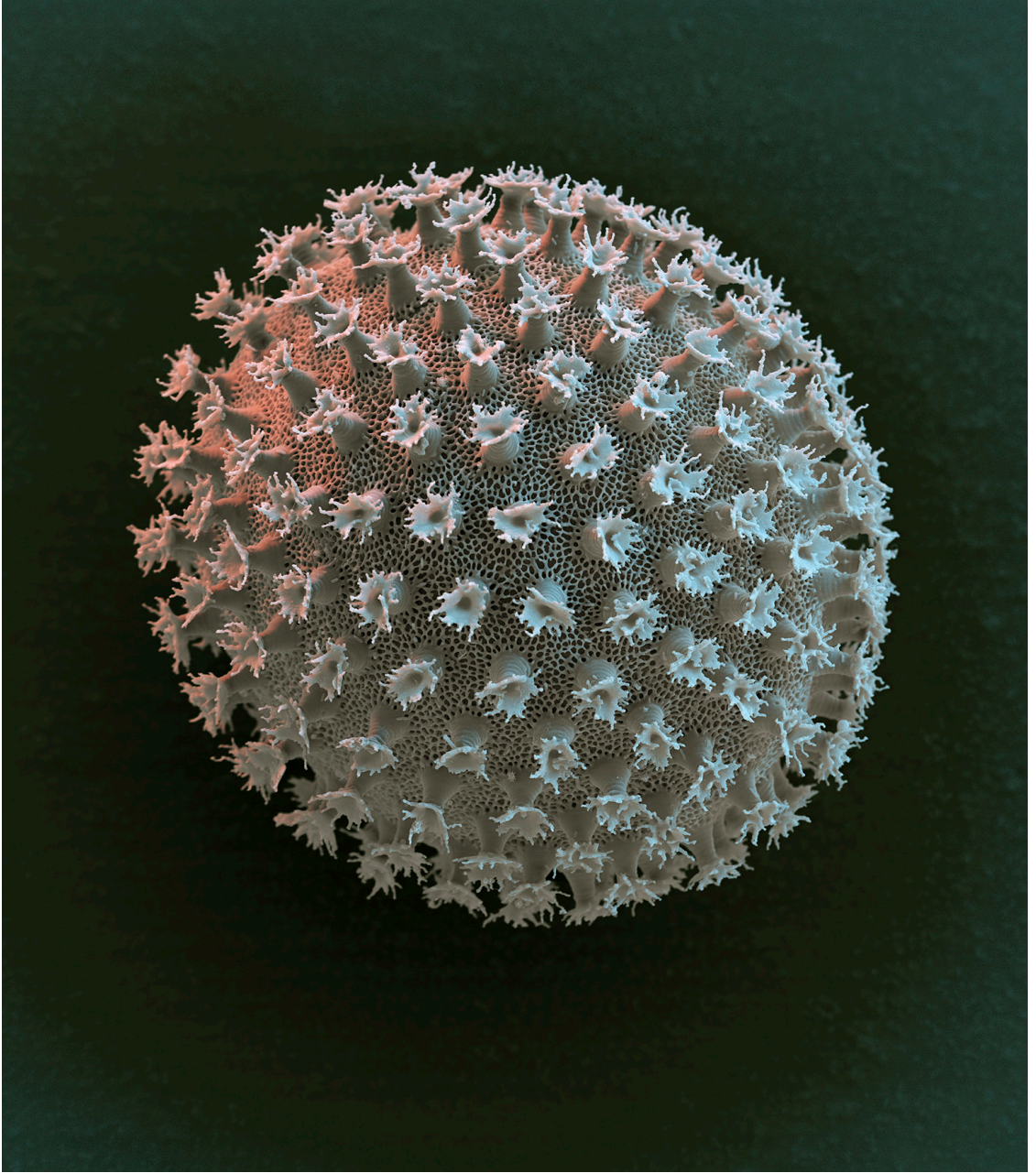
Polyommatus sp. Larva. The grass-green caterpillars of the common blues are well camouflaged on the leaves of restharrow and bird's-foot-trefoil plants. Scanning Electron Microscope, 80:1

eye of science

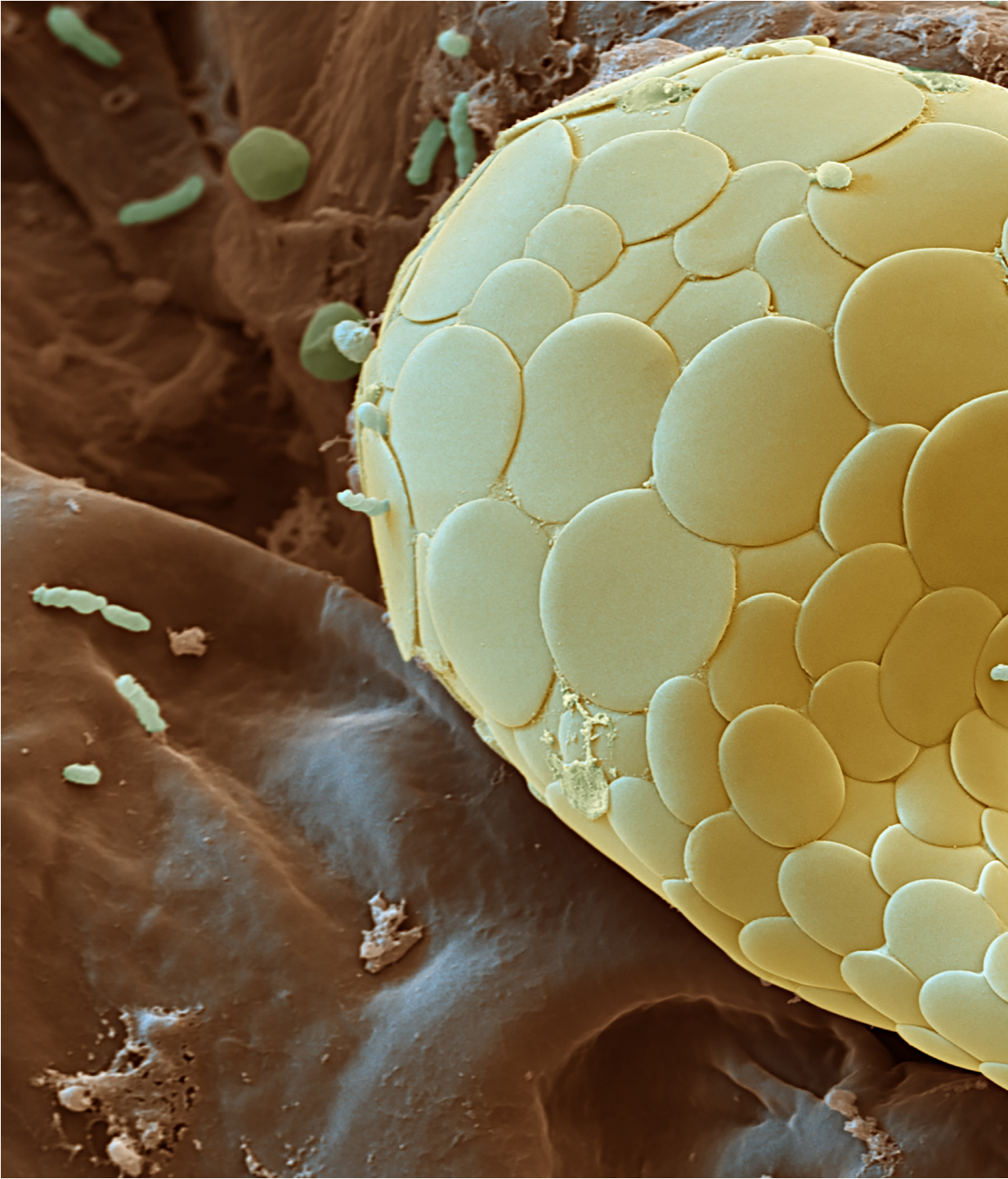
Nicole Ottawa and Oliver Meckes



Ramazottius kretschmanni. This tardigrade species is newly discovered in the Black Forest National Park, Germany. *R. kretschmanni* feeds on algae and moss and was found in moss on dead tree trunks. As all tardigrades it is able to withstand long phases of drought. Scanning electron microscope, 800:1

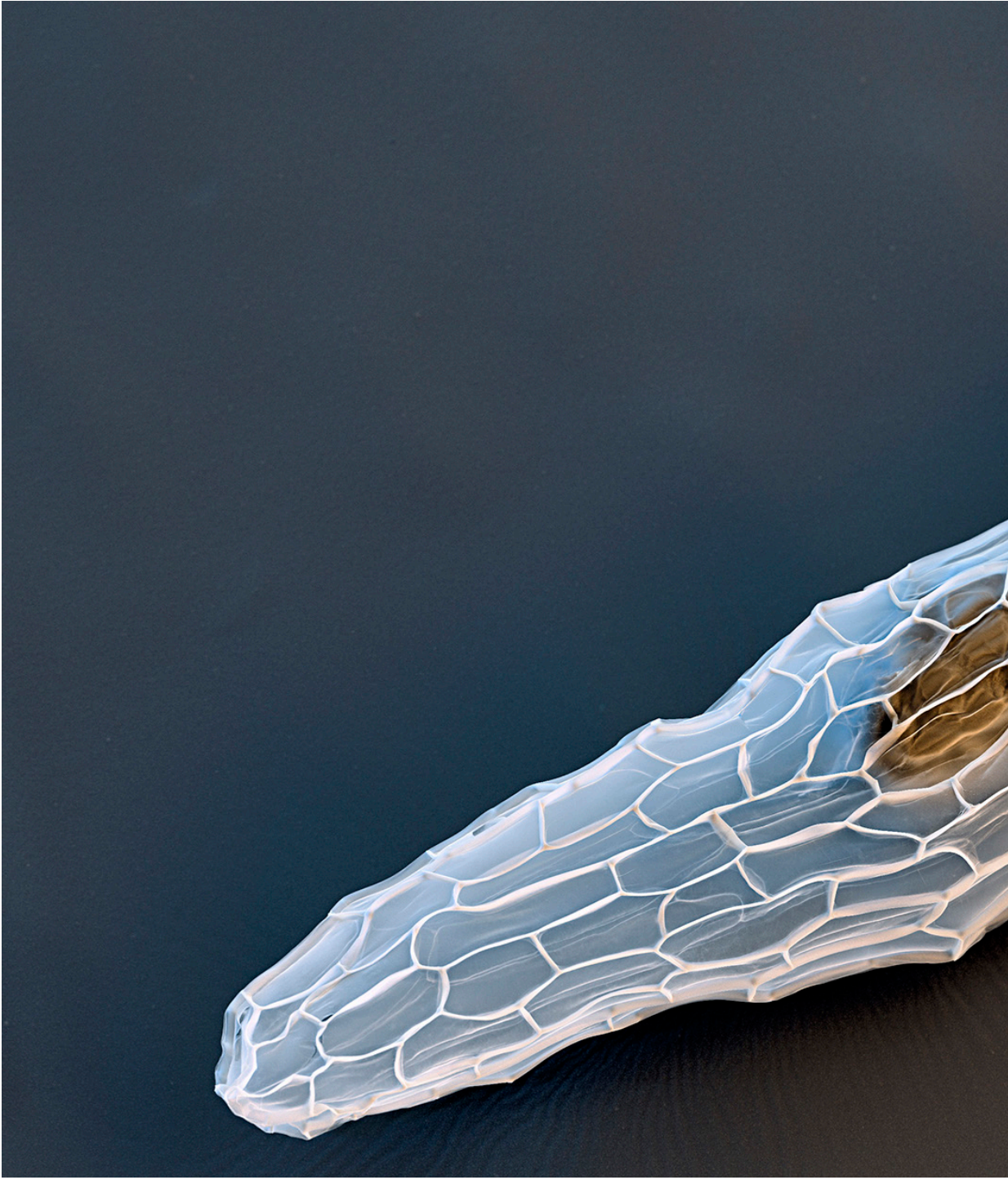


Milnesium sapiens, Egg. Most tardigrade species have complex shaped eggs. Scanning Electron Microscope, 1100:1

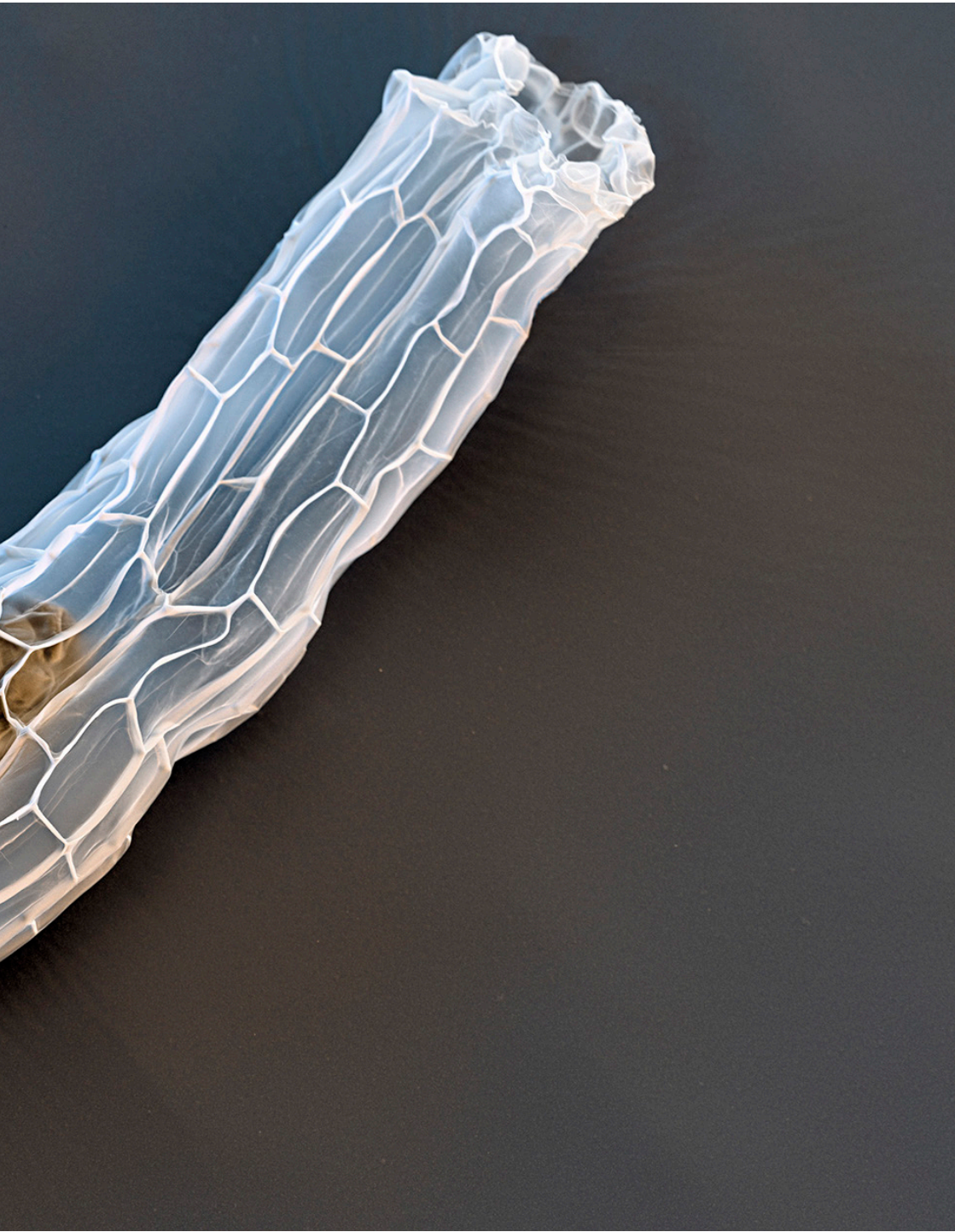


Trinema complanatum. Testate amoeba are unicellular amoeboid protists. They build themselves a test (or cover) that encloses the cell and provides it with shelter from predators and environmental conditions. Scanning Electron Microscope, 14,000:1





