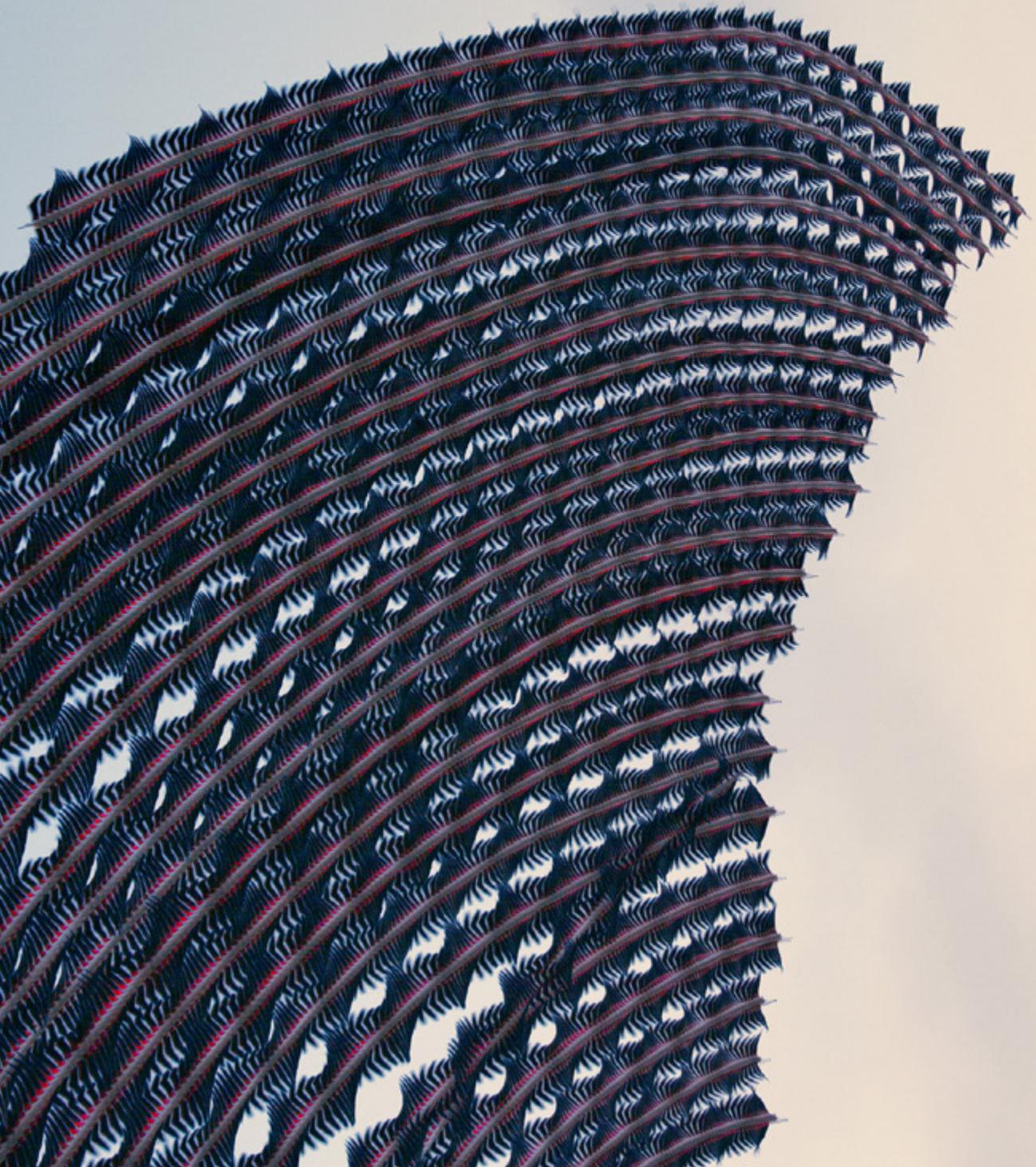


zq¹⁹

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About Zygote Quarterly

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Snail trail | Photo: coda, 2007 | Flickr.cc

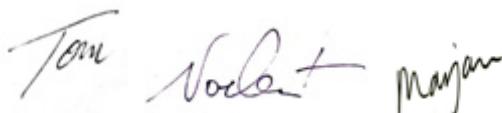
These are turbulent political times, particularly in the western democracies, where established orders and principles are being challenged by a wave of reactionary populism. Long simmering embers of dissatisfaction and resentment have flashed into flame in several countries, with the United States being the most consequential. Whether this flame will be cleansing, as adherents hope, or irrevocably destructive, as opponents fear, remains to be seen.