Listera ovata. The seeds of orchids, here the common twayblade is reduced to a covering and the embryo inside, without nutrients. They depend on a symbiosis with fungi to provide nutrients for germination. Scanning-Electron Microscope, 1200:1





A diverse mix of perennial prairie plants at the Konza Prairie Biological Field Station in Manhattan, KS.
Photo courtesy of The Land Institute

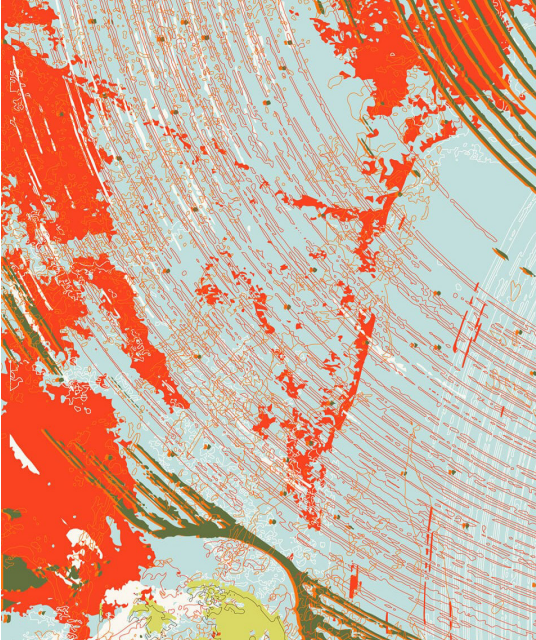


Looking Back/Looking Forward
The Land Institute
Aubrey Streit Krug

The Land Institute

Aubrey Streit Krug

In the 14 years since Wes Jackson’s interview in ZQ03 (https://zqjournal.org/pdfs/ZQ_issue_03.pdf#page=90), and as social-ecological crises intensify, I’ve seen increasing interest in learning from and with the more-than-human world. *Emergent Strategy*, by adrienne maree brown, has been a galvanizing force. In efforts to build food systems that can endure, people have continued to turn toward diverse, perennial terrestrial ecosystems stewarded by dynamic human communities for insight – think forests, savannas, grasslands, prairies, agroforestry, regenerative grazing, and perennial grain polycultures.



Flint pattern

Graphic courtesy of The Land Institute.

Back in 2012, Wes characterized Kernza® perennial grain as “It’s not farmer-ready yet, but will be in about nine to ten years especially if the farmer can be working alongside an agronomist or an ecologist.” Fourteen years later, Kernza® is indeed being grown by farmers and enjoyed by eaters.¹ Breeding, and agronomic, ecological, economic, social, and cultural research, as well as community learning, continues apace for this emerging crop – in the US and beyond. The Land Institute is deepening and broadening our collaborative approach. Building perennial agriculture and making a just transition involves and requires many people, plants, and places. There’s a need for locally adapted, nutritious, valuable perennial grains in more diverse food systems that are sustainable, equitable, and resilient to climate change. For the people developing these food systems in places around the world, sharing knowledge and methods across the network can help grow and advance the work.

Questions of scale and speed are coming to the forefront in the practice of bio-inspired design. What kind of changes are necessary and possible, and at what pace? Engaging with these questions involves grappling with practical choices in the context of ecological limits and social relationships about digital technologies (such

¹ <https://kernza.org/wp-content/uploads/2022-Kernza-Planting-Harvest-Report.pdf>

as AI and gene editing) and physical energy involved in digital technologies. Considering what is necessary and possible means grappling solar energy, fossil fuels, and human experiences with hands-on labor and sensory engagement. What kinds of worlds are we building, with whom, and for whom? I find myself contemplating a point made by Max Liboiron, who writes that “Scale is about what relationships matter within a particular context.”

Participatory research methods and processes are essential for ethically and effectively identifying, investigating, and responding to issues within the context of

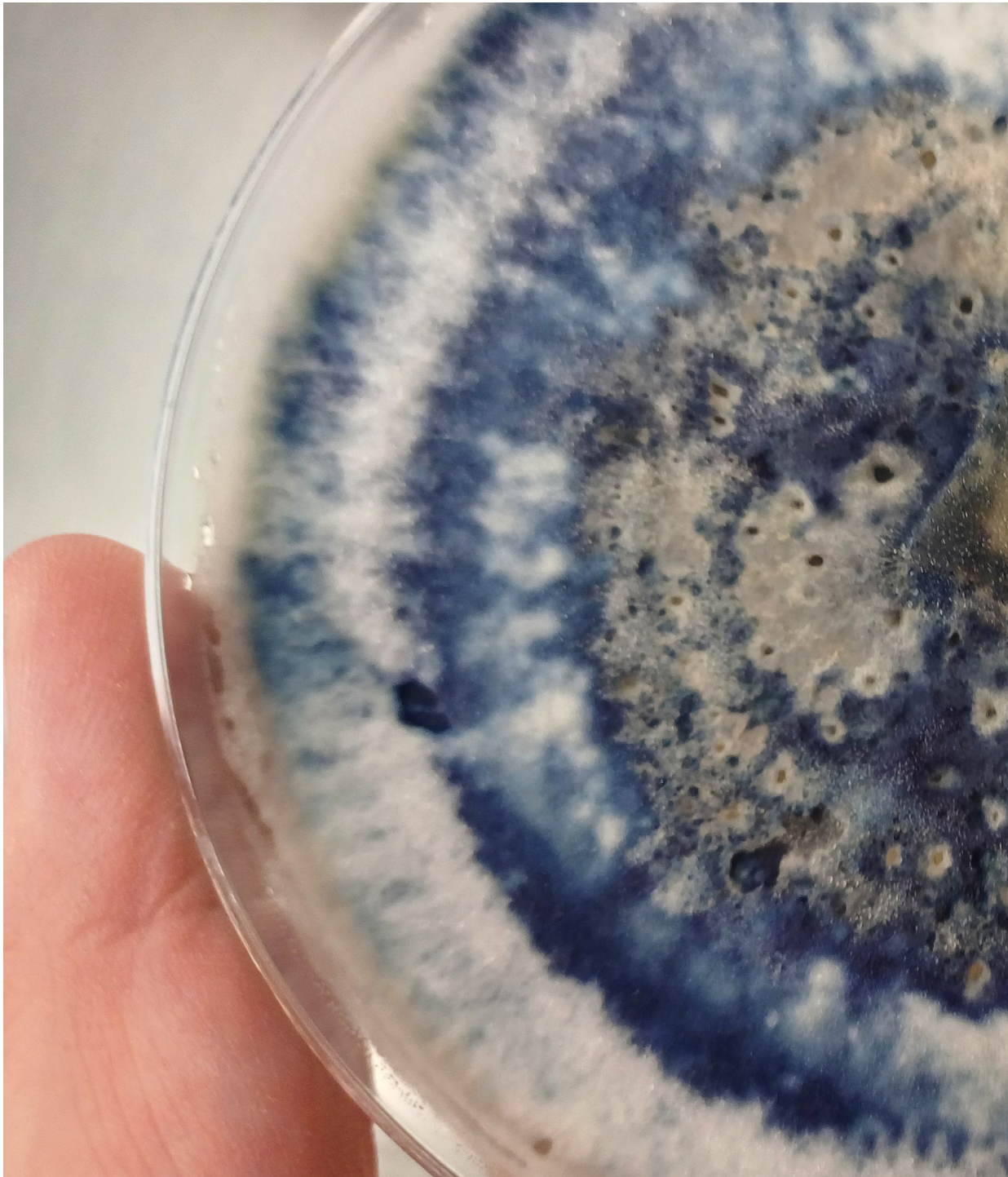


Aubrey Streit Krug

communities, places, and systems. Projects that feature intergenerational learning with the land, where youth, adults, and elders engage together with the place through repeated practices such as walking, cooking, art making, storytelling, land stewardship, and scientific observation, are especially compelling to me.

I am perpetually amazed by how deeply rooted, long-lived perennial plant communities can span across human generations and find it so powerful when people gather around perennials for creative study and care, for the restoration and development of perennial food systems. But I also see how these kinds of collective interactions can spark insights for individuals. In the challenge of engaging with any particular community, we have the everyday chance to find our own life’s work and ways to navigate existential challenges together. ×

Aubrey Streit Krug is a writer and researcher who investigates relationships among humans, plants, and places. She is the Director of the Perennial Cultures Lab at The Land Institute, where her team leads social and cultural research and educational efforts like civic science that feature learning with communities to help realize more just, diverse, and perennial grain agricultures. Her most recent project, co-edited with Liz Carlisle, is the collection *Living Roots: The Promise of Perennial Foods*. She loves rocky prairie hillsides and lives in Kansas.



Cobalt crust fungus (*Terrana caerulea*).
Photo courtesy of Ilse Rovers

A close-up photograph of a petri dish containing a blue mold culture. The mold is growing on a surface, with some areas appearing more dense and others more sparse. The petri dish is held by a hand, and the background is a light-colored surface.

Article

***From hype to hyphae:
Learning from
mycelium on what
will (and won't) work***

Ilse (C.A.) Rovers

From hype to hyphae: Learning from mycelium on what will (and won't) work

Ilse (C.A.) Rovers

When I first started working with mycelium materials, the story seemed too good to be true. A fungus that could grow itself into shapes, bind agricultural waste, replace plastics, foam, or leather, even become a construction material, all while remaining biodegradable and low energy. Nature, it seemed, had already solved the problem. Our job was simply to copy it and optimise for our own practice.

That assumption did not survive my first extended period of lab work.

Mycelium does not behave like a conventional material. It grows, responds, ages, and sometimes simply refuses. Two samples grown “the same way” can behave very differently. Even under seemingly identical growth conditions, the resulting mycelium can look different. Change the fungal species, the growth stage, or the temperature by a few degrees, and the resulting material can shift from flexible to brittle, from strong to fragile, or refuse to grow at all. Early on, I treated this as a problem to be eliminated: noise in the system that needed tighter control. I just needed to understand how to control it.

This was the point at which the elegant narrative began to break down.

Much of the public narrative around bio-based materials jumps directly from inspiration to application: from mushroom

to building panel. What gets skipped are the years spent discovering what doesn't work. In my case, that meant learning that mycelium is not one material, but many. Species are not interchangeable. Growth conditions are not neutral. And performance metrics borrowed from traditional materials science (density, strength, and stiffness) only tell part of the story when the material itself is alive and developing. It is continuously changing and therefore not as homogenous as other materials.

Early in my work with mycelium materials, I assumed that once a target performance could be demonstrated under controlled conditions, optimisation would be a matter of refinement. In practice, that assumption failed quickly. Small variations in growth conditions, often the ones I initially dismissed as minor, produced materially different outcomes, even when peak values looked promising. What mattered was not whether a structure *could* reach a given benchmark, but whether it did so consistently enough to be reproduced by other researchers, under less forgiving conditions. That realisation forced a shift: away from optimising for best-case performance, and toward identifying conditions under which useful behaviour was reliably expressed. This shift changed not only what

I measure, but what I consider meaningful evidence.

One of the hardest shifts was letting go of the engineering idea that optimisation of performance meant identifying *the* best formula. In biology, diversity is the strategy. Fungi have evolved to solve different problems: rapid colonisation, resilience, flexibility, persistence, reproduction strategy, symbiosis. When we discovered that we

could make a foamy and biodegradable material from mycelium, we assumed it was suitable as a packing material that was shock absorbent, light weight, biodegradable, and cheap. But by focusing on only one application, we are already working against mycelium's biology and ignoring other capabilities it has.

This reframed how I evaluate feasibility. I value biomimicry's function-based way of



Building on mycelium: different substrate mushroom mycelium biocomposites fabricated to test adequacy as a construction material. Photo courtesy of Ilaria di Bianca

From hype to hyphae: Learning from mycelium on what will (and won't) work
Ilse (C.A.) Rovers



Cinnabar polypore, a white rot saprobic fungus (*Pycnoporus sanguineus*).
Photo courtesy of Ilse Rovers

thinking. But instead of asking, “Can this material meet a target value?” I now ask questions more attuned to the needs of the species itself. “Under what conditions does this organism reliably produce a useful structure?” Reliability, repeatability, and tolerance to variation matter as much as peak performance. A material that performs slightly less well, but behaves consistently, may be far more viable in the real world. It does, however, mean that industry must learn to accept that the same outcome can be reached through different paths.

This perspective has also shaped how I work with my students and collaborators. Real-world problems are messy, and bio-based solutions amplify that messiness. We test ideas not only in controlled experiments, but against constraints: time, scale, regulation, and ecological fit. A solution is not just something that works once in the lab, but something that survives contact with reality. Sometimes a solution fits only a specific niche. Understanding the size and limits, the conditions of that niche is essential when assessing its viability, and it is precisely why we need multiple solutions rather than a single universal answer.