What is clear, however, is that reflection on basic values and beliefs has been brought to center stage for the citizens of these countries as not seen in decades. In that sense, all activities have become political. Witness the planned march on Washington of U.S. scientists scheduled for April 22, 2017, the traditional Earth Day. The main message from these usually apolitical professionals: facts and science matter.

We at ZQ feel compelled to re-affirm our beliefs, starting with an echo of the sentiment that will be carried to Washington in April. The search for truth, either in science or art, is more important than ever. Collaboration and working together are the keys to success. Nature's abundance, restorative power, and awe-inspiring complexity should be honored, studied, and preserved, so that everyone, no matter what background, can benefit from her bounty and live a peaceful and prosperous life.

This issue celebrates the search for nature's secrets, whether it is deciphering the communication of birds, as Heidi Fischer recounts the work of wildlife biologist Erick Greene, or the serendipitous discovery of a common molecular structure seen in a moment in Sir Harold Kroto's illustrious career, or in the photographic reduction of the mechanics of flight, as pursued by artist Xavi Bou. We also interview those who translate these lessons to useful applications: Thierry Chopin about his work in aquaculture, and Brook Kennedy about his Macronaut lens for your mobile phone.

We hope you find your own re-affirmation in these inspiring stories. Happy reading! x

The image shows three handwritten signatures in black ink. The first signature on the left is 'Tom'. The middle signature is 'Norbert' with a small plus sign to its right. The third signature on the right is 'Marjan'.

Tom McKeag, Norbert Hoeller and Marjan Eggermont



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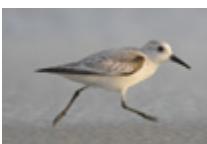
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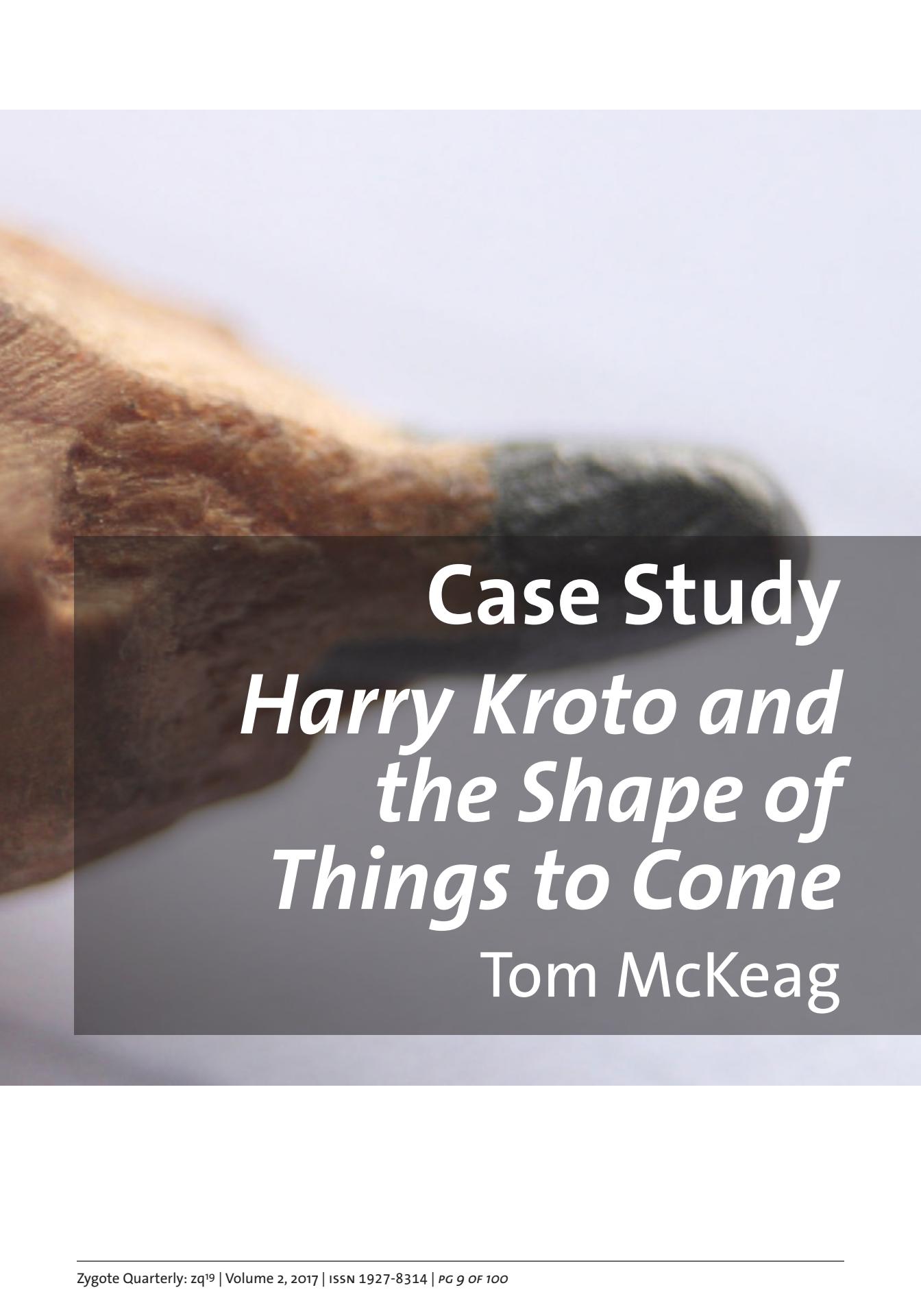
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Photo: Frank Green, 2010 | Flickr cc