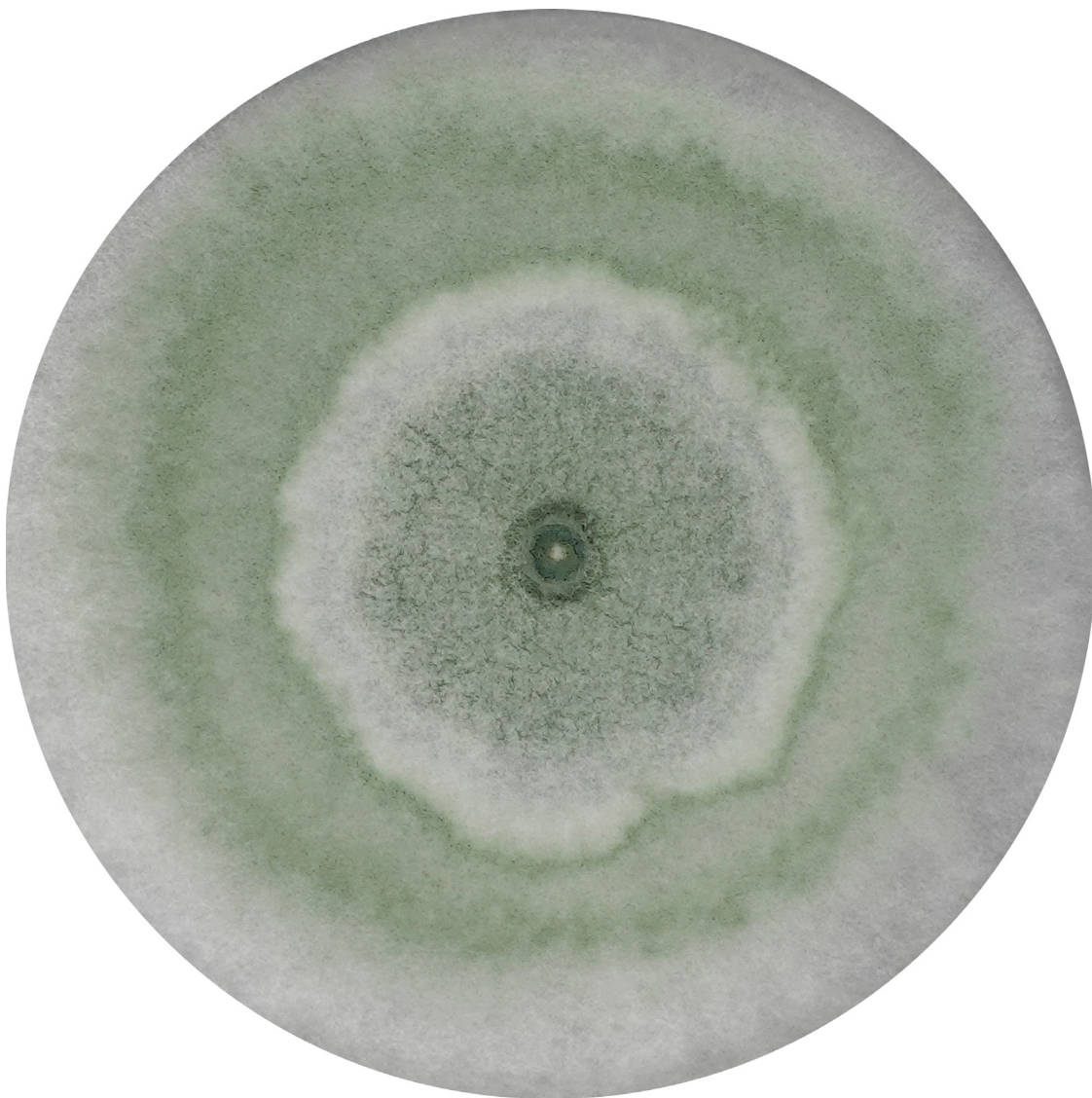
Looking forward, I believe this is where “learning from nature” is heading. Not toward perfect imitation, but toward respectful negotiation. Learning from

nature has taught me that understanding takes time, and coexistence with nature even more. Biology is not a machine waiting to be tuned; it operates according to its own logic. Working with mycelium has repeatedly shown me that biology does not optimise for maximum performance, but for species survivability. When we attempt to extract only what serves us, we risk ignoring the system, since we reduce it to only what we need and the knowledge we have at that time. This means we probably miss key features of that system. In my lab I therefore collaborate with biologists as well as chemists and material scientists, and sometimes artists, and still, it is hard to go beyond our own mindset.

If we meet nature halfway, accepting limits as well as possibilities, we often gain materials that require more care and maintenance, but support biodiversity and human health. The other day we cooperated on a research project on a corridor of a building that had bad air quality: would the application of a mycelium bound composite improve the air quality and insulate well at the same time? A next step is to improve insulation even further by growing panels together on the spot: no more crevices, which improves the insulation value and the crevices do not need to be filled with foreign materials. And we gain systems that are

From hype to hyphae: Learning from mycelium on what will (and won't) work

Ilse (C.A.) Rovers



This page: *Trichoderma harzianum* is a green mold, present in nearly every soil and is applied as a natural fungicide to suppress fungal pathogens. | Opposite: *Fusarium venenatum* is a microfungus, applied for its mycoprotein, which can help aid the protein transition.
Photos courtesy of Ilse Rovers

robust, adaptable, and honest about what they can do.


This raises a final question: are we using biomimicry to design better products, or to understand which forms of efficiency, adaptation, and restraint are actually viable in practice? While biomimicry often aims to reconcile innovation with sustainability, its real-world impact depends on whether these ideas can be implemented at scale and accepted beyond the lab, by the majority. In that sense, learning from nature may be less about maximising performance and more about identifying when we can do less, benefitting from allowing interactions to take place within the system. ×



Ilse (C.A.) Rovers (1977) has been working as a biologist since 2002, initially for engineering consultants and for governmental agencies. In 2014 she changed her career to go from commerce to science and was infected by the biomimicry virus as a lecturer at the environmental science program at the Avans University of Applied Sciences in Breda (the Netherlands). Aided by BiomimicryNL, she set up transdisciplinary biomimicry courses where different disciplines work together: environmentalists, biologists, and people from construction, design, and economics. Students loved the freedom, the discovery, the discussions, and the creativity. She also started to do research on mycelium materials in the research group of Biobased Constructions (<https://www.mnext.nl/en/>). The research posed more questions than answers, so she started a PhD on Pure Mycelium Materials in the Environmental Biology microbiology program at Utrecht University, while maintaining her connection as a lecturer-researcher at the environmental program of Avans University.



Hagfish slime
Photo by Dean Palmer | Fudge Comparative Biomaterials Lab



Interview
**Outperforming in
the natural world**
Douglas Fudge
Shoshanah Jacobs

Outperforming in the natural world Douglas Fudge

Shoshanah Jacobs

Imagine a material that, upon contact with water, expands up to 10,000 times its original size and its coiled threads always unravel without knotting. You might compare it to dinosaur sponge pills (which expand 10 times their volume), wired earbuds (which frequently knot), or silly string (which can grow up to 100 times in length). The slime produced by hagfish outperforms all human-made materials designed to expand and unravel. It is a remarkable natural adaptation for living as a hagfish, where predators abound in the rocky habitats of the ocean floor.

We sat down with Dr. Douglas Fudge, a biologist at Chapman University who studies this unique biological material, to learn more about his thoughts on biomimetics and what comes next for his research.

Sho: What are your impressions of the current state of biomimicry or bio-inspired design?

Doug: From my perspective, bio-inspired design is clearly accelerating. When I first entered this space, there were only a handful of canonical examples—Velcro being the one everyone cited. Now there are too many to list. That growth is exciting.

That said, I don't personally think of myself as belonging to a distinct field of

biomimicry or bio-inspired design. I see myself as a biologist who sometimes works on problems that interest engineers. Occasionally, those overlaps turn into collaborations, but my intellectual home is still biology.

What do you see as the biggest challenges in the field?

One of the major challenges is scale, especially when we try to replicate biological materials. Biology often produces extraordinary structures, but it does so slowly and efficiently, using processes we don't yet know how to reproduce industrially.

For example, in our work on hagfish slime, engineers can now fabricate coiled synthetic fibres that look remarkably like the real thing. But while a hagfish produces tens of thousands of these skeins to make a litre of slime, engineers can currently make only a few dozen at a time, and it takes hours. Biology has patience that engineering and markets often do not.

There's also the issue of materials. Many synthetic analogues rely on polymers that are not environmentally benign, which raises serious questions about whether a biomimetic solution is actually improving on the system it draws inspiration from.



Hagfish
Photo by Dean Palmer | Fudge Comparative Biomaterials Lab

Outperforming in the natural world Douglas Fudge

Shoshanah Jacobs

What areas should we focus on to advance biomimetics?

I think we need to be realistic about what biology is actually doing well, and why. Sometimes biology's solutions work precisely because they are slow, redundant, or deeply integrated into living systems. We shouldn't assume that every biological strategy can be scaled up or commercialized. There's also value in asking whether we can or should do better than biology. In many cases, the answer is probably no, and that realization itself can be instructive.

How did you develop your interest in biomimicry?

My introduction came during my PhD in John Gosline's lab, which focused heavily on spider silk at a time when excitement around synthetic spider silk was at its peak. This was when people believed that once we had the gene, we could simply manufacture the material—but it eventually became clear that it wasn't that simple.

I was working on marine systems and eventually found my way to hagfish slime, which contains silk-like fibres with material properties similar to spider silk, but produced via a completely different biological mechanism using completely different

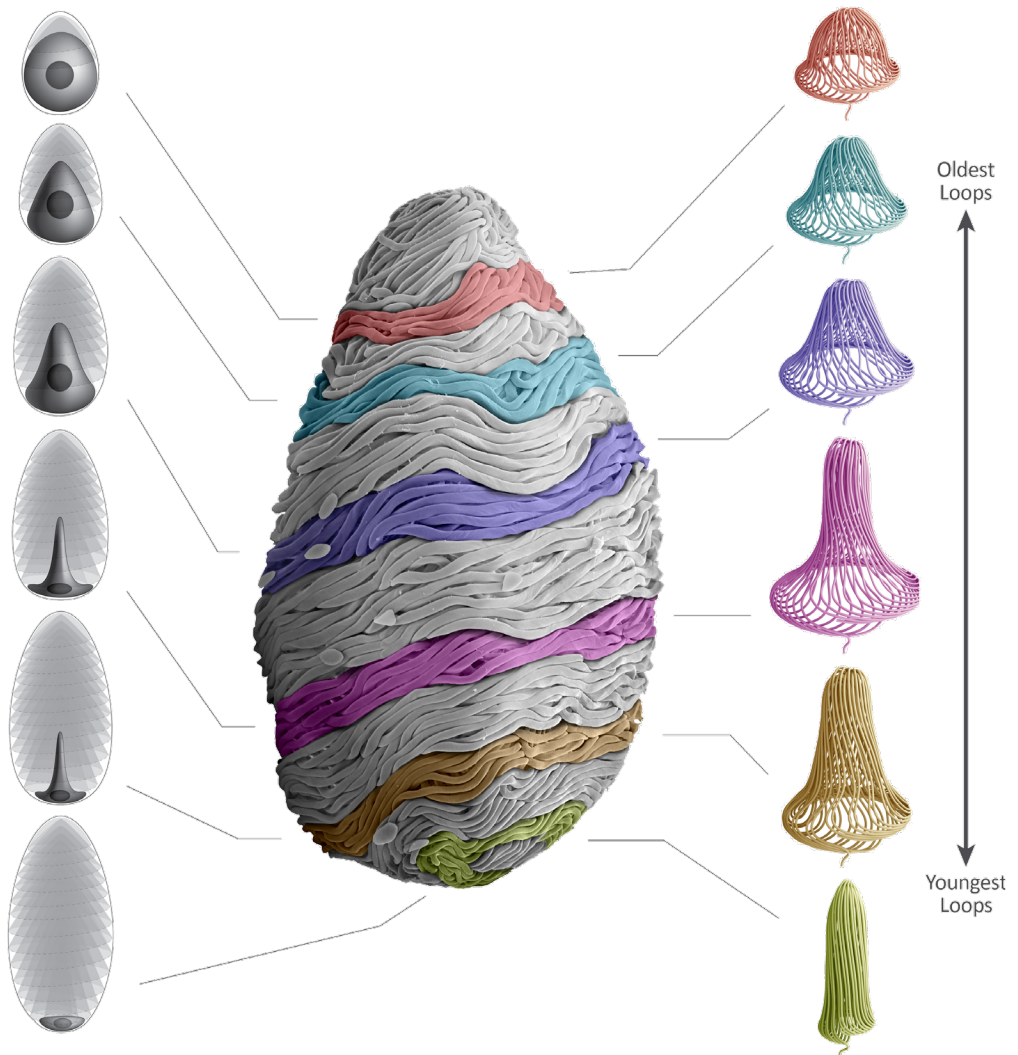
genes. That contrast—similar function, radically different biology—was fascinating and highlighted both the promise and the difficulty of biomimetic translation.

I was also influenced by conversations and collaborations with people like Jeannette Yen, whose work helped connect biological insight to engineering questions in a very thoughtful way.

What are you working on now?

Much of my recent work has focused on the biology of hagfishes, with the translational work mostly on hagfish slime biomimetics. This began through collaborations initiated by external partners such as the U.S. Navy and later DARPA, who were interested in the material's unusual mechanical properties.

We've worked with engineers to understand how hagfish slime achieves its combination of strength, extensibility, and rapid deployment. We're continuing to develop proposals to explore how similar properties might be achieved synthetically. Early interest centred on non-lethal technologies for stopping boats by interfering with propellers. More recently, we've explored whether slime-like materials could inform new approaches to wildfire suppression—particularly if biodegradable alternatives



The numerous protein fibers that are found within hagfish slime are produced individually within the cytoplasm of highly specialized cells know as gland thread cells. In a recent paper (Winegard et al. 2014), some of the mechanisms involved in the sub-cellular production of these 15 cm long threads were demonstrated. Image courtesy of the Fudge Comparative Biomaterials Lab

Outperforming in the natural world Douglas Fudge

Shoshanah Jacobs

could outperform existing fire-retardant systems.

That's fascinating. What are your favourite biomimetic examples?

I've been especially excited by Brooke Flammang's work on remoras. Her research has clarified how the remora suction disc functions and how it evolved, and this knowledge is now being used to design

improved suction-based tagging systems for whales.

What I love about this example is that the biomimetic application feeds directly back into biology. Better attachment systems enable researchers to collect more reliable data, which, in turn, deepens our understanding of the organisms themselves.

Another example that I like is Kate Loudon's work on trichomes on bean leaves, which are tiny hooks that ensnare



Left: The sucking disc of Slender Suckerfish/remora (*Echeneis naucrates*)

Photo: Richard Ling, 2008 | Wikimedia Commons

Right: Cross-section of a pubescent leaf showing trichomes.

Photo: Brandon Antonio Segura Torres & Priscilla Vieto Bonilla, 2022 | Wikimedia Commons

harmful insects. This work has important implications for pest control and bedbug mitigation. Her work really highlights how biological systems routinely outperform our best engineering efforts, often at scales and efficiencies we still struggle to match.

What's the last book you enjoyed?

West with the Night by Beryl Markham. It's an extraordinary memoir about her life as one of the first female pilots in Africa, and it is beautifully written.

What is a quotation that you think of?

Marie Curie said, "Nothing in life is to be feared; it is only to be understood." It's such a simple and bold statement, and I'm not even sure I completely agree with it, but I find myself thinking a lot about this idea.

What is your idea of perfect happiness?

I'm happiest when I'm working toward something difficult. Not when I've achieved it, but when I'm in that suspended state of effort and uncertainty. Once I solve one problem, I'm usually already thinking about the next.

If not a scientist, what would you be?

I like to think that I'd be a painter. I paint casually now, mostly with acrylics because they're forgiving. I don't know if I could ever make a living at it—but in another world, that would be my second choice. ×



Dr. Fudge runs the Comparative Biomaterials Lab at Chapman University. As an undergraduate, he studied biology at Cornell University, followed by an M.A.T. in science education, also at Cornell. For his M.Sc. research, he worked on the biology of bluefin tuna at the University of Guelph, and then moved to the University of British Columbia for his Ph.D., where he worked on the biomechanics of hagfish slime in John Gosline's lab. As an NSERC postdoctoral fellow, he worked on cell biomechanics in Wayne Vogl's lab in the Faculty of Medicine at the University of British Columbia. He joined the faculty in the Department of Integrative Biology at the University of Guelph in 2005, where he worked until 2016.



Mountain landscape UV light as perceived by insects. Somiedo Pass, Asturias, Spain.
Courtesy of the author O. Aguado.



Article

Who Controls Whom? Part II

Manuel Quirós and Oscar
Aguado

Who Controls Whom? Part II

Manuel Quirós and Oscar Aguado

According to the European Environment Agency, Spain has one of the highest biodiversity indices in Europe, with more than 5,200 pollinator species pollinating the approximately 7,100 flowering plant species found on the Iberian Peninsula. Of the 2,000 species of solitary and wild bees found in Europe, Spain is home to 1,180 species (60%). Pollinators are fundamental to the maintenance and resilience of terrestrial ecosystems, with an economic contribution in Europe around €15 billion annually, primarily in the agricultural sector. One in three bites of what we eat is due to pollinators. Based on frequency of visiting flowers, their tendency to actively collect pollen, as well as the likelihood of successfully depositing pollen on stigma, solitary and wild bees appear to be the most effective at over 70%, compared to 35% for the better-known bumblebees and honeybees.¹

Co-evolution drives the diversity of both plants and pollinators. Pollinators gain access to food from plants in the form of nectar along with protein-rich pollen. In turn, pollinators transfer the pollen to other plants. Plant species can improve pollination efficiency by attracting specific pollinators using advertising (colours, scents), rewards (nectar, nutrient rich pollen), and timing (when flowers open). Some plants also restrict access to the rewards.

1. <https://nora.nerc.ac.uk/id/eprint/500510/1/No500510PP.pdf>

Pollinators are under evolutionary pressure to adapt and maintain access to important food sources. They also benefit from reduced competition by specialization. The interplay of these two evolutionary pressures results in multiple diverse plant/pollinator niches. But over-specialization brings risks. Falling pollinator populations may disrupt the pollination of the related plants. If the plant population collapses, pollinators dependent on the plants for food are at risk.

As discussed in Part 1 of this article (https://zqjournal.org/pdfs/ZQ_issue_38.pdf#page=36), flower colour plays an important role in pollination success. Numerous plant families visited by insects have incorporated spots or lines called “honey marks” on their corollas oriented toward the center of the flower that direct the pollinating insects toward the nectar. Human eyes can visualize colours from red to violet, but many pollinators including bees and

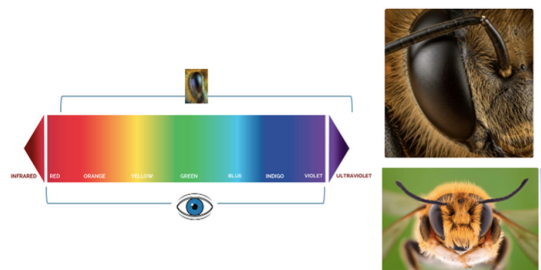


Figure 1: Spectrum of vision between humans and bees. Close-up view of solitary bee eyes.

butterflies have UV photoreceptors that extend their colour range (Figure 1).

Some flowers have honey marks that are only visible in UV light. Images 1 and 2 show examples from different plant families, each accompanied by two photographs: as we humans perceive them (on the left)

compared to how we believe they look to bees (on the right).

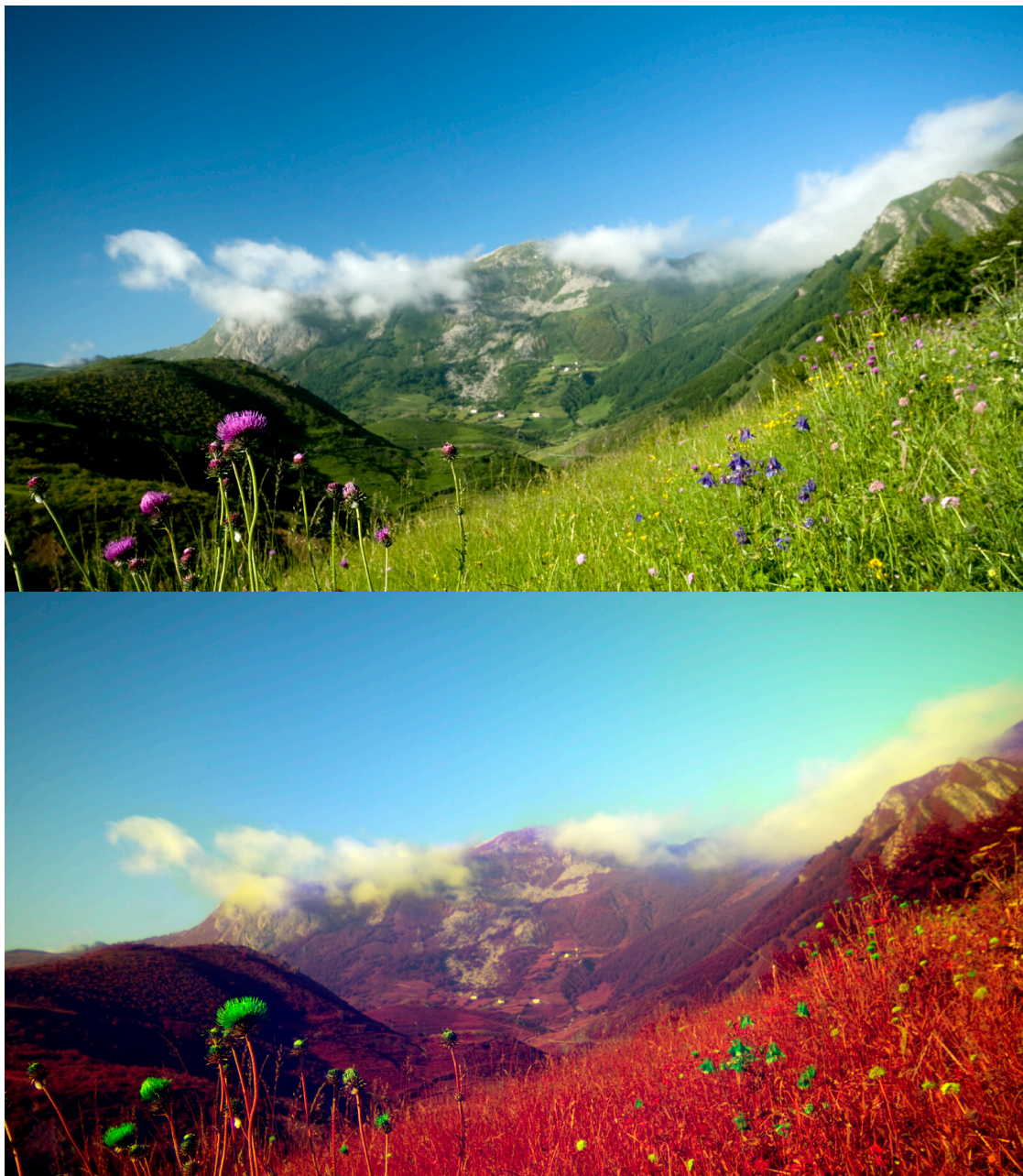
Flower colour can also convey additional information to pollinating insects. In some legumes, such as *Lotus corniculatus* (the common bird's-foot trefoil), yellow predominates when flowers emerge, but they turn



Images 1: Flower recognition: Top left: poppies (genus *Papaver*) as seen by humans; right: as perceived by pollinating insects. Center: flowers of *Arctotheca calendula*, which under ultraviolet light display honeycombs to encourage visits by pollinators. Below left: flowers of *Anagallis arvensis* or scarlet/red pimpernel, as perceived by bees; its turquoise-blue petals contrast sharply with the red pollen stains and a green central area that indicate where they should go to obtain nectar. Photos by L. O. Aguado.

Who Controls Whom? Part II

Manuel Quirós and Oscar Aguado



Images 2: Mountain landscape as seen by humans (above) and UV light as perceived by insects. Somiedo Pass, Asturias, Spain.

Courtesy of the author O. Aguado.

orange when pollinated, signaling insects to stop visiting. This discrimination between different colours is not only due to greater informational visibility, but also due to learned associations: certain bumblebees can learn to recognize certain colours or markings, providing them with information about beneficial rewards.

Colours in plants, like animals, depend on how they reflect different frequencies of light. The most common method is through pigments that absorb certain frequencies of light while reflecting the rest. Chlorophyll absorbs violet-blue through orange-red light strongly, but not green light. Although more

commonly seen in butterflies, beetles, and birds, some plants can produce structural colours through a nanostructured surface that enhances certain frequencies of light through constructive interference, while reducing others through destructive interference (Figure 2). Examples are hibiscus plants that display an oily iridescence and the iridescent petals of the tulip cultivar “Queen of the night”.

Buttercup petals (Figure 3) combine starch pigments that strongly reflect yellow, an air layer, and a highly reflective outer thin film that makes the petals glossy while

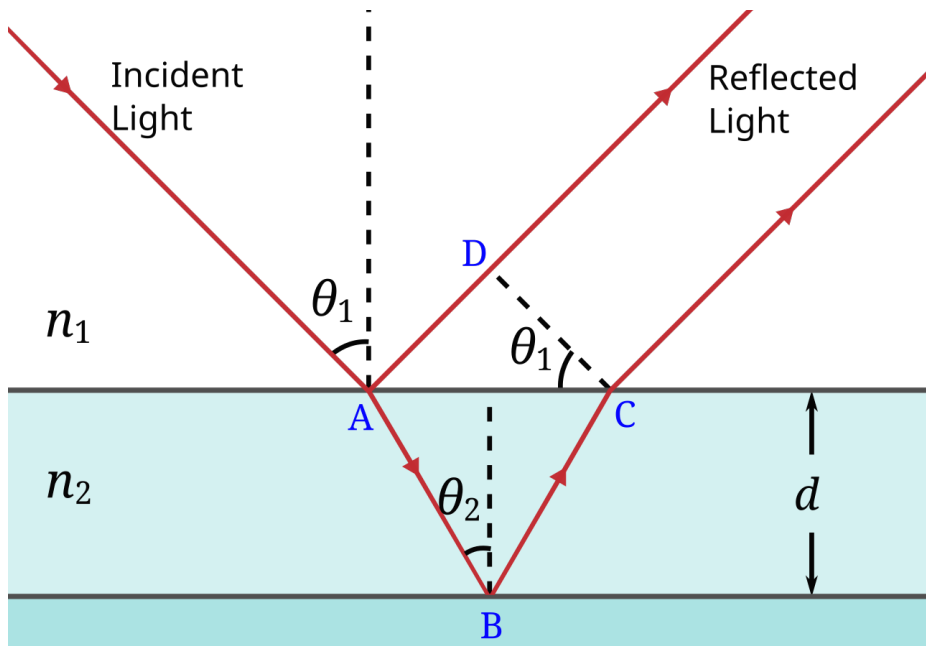


Figure 2: Depending on the angle, light rays bouncing off the upper and lower surface of a thin film travel different distances, resulting in wave interference. (https://en.wikipedia.org/wiki/File:Thin_film_interference.svg)

Who Controls Whom? Part II

Manuel Quirós and Oscar Aguado

also filtering the backscatter from the starch layer.²

Some pollinators are adapted to seeing movement, even while flying at speeds of 25-30 km/h. Plants have been able to take advantage of this ability by growing small or medium-sized flowers on long, slender stems which sway in the wind, standing out from their surroundings. Many bumblebees, honeybees, and butterflies associate the swaying of flowering plants with abundant food rewards.

It is time-consuming to observe specific pollinator/flower interactions. Researchers have identified clusters of floral traits that

are preferred by specific pollinators. These “pollination syndromes” can help predict what pollinator is likely to visit a specific flower. For example, bees are attracted to bright white, yellow, blue, or UV colours; nectar; nectar guides; fresh scents; and shallow flowers with landing platforms. In contrast, bats are attracted to dull white, green, or purple flowers; abundant nectar but without nectar guides; musty scents; and bowl shaped flowers that are closed during the day (adapted from https://www.fs.usda.gov/wildflowers/pollinators/What_is_Pollination/syndromes.shtml).

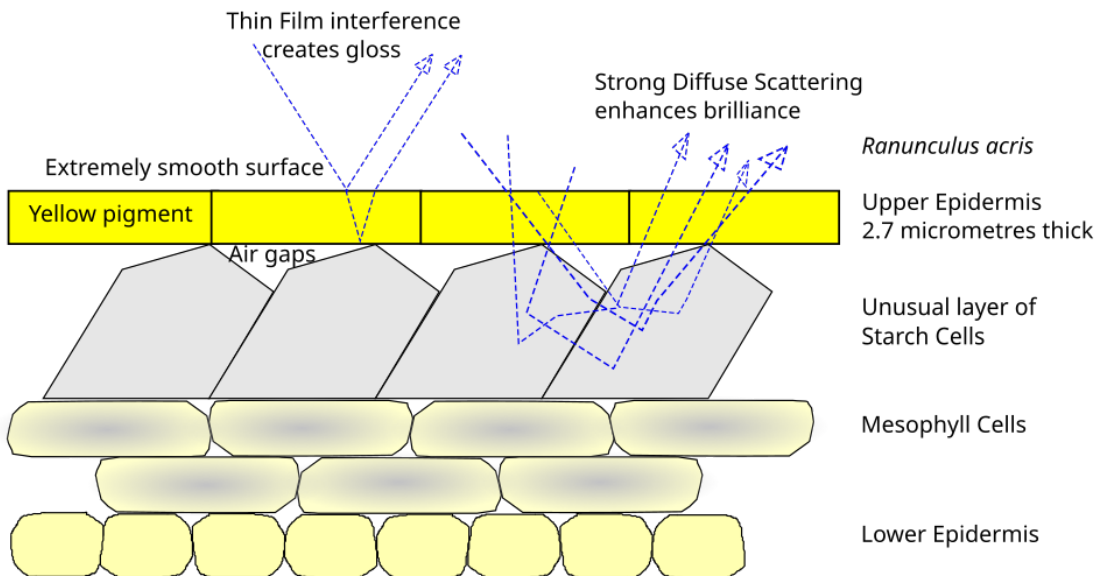


Figure 3: The buttercup (*Ranunculus acris*) petal combines an upper 2.7 micrometer layer that is both iridescent and reflective, above starch cells that function as strong reflectors diffusing the light. (https://commons.wikimedia.org/wiki/File:Buttercup_petal_structural_and_pigment_coloration.svg)

2. <https://royalsocietypublishing.org/rsif/article/14/127/20160933/35777/>

Many food crops, particularly almonds, blueberries, coffee, and apples, depend on animal pollinators. Understanding pollination syndromes helps identify which pollinators are most effective for a specific crop, improving yields as well as yield stability. In natural habitats, these specialized relationships maintain plant diversity, improving ecosystem resilience. Knowing the pollination syndromes of native and cultivated plants supports habitat design and pollinator conservation strategies, particularly important as pollinators decline globally.

Pollinators and flowers have been partners in nature's emergent complexity for millions of years. By understanding and protecting pollinators, we not only safeguard terrestrial biodiversity, but also ensure our own future. The survival of these sophisticated organisms and masters of life is closely linked to the health of ecosystems, human culture, and food systems - an interdependence that deserves our attention, respect, and action. ×

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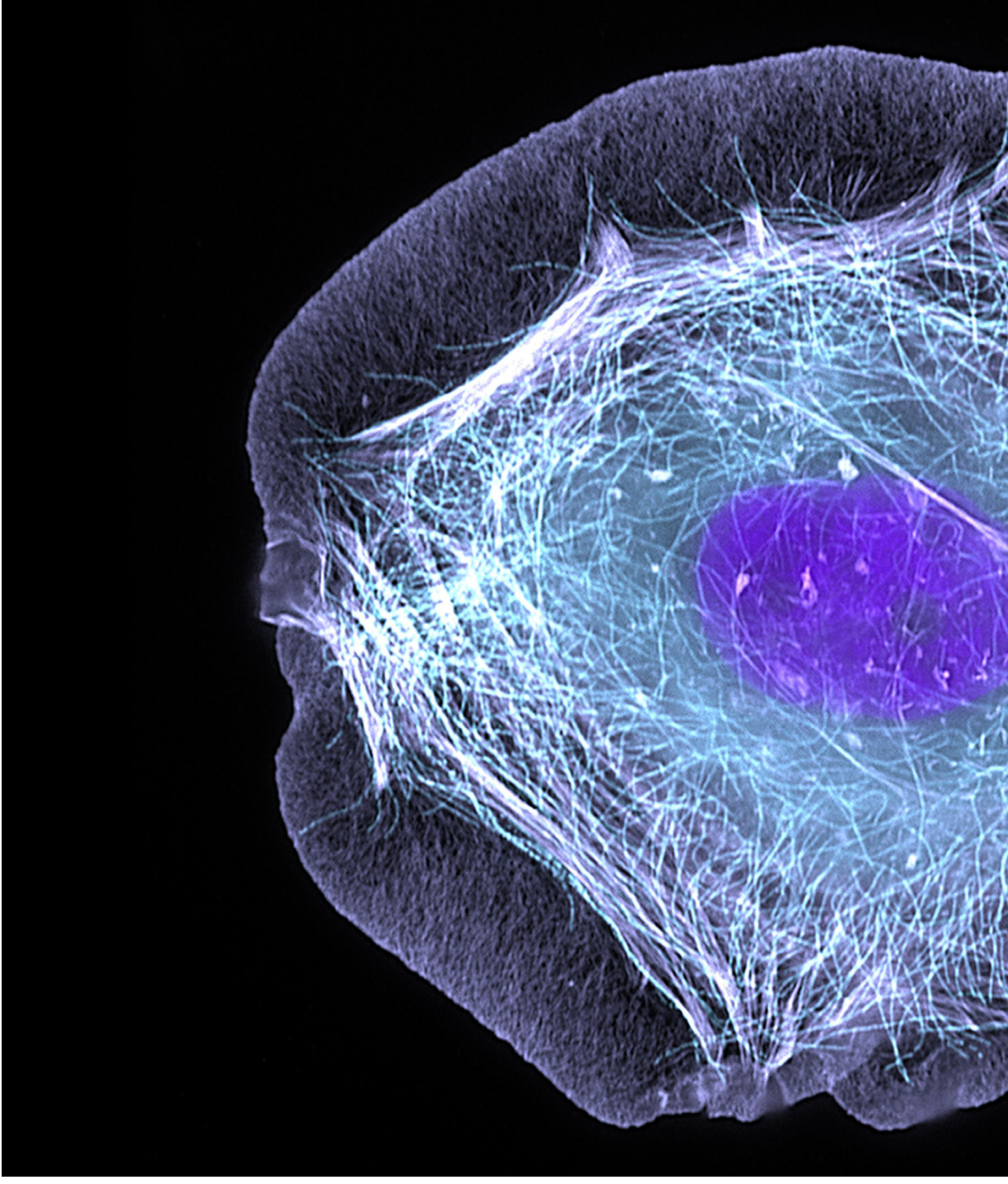
Manuel Quirós, BSc, MSc, PhD in zoology, is a passionate nature conservationist. He guides, and as an independent teacher at several Spanish universities inspires the next generation of leaders to adopt sustainable and regenerative practices as well as biomimicry as a transformational behavior strategy. He is the owner of NIU (www.natureinspireus.com), co-founder of Biomimicry Iberia and Red Internacional Biomimesis (RI3: <https://redinternacionalbiomimesis.org/>). He participates as a speaker in many international symposia such as ONU-Habitat and COP 25. He has been a contributing editor and author at *Zygote Quarterly* (ZQ29/30/34/38) since 2013.



For over 25 years, Luis Oscar Aguado has focused on the study, dissemination, and conservation of pollinators, including plant-insect interactions, as well as their ecology and taxonomy. He works as a consultant on entomological biodiversity for various government agencies and the private sector, both on the Iberian Peninsula and in the Canary Islands, as well as in countries such as Chile, Costa Rica, and Argentina. Since childhood, he has curated a significant collection of pollinating and saproxylic insects, with more than 150,000 specimens from around the world, with the goal of creating his own foundation in Spain. He has achieved national prominence through numerous articles, his courses, conferences, and events. He authored the award-winning *Guide to Pollinators of Spain* and two volumes of *Butterflies of Castilla y León*.



Mountain landscape as seen by humans. Somiedo Pass, Asturias, Spain.
Courtesy of the author O. Aguado.



Skin cell tensegrity
Photo: ZEISS Microscopy, 2014 | Flickr cc



Looking Back/Looking Forward
Evolution of Robotics
Vytautas SunSpiral

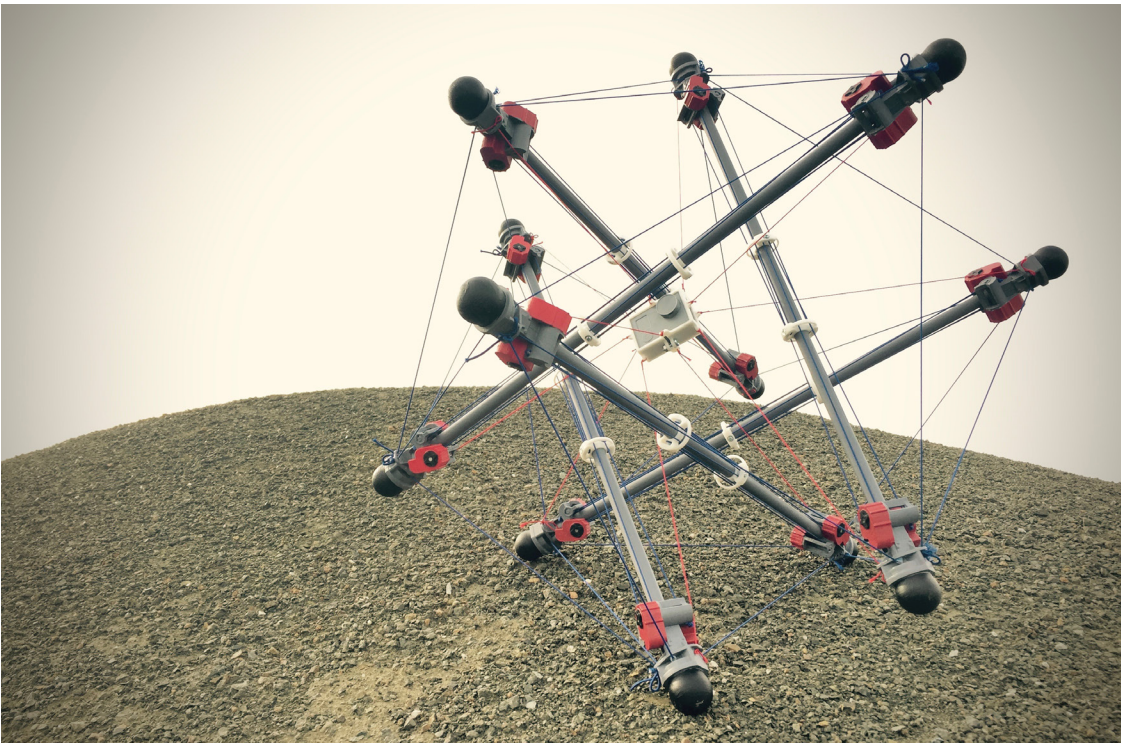
Evolution of Robotics

Vytas SunSpiral

The field of robotics has undergone a significant transformation in the last decade, embracing compliance and adaptability. For a very long time, humans have been trying to build systems that mimicked nature in form, but we have been using entirely different principles and mechanisms. Mechanisms designed around rigid linkages and rotary motors will always function differently in some fundamental ways from systems designed around compliance, elasticity, and tensile actuation. The current

shift towards compliance and adaptability is evident across both hardware and control systems. Unlike the rigid, precise robots of the past designed for controlled workcells, modern robots are increasingly mobile, operating in dynamic environments shared by humans.

To navigate this complexity, robots are incorporating flexible and compliant components for mechanical adaptability, often utilizing lightweight materials and structures. The increasing use of tendon-driven



Simplified tensegrity robot: scaled model of SUPERball V2.
Image courtesy of Vytas SunSpiral

actuation to move actuator mass closer to the base naturally introduces compliance and elasticity.

Control methods have similarly evolved, moving from high-precision trajectory control to approaches like impedance control. This method defines a stiffness manifold around a motion trajectory, allowing a robot to safely adapt to unexpected events. For example, a robot can be very stiff vertically to carry a heavy load while remaining compliant in other directions if accidentally bumped.

Much of this change is rooted in ideas from the soft and bio-inspired robotics communities, particularly the focus on elastic tensile actuation, the key to biologically inspired design. You cannot replicate animal gait with rotary motors; you need a system of elastic muscles that pull and relax. This led to my excitement about the recent breakthrough by Elysium Robotics, which is commercializing artificial muscle fibers. These tiny, electrically active, elastic contractile fibers can be bundled to create skeletal muscles with complex morphologies, mimicking nature.

To understand their significance, we must go back to when I left my bio-inspired tensegrity robotics lab at NASA. I was frustrated that a suitable artificial muscle actuator for bio-inspired robots simply

didn't exist and I hoped to learn more by diving deep into genomic engineering for advanced materials production. I wanted a small, fast, electrically active elastic contractile fiber that could be used in series and parallel. Nature's true actuators are the muscle fibers, not the larger skeletal muscles (like the biceps) that most people envision. Skeletal muscles are composed of hundreds or thousands of fiber bundles, each independently controlled. This suggests we have on the order of 200,000 individually controllable actuators, a number orders of magnitude larger than the mere hundreds of skeletal muscles usually cited. This scale rules out pneumatics, hydraulics, or slow thermal state-change actuators.

There are many functional reasons that nature has developed the muscle fiber bundle as the fundamental unit of actuation. For one, form and function are intimately related in muscles, and the morphology of skeletal muscles is far more complex than simple linear connectors.¹ As can be seen in the simplified tensegrity robots I built at NASA (https://zqjournal.org/pdfs/ZQ_issue_20.pdf#page=32), the contraction of any tensile element will cause a global shift in the shape of the structure, as the balance of forces is maintained.

1. "From muscle fibres to gears: How fibre rotation and shape change impact muscle function" <https://www.biorxiv.org/content/10.1101/2025.06.15.659256v1.full>

Evolution of Robotics

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In order to generate specific motions or apply force on the environment, animal muscles need to constantly adjust their shape and the force vectors they are applying to the structure while they are “contracting.” This is possible because the fiber bundles within them do not all contract together and are independently controlled, producing heterogenous strain through different regions of the muscle. There are even examples, especially in multi-articular muscles, of some bundles contracting while others lengthen.² This behavior results in complex 3D shape changes of the skeletal muscle during activation, enabling very precise control over both the pose of the animal and the applied forces. This fiber-based architecture is a critical design quality.

Another quality of fiber bundle actuation is the level of precision over lines of tensile force that is enabled. My work with tensegrity robots at NASA demonstrated how the primary lines of tensile load-bearing define a structure's shape and how these force lines shift with changes in pose. Unlike my tensegrity robots, which had few actuated cables, animal muscles use thousands of fibers, enabling the key line of activation to move smoothly within a larger skeletal muscle.

You can try this out for yourself right now. First stand up and place your hands on your quads and then slowly roll your weight to the right and left side of your feet and feel the line of muscle activation within your quads smoothly shift around. You can also put your hands on your hips and slowly lower into a squat and stand up again. As the angle of your legs change you can feel the main lines of activation shifting through the arc of attachment to your hip bone. Even a very small motion can produce a noticeable shift, and the level of precision of that shift is far smaller than the large skeletal muscles that attach there. You are feeling shifts in which fiber bundles are physically aligned with the main tensile load path your body needs to maintain that exact pose you are in.

One of the key insights I gained from my time in the synthetic biology field is that biological innovation begins with molecular and materials innovation. The physical structures and control machinery of life are systems of novel materials expressed through a cascade of molecular machines, and I now hold material innovation as key to many technological advances. When I first found Elysium Robotics, I immediately recognized that they had created the artificial muscle fiber I had sought for a decade. Their technology, true to nature's focus,

2. “Different Segments within Vertebrate Muscles Can Operate on Different Regions of Their Force–Length Relationships” <https://pmc.ncbi.nlm.nih.gov/articles/PMC6104704/>

relies on a complex interplay of unique materials to enable this micro-fiber scale tensile actuation.

A key design opportunity with this fiber-based approach is the ability to create

a wide range of skeletal muscle scale actuators from a single fundamental fiber type (Figure 1). By changing how the fibers are assembled into bundles and larger muscles, we can alter their mechanical

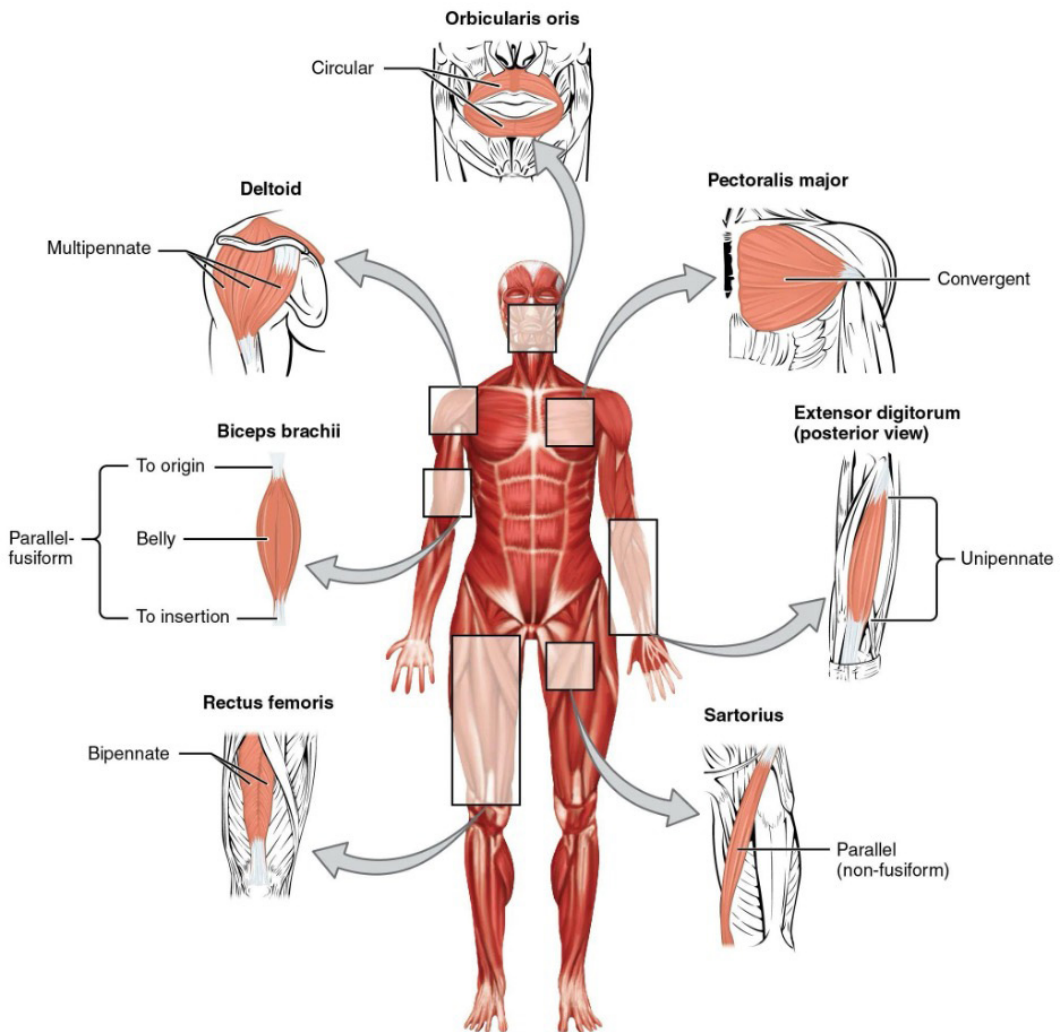


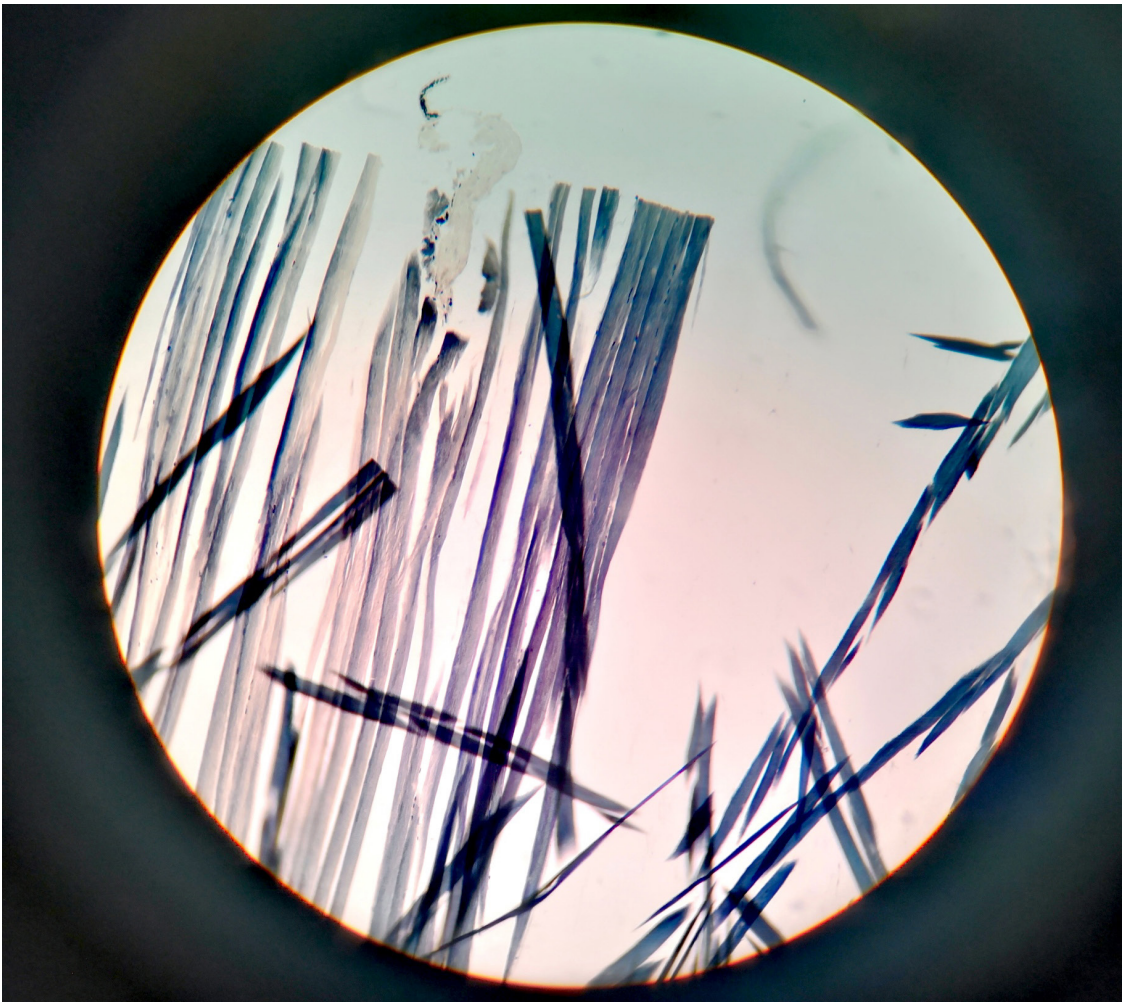
Figure 1: Differing orientations of fiber bundles in a muscle can enable a range of different performance capabilities. Image from chapter 11.1 of <https://openstax.org/books/anatomy-and-physiology-2e>

Evolution of Robotics

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function—stroke length, power, and dynamics—just like in animals:

- Parallel-fibered muscles (e.g., the biceps, <https://en.wikipedia.org/wiki/Biceps>) have fibers aligned with the line of action, enabling longer strokes and higher contraction velocities, ideal for large displacements.
- Pennate muscles (e.g., the branches of the deltoid, https://en.wikipedia.org/wiki/Deltoid_muscle) have fibers arranged at an angle, packing more fibers into a



Striated Muscle Tissue.

Photo: Naz Amann, 2019 | Wikimedia Commons

volume for greater force production at the cost of reduced stroke. Asymmetrical activation allows them to control the angle of the force-generating axis.

Elysium’s actuators can replicate this geometric diversity using a single fiber type, bundling them in different spatial arrangements—parallel for high stroke, pennate for high force, and other patterns for tailored motion profiles.

Zooming back out to a broad perspective on the field, I see that we are finally gathering the right tools and capabilities to explore a similar design space as nature. Until now, engineers were limited to mimicking the form of natural systems, but we did not have actuation and sensing systems that could match the functionality of animals. Now that usable fiber scale tensile elastic actuators are becoming available, we will finally be able to explore the system architecture and design space that nature has used for millions of years to enable reliable, energy efficient, and graceful motion in dynamic and unpredictable environments.

x



Vytas SunSpiral has spent the last 30 years exploring robotics and AI, and has authored over 60 publications, including contributions to the 2013 Roadmap for US Robotics. Vytas led the creation of the world’s first fully autonomous publicly deployed robots in the 1990s at his first startup, Mobot Inc. While at NASA, Vytas became a fellow of the NASA Innovative Advanced Concepts (NIAC) program and built a robotics and AI lab to explore bio-inspired tensegrity robotics. As part of this work, Vytas explored all the artificial muscle technologies available at the time, and found that they all had critical flaws. In search of better biologically inspired actuators, Vytas left NASA and joined Zymergen, the leading synthetic biology company at that time. There he established the Advanced Technology Program to develop AI accelerated genomic engineering tools and he also established the Computational Chemistry team to support polymer innovations with AI powered material property prediction engines. After Zymergen, Vytas ran his own deep tech consulting firm supporting innovative AI powered startups in manufacturing robotics, quantum computing, solid state synthesis planning, emotive robotics and more. Vytas is currently the Chief Scientist at Elysium Robotics where he is helping commercialize the artificial actuators that he left NASA to find.



Abstract motion blur of water and grass
Photo: Robert Clark, 2026 | Unsplash cc



Interview

**From Inspiration to
Outcome**

*Richard James
MacCowan*

Shoshanah Jacobs

From Inspiration to Outcome Richard James MacCowan

Shoshanah Jacobs

Speaking with Richard James MacCowan is always joyful. He has engaged with bio-inspired design in many ways across a variety of projects, and it is easy to get the sense that his experiences have informed both his views and his career plans. Able to jump quickly from one topic to another in animated discussion, I sat down with Richard to learn more about what he has learned and what he is up to.

Sho: What are your impressions of the current state of biomimicry or bio-inspired design?

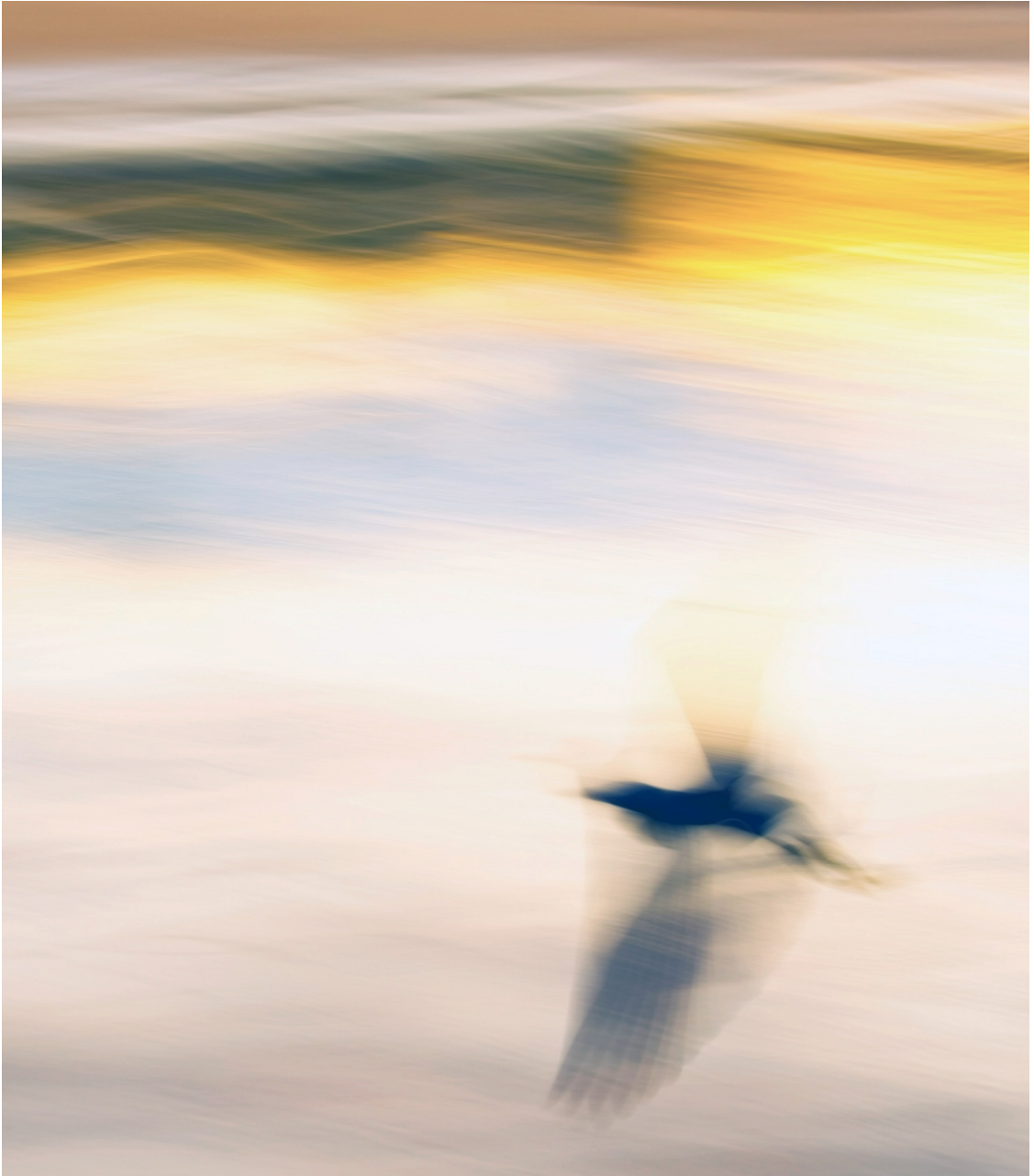
Richard: There's a very accessible meta-design narrative around biomimicry that welcomes everyone into the conversation. That openness is powerful because it inspires excitement and engagement. However, for the field to develop further, we need to shift from just inspiration to tangible outcomes. It's not solely about framing design thinking in the language of nature; it's about demonstrating real-world value. There is a highly rigorous, science-driven aspect of biomimetics that yields deep biological insights. This work is crucial. The next step is to strengthen the connection between that research and practical application.

The real opportunity lies in meeting in the middle. We need to translate biological mechanisms into manufacturing contexts with clarity. What are the constraints? What are the trade-offs? When constraints guide the process, they naturally point us toward relevant biological analogies, not superficial resemblance, but meaningful mechanism translation. This is important. Solutions we see and use as case studies, understand the mechanism of transfer and how they work under rigid physical laws. We can't bypass physics, I'm afraid.

Compared to fields like biotech or biodesign, which have developed strong translational pathways, biomimetics is still defining its structure. That's not a weakness; it's a sign that the field is still growing. With clearer frameworks for translation and evaluation, biomimetics has enormous potential to become more impactful and more widely adopted. This is why it's important to see what is happening with the ISO Standards and the German VDI Standards.

What do you see as the biggest challenges in the field?

It really helps when the field brings its different strengths together so that we're clear on what we're trying to create, and



Abstract motion blur of bird flying over the water
Photo: Robert Clark, 2024 | Unsplash cc

From Inspiration to Outcome Richard James MacCowan

Shoshanah Jacobs

why, and we can connect biological insight with real-world constraints.

It's also worth being honest (and pragmatic) about when biomimetics is the right tool for the job. Nature isn't a catalogue of ready-made "answers" so much as a rich set of hypotheses and characteristics to explore and test. And in some cases, there are already strong solutions out there, so the opportunity is to decide when learning from biology adds real value, and when it doesn't need to.

Where I think we can raise the bar is in how we talk about inspiration and novelty. If an idea already exists, it's better



Abstract motion blur of a forest with trees in the background.
Photo: Robert Clark, 2024 | Unsplash cc

to acknowledge that plainly rather than re-labelling it as biomimicry after the fact. Being clear about what's genuinely biology-derived and what's simply been "nature-branded" protects the credibility of the field and keeps the focus on meaningful advances.

What areas should we focus on to advance biomimetics?

We should focus on constraint-led translation. Start with the manufacturing, material, and system constraints, and then look to biology for elements that operate under similar pressures.

We also need stronger interdisciplinary literacy. Practitioners should understand enough biology to avoid superficial analogy, and enough engineering to make implementation viable. Advancing the field means moving beyond metaphor and toward mechanism and understanding the real-world challenges that it takes to get something new to market, whether shallow or deep-technology.

How did you develop your interest in biomimicry?

I first encountered it in school in the early 1990s. My art (which was part of an art and

design course) was poor, but the teacher focused on intersections between technology and biology, which I backed up with my keen interest in aeronautical engineering, which I briefly studied. Later, after leaving the real estate industry and retraining in urban and landscape design, I came across a design competition that made it all click: the skills I developed in school and university, along with what I learned about ecology from my grandparents.

What is your best definition of what we do?

Biomimetics is the disciplined translation of biological mechanisms into functional human-built systems.

It's not about resemblance. It's about understanding how something works in nature and asking: under what constraints does it operate? And can those operating principles be transferred whilst understanding the physics?

I sometimes borrow your way of framing it, Shoshanah, looking at function through form, process, systems, and relationships. I really like that because it pushes you to think about the relationships between those elements, not just copying a shape but understanding how the whole thing works together. This is where spending time with Julian Vincent and other notable

academics who have shaped the field has taken me in new directions.

What are you working on now?

At the moment, I'm venture scouting for investors, focusing on deep tech solutions. We have an upcoming project on industrial ecology and remanufacturing in our region and get my startup's equine tech solutions going again. Alongside this we are developing projects in materials, methane capture, and novel additive manufacturing solutions.

And I'm building a business intelligence around the field, looking at what skills are required for jobs, who's recruiting, which companies are doing it, academic spin-offs, anything close to Technology Readiness Levels 7 and above. Then, understanding what success rates are in manufacturing to see what commonalities people use, rather than just relying on guesswork.

It's useful because the job thing came from people just wanting me to post jobs, and then I thought: if I'm just posting, why not look at what hard and soft skills are required? I'm going to be writing a paper later in the year with someone doing her PhD in industrial design: what do we actually need to teach students?

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By what criteria should we judge the work?

One helpful anchor for the field is ISO 18458:2015 *Biomimetics — Terminology, concepts and methodology*. It gives us a shared reference point: are we genuinely translating a biological function? Have we taken the time to really understand the biology before applying it? That level of rigour ultimately strengthens the credibility of biomimetics.

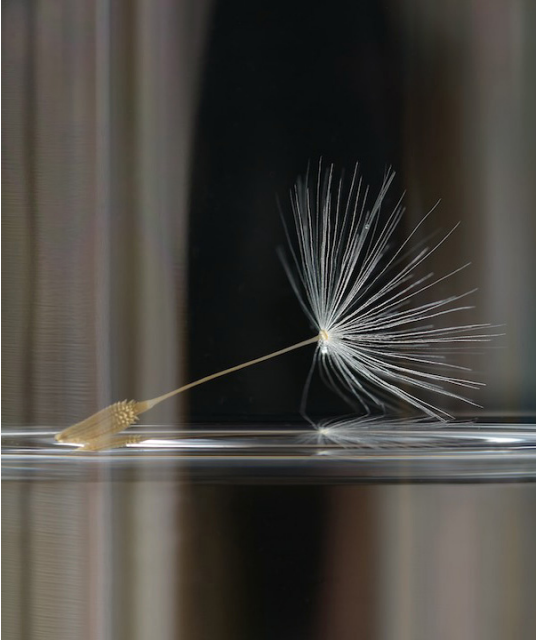
And this connects to a broader cultural point: the field benefits when evaluation is grounded in shared standards rather than individual authority. Instead of relying on

particular figures to validate whether something “counts” as biomimicry, we’re stronger when we use clear criteria and collective understanding. That keeps the discipline open, rigorous, and evolving. If not, you end up delving into pseudoscience, which Carl Sagan writes about eloquently in *The Demon-Haunted World*.

Which work have you seen recently that really excited you?

I like a UK company called Opteran. They’ve looked at these large, powerful machine learning models like DeepMind and realised that insects actually solve complex problems. They were already researching honeybee neurons for machine-learning, and this was the spark to develop these learning algorithms based on around one million neurons compared to 86 billion in the human brain. This has allowed them to use processors that are cheaper, lighter, and need less energy. They’re taking this into various sectors in robotics, manufacturing, and drone technologies.

I also get really excited about the experiments universities are conducting to understand biological mechanisms. For example, at the University of Edinburgh, they had to build a highly intricate wind tunnel to get a dandelion seed to float.



Dandelion seed floating

Photo: arnie2105, 2012 | Wikimedia Commons

Imagine how much patience that would take! They're doing that because they want to understand the aerodynamics of an individual dandelion seed, and they've found that by running smoke through it, it creates a little vortex ring above the seed umbrella that generates lift. What they're doing now is making engineless microdrones.

What's the last book you enjoyed?

I really like the one I'm reviewing, called *Birds Up Close* by Lorna J. Gibson. It doesn't teach you about biomimicry or biomimetics, but it teaches you where to look in terms of materials science. It's a nice read. She introduced looking at biology, in this case birds, into material science courses, and students got more interested.

What's your idea of perfect happiness?

Spending time with my kids and wife on a sunny afternoon in the garden.

If you weren't doing what you do, what would you do?

I'd probably be working in applied research in some capacity. I like to understand how things work. x



Richard James MacCowan is a researcher and R&D advisor specialising in biomimetics and complexity science. He is the founder of Biomimicry Innovation Lab, which applies evidence-based scientific principles to manufacturing, agrifood, and urban systems, and provides technical advisory support for organisations developing nature-inspired technologies.

His work spans collaborations across North America, Europe, Africa, and Asia, focusing on translating biological mechanisms into deployable technologies, materials, and decision frameworks. Richard also serves as CEO of Smart Stable Ltd, an equine technology company.

Alongside his consulting and technology scouting for deeptech and nature-inspired ventures, he is a jury member for the European Innovation Council (EIC), assessing frontier technologies and startups.

His research on the state, constraints, and future of nature-inspired engineering is captured in The State of Nature-Inspired Innovation series: <https://www.biomimicryinnovationlab.com/research>.



Worms eye view of forest during day time, bamboo leaf canopy
Photo: kazuend, 2015 | Unsplash cc



Article

Building a BiosVerse™

Compatible Industry

Michael W. Wright

Building a BiosVerse™ Compatible Industry

Michael W. Wright

Over two days last November in Minnesota, the second annual Biomimetics International conference, Biomimetics25,¹ did what nature does best: we created conditions for emergence. We brought biologists, designers, engineers, corporate operators, policy shapers, investors, and tool-builders into the same BiosVerse™, "a living, breathing ecosystem where biology, technology, and human ingenuity come together to create a future inspired by nature's unparalleled wisdom".² We asked a simple question: how do we move biomimetics from pilots to a BiosVerse™ compatible, high-impact industry, at speed and at scale?

We have an opportunity window that's opening and closing, likely only once. We're at an inflection point. Climate stress, supply chain shocks, AI, regulatory pressure, and public health realities are narrowing the opportunity window. Nature-aligned innovation, design, and commercialization is moving from "nice to have" to a no-choices-left, non-negotiable must-have. The opportunity is equally vivid.

Our job is to intercept horizons at the point of convergence – not too early to be ignored, not too late to be commoditized. Biomimetics25 was designed as a timing exercise as much as a technical one: can we synchronize signals across research, industry,

capital, and policy so that biomimetics shows up as a coherent "category" as the world comes looking for it?

A recurring theme was distinguishing growth from scale. Growth is more head-count, more labs, more SKUs. Scale amplifies impact – more BiosVerse™-compatible outcomes per unit of material, energy, and capital. Whether it is the University of Minnesota's "Building with Biology" network,³ the Biomimicry Institute's community-inspiration-innovation model, or corporate case studies, the focus was on scaling outcomes like emissions avoided, ecosystem function restored, and equity improved – not just scaling organizations.

Virtually every speaker repeated some variation of "we cannot do this alone." Biomimicry 3.8 showed how significant ecosystem improvement on sites only happened when toolmakers, designers, engineers, and clients worked as one integrated system. Design leaders challenged us to think about scaling down, decentralizing, and "de-centering" practice and not abandoning authorship but relocating it into teams, materials, and contexts. That's a more biological model of scale: many nodes, shared principles. We are not trying to build the most enormous tree in the forest; we're trying to grow the forest.

1. <https://www.biomimeticsinternational.com/biomimetics25/agenda>

2. <https://medium.com/biomimetics-international/welcome-to-the-biosverse-bc945f8a5c3b>

3. https://zqjournal.org/pdfs/ZQ_issue_39.pdf#page=86



Aokigahara forest in Yamanashi, Japan
Photo: Ajari, 2008 | Wikimedia Commons

Building a BiosVerse™ Compatible Industry

Michael W. Wright

We saw convincing evidence that biomimetic strategies can scale in the real world when the right ecosystems are in place, in built environment and infrastructure, global tech platforms, mass-market retail, green chemistry, and lab-to-market. Rachel Hahs talked about how Project Positive and EcoMetrix Solutions Group have moved from theory to portfolios of projects, delivering 200–300% ecosystem performance improvements and quantifiable business value across dozens of sites globally. John Warner reminded us that we need to translate “why” and “how” into molecules, manufacturing, and safe chemistries. The Biomimicry Institute’s Launchpad portfolio has attracted hundreds of millions in follow-on investment, while still centering nature’s principles, impact metrics, and patient capital. The real question is “how fast can we compound it, and who’s missing from the loop?”

Through the session, I started to see an architecture for a biomimetics ecosystem taking shape which was very close to the five-pillar framework we laid out at the start of the week:

- Adaptive networks & swarm intelligence: Thinkscape and Unanimous AI showed how swarm intelligence can help groups deliberate, prioritize, and decide much more effectively than traditional meetings.
- Innovation fusion labs and “intentional collisions”: formalizing places (physical and virtual) where green chemistry, circular supply chains, materials informatics, AI, and biomimetics collide on specific challenges, connecting the sciences with industries.
- Metrics, trust, and proactive economies: net positive (not net zero) is the only trajectory that repairs past harm in the form of sunk costs and unremediated infrastructure. We now have tools to measure it. When we can quantify positive and negative impacts, we can design regulatory environments and capital flows that incentivize regenerative choices.
- Bridges across silos: universities reframed silos as neighborhoods and connected them so that a biologist’s fascinating organism becomes an engineer’s breakthrough surface or a startup’s next platform.
- Global stage setting: the Minnesota World Expo 31 (<https://www.expo2031.org/>) was presented as a proof-of-concept high-visibility stage for biomimetics, a place to demonstrate, on an international scale, the kinds of technologies, materials, and governance structures this community can generate.

When I said last year at Biomimetics^{24,4,5} that I saw “lots of nodes without a mycelium-like network” it wasn’t a criticism – it was a diagnosis. Biomimetics²⁵ confirmed the diagnosis and gave us a treatment plan. Biomimetics International (<https://www.biomimeticsinternational.com/>) exists to be the mycelial network connecting labs, startups, corporates, investors, and policy-makers. It is the category shaper that makes “biomimetics” as familiar and investable as “semiconductors” became a few decades ago. It is the backbone organization that cycles value like an ecosystem cycles nutrients through mentorship, shared IP pathways, swarm-based decision processes, and tangible opportunities like Expo 31, joint pilots, and co-investment.

Our mandate is straightforward: build the ecosystem that enables breakthroughs.

We need to:

- Formalize membership and roles.
- Build working groups around the real scaling bottlenecks.
- Use swarm tools to decide together, faster.
- Design “innovation fusion labs” and demonstration corridors.
- Build toward Expo 2031 as a shared horizon.

Nature has had roughly four billion years to test what works, providing a rich source of design patterns. Our task is to translate those learnings into markets fast enough to matter without losing the ethics, equity, and humility embedded in those patterns. ×



Michael W. Wright is CEO/Founder of Intercepting Horizons, LLC, a Fellow of the Caux Round Table, and Executive Director of Biomimetics International. A former global technology executive at scale (President of Entegris, ENTG), futurist, author, and strategic advisor, Wright’s work explores the intersection of human systems, exponential technologies, and ethical design. He is the author of over 50 articles on technology and business, the author of *The New Business Normal*; his most recent book *The Exponential Era* (Wiley) examines strategies for a world transformed by accelerating technological change; he is a frequent contributor to illumine.com <https://illumine.com/illuminevoicesprofile/michael-wright>

4. <https://www.biomimetics24.org/>

5. https://zqjournal.org/pdfs/ZQ_issue_36.pdf#page=62



Closeup Photo of Yellow and Black Butterfly
Photo: Egor Kamelev, 2017 | Pexels cc



Looking Back/Looking Forward
*Repositioning
Biomimicry*
Pete Foley

Repositioning Biomimicry

Pete Foley

Repositioning Biomimicry to Expand Its Appeal to Today's Designers and Innovators

My view of biomimicry has evolved, though not dramatically, over recent years. I still value it as a source of inspiration, a way of unlocking surprisingly obvious solutions to difficult problems, and as a way of breaking us out of biases created by our own specialization and expertise.

However, I feel more strongly than ever that it works best as part of a portfolio of innovation techniques. Compared to other innovation processes, it has both pros and cons. There will be times when it suggests great solutions, but also situations where other techniques provide more viable ones. Integrating it with other innovation techniques, as opposed to competing with them will inevitably provide more consistent success. And it is success that drives adoption of new processes.

Its biggest strength is that it can help us to reframe problems in quite different ways, and thus provoke sometimes counterintuitive or breakthrough solutions. Mimicking whale tubercles in wing, windmill or underwater craft design is an old, but pertinent example. The concept of adding structure to the front of a wing to improve hydrodynamics or aerodynamics was somewhat counterintuitive, and thus inspired us to

think outside of more conventional solutions or technologies. However, the fact that this concept has existed for over 10 years yet still hasn't penetrated mainstream designs highlights the inherent difficulty in turning interesting, even breakthrough, concepts into commercially and technically viable innovations. This journey from idea to commercial success is always difficult, typically involving multiple challenges and compromises along the way. But it is inherently bigger for bioinspired innovation, given the huge differences in materials science, technology and manufacturing processes between nature and existing industrial capability.

That said, I also suspect that bio-inspired innovation may simply be a concept that was ahead of its time. Advances in materials science, flexible manufacturing techniques, 3D printing, genetic engineering, AI, and quantum computing may finally unlock its potential. The step-change in computational and pattern matching power these provide can help us with the 'needle in a haystack' challenge of matching problems to the vast array of potential solutions available in nature. Meanwhile, increased prototyping capability and the ability to build ever more



Macro Photography of a Moth
Photo: Egor Kamelev, 2020 | Pexels cc

Repositioning Biomimicry

Pete Foley

sophisticated models can only help translate biological concepts into commercial reality.

But despite this, biomimicry will not be the only answer. It will still get more traction if used as part of a broader innovation toolbox. The innovation community and those it serves focus far more on outcomes than on the process itself. Innovation capability is a marketplace like any other. From a customer perspective, we will get far more market share if we integrate it with other methods to maximize overall success, rather than selling it as a 'special' process to be used in isolation from the broader innovation process.

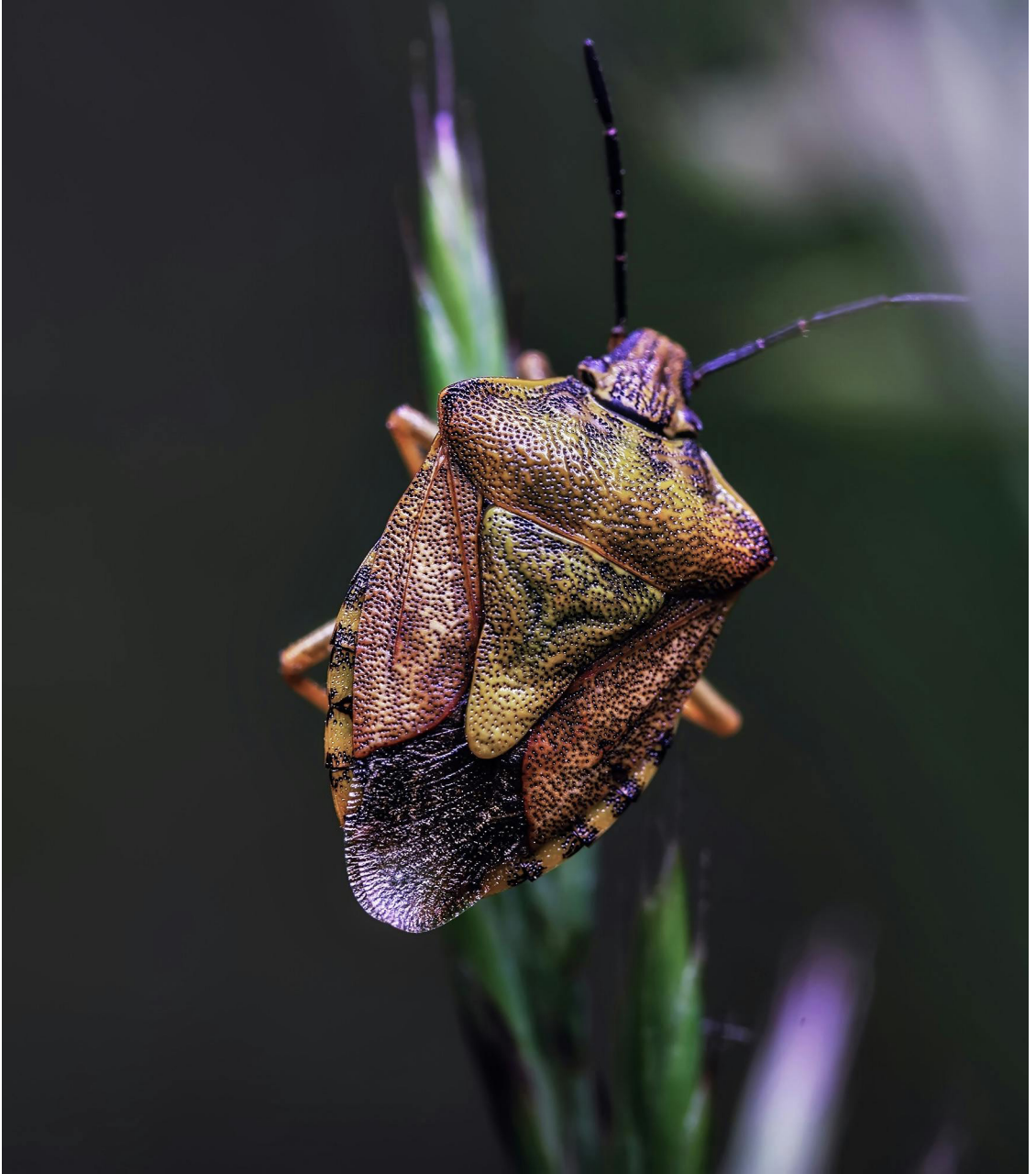
And while this will be an unpopular opinion with some, we need to move away from thinking that biomimicry will magically create more sustainable or green innovations. We are mimicking, not reproducing nature, so while some solutions may improve sustainability profiles, others may not. To illustrate this, look no further than VELCRO®, an early example of bio-inspired innovation that used plastics rather than natural materials.

The world is moving towards more sustainable innovation. But any policing of that journey needs to come from strategy, not methodology. Attempts to enforce sustainable design or any other 'outcome criteria' from a biomimetic process will only

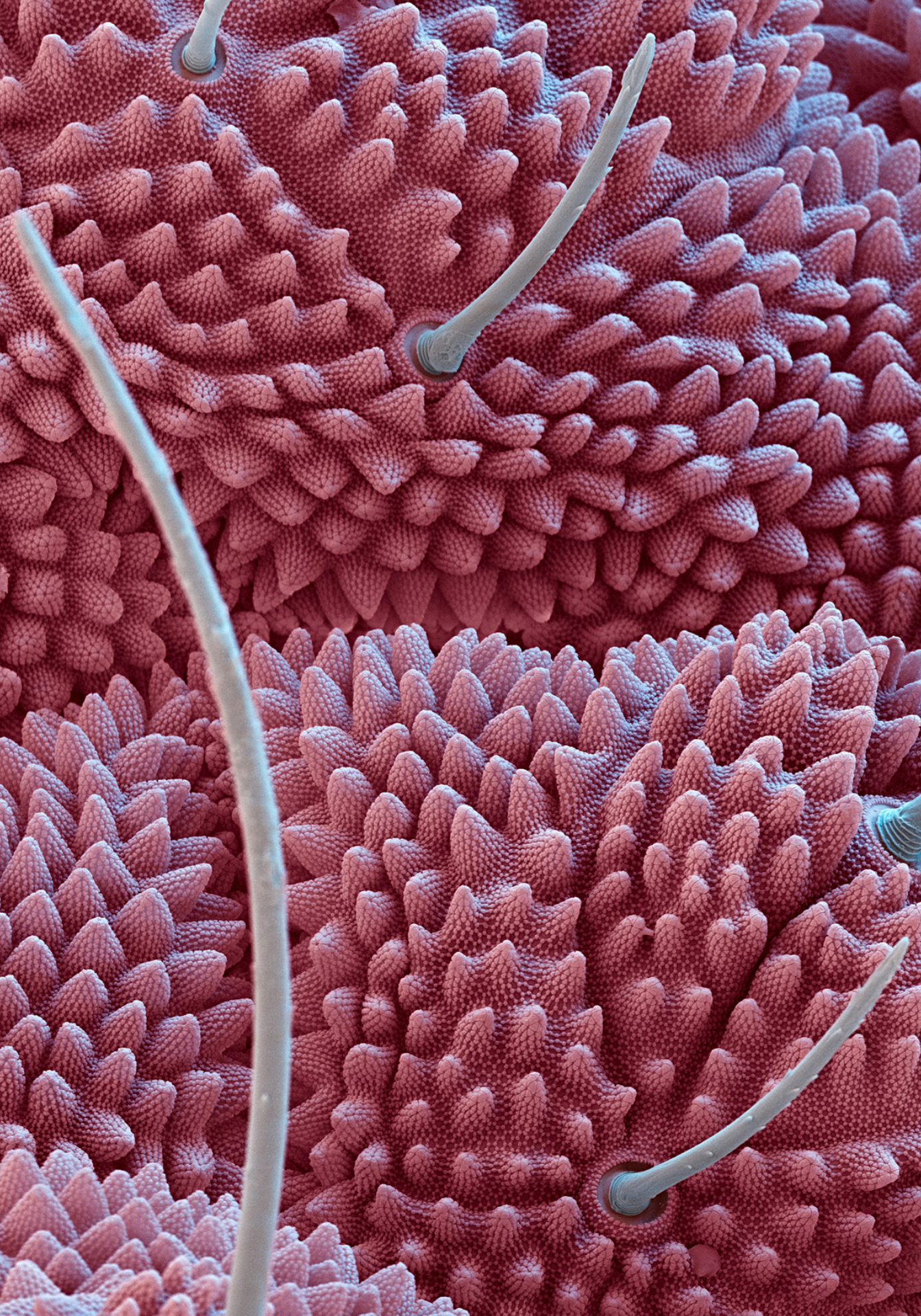
make it a less attractive option. We as a biom* community have already been guilty of over-promise, and so often face reasonable skepticism from the broad innovation community. Any attempts to add additional constraints onto the outcomes of biom* research will only make it even harder for the concept to gain a meaningful foothold with the innovation community. And any attempts to have an innovation process define strategy will only make an already difficult sell even harder. ×

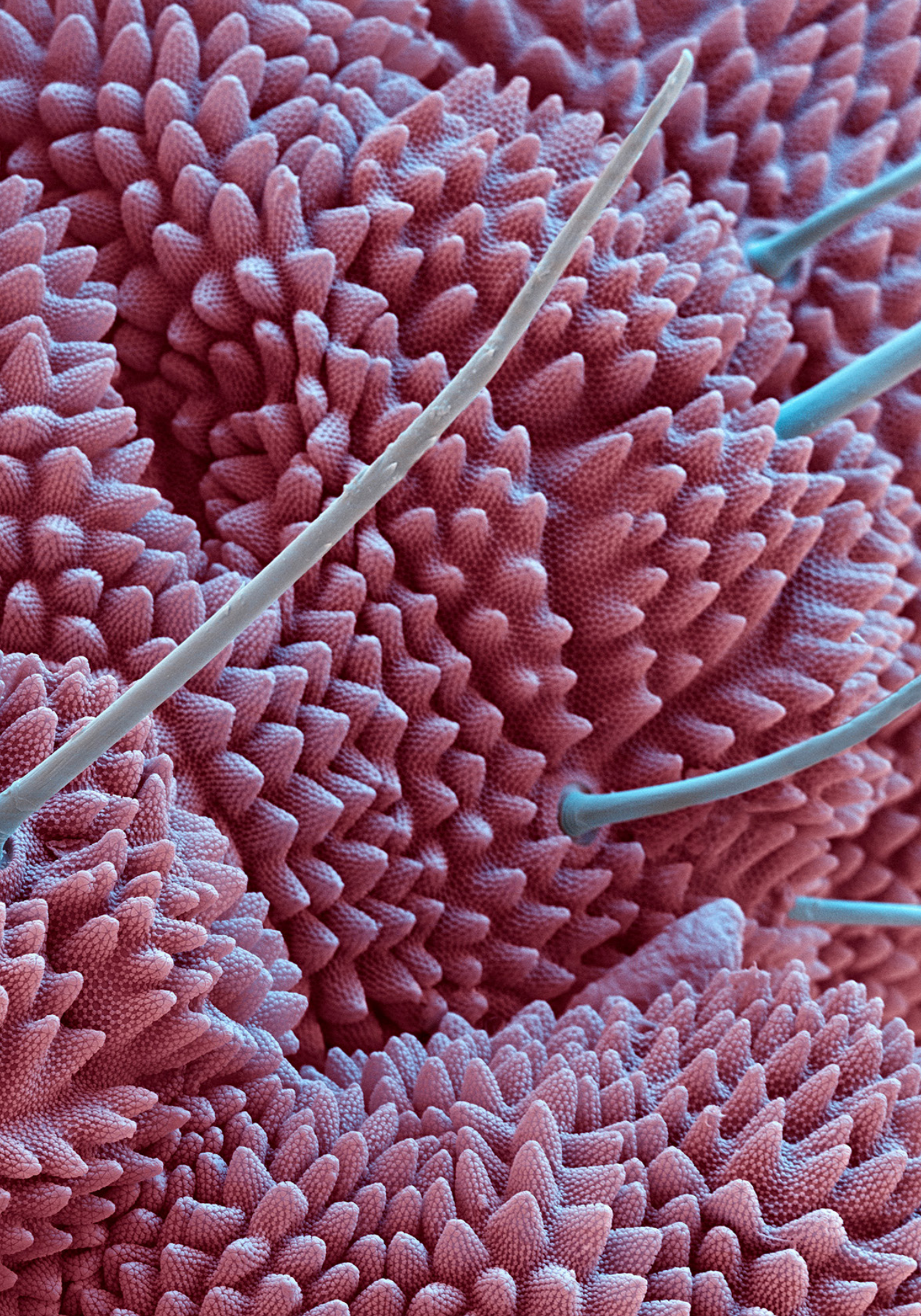


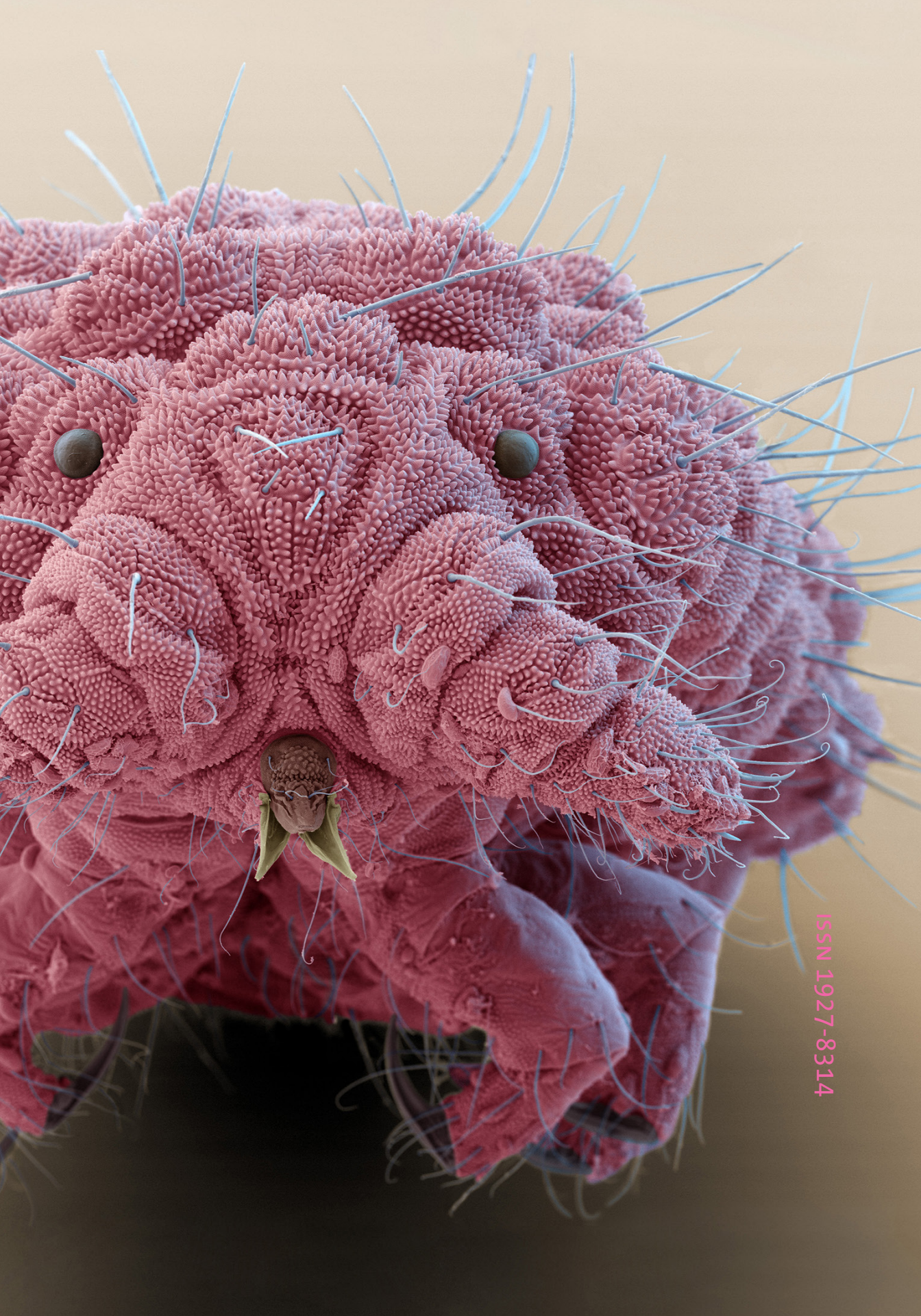
Pete Foley is an innovation consultant who combines technical expertise with deep knowledge of the psychology behind the creative process. He draws on 25 years as a serial innovator at P&G, is an award-winning innovation blogger, and has co-authored papers with world-renowned academic experts from a wide range of disciplines associated with applied psychology, behavioral and perceptual science. ×



Macro Photography Of Beetle
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ISSN 1927-8314