Case Study

Harry Kroto and the Shape of Things to Come

Tom McKeag

Harry Kroto and the Shape of Things to Come

In 2016, the world lost four of its Nobel Laureates in Chemistry, among them Sir Harold W. Kroto, winner of the 1996 Nobel Prize in Chemistry, which he shared with Richard Smalley and Robert Curl of Rice University for the discovery of fullerenes in 1985.

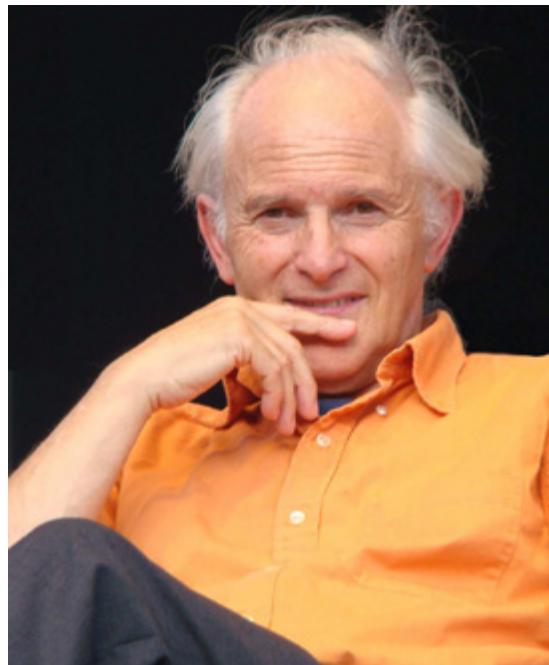
The discovery of fullerenes is a tale of trans-disciplinary serendipity that includes the exploration of space, a visit to an exposition, and the

personal rediscovery of geometry known to the ancient Greeks. It also includes a pivotal inspiration gleaned not from a scientist, but a nature-inspired designer.

Fullerenes are molecules of pure carbon structured in hollow forms; spheres, ellipsoids, and tubes. When discovered they were an entirely new and previously unknown shape of carbon. Different molecular structures of the same material are known as allotropes. Graphene, diamond, graphite are all allotropes of carbon.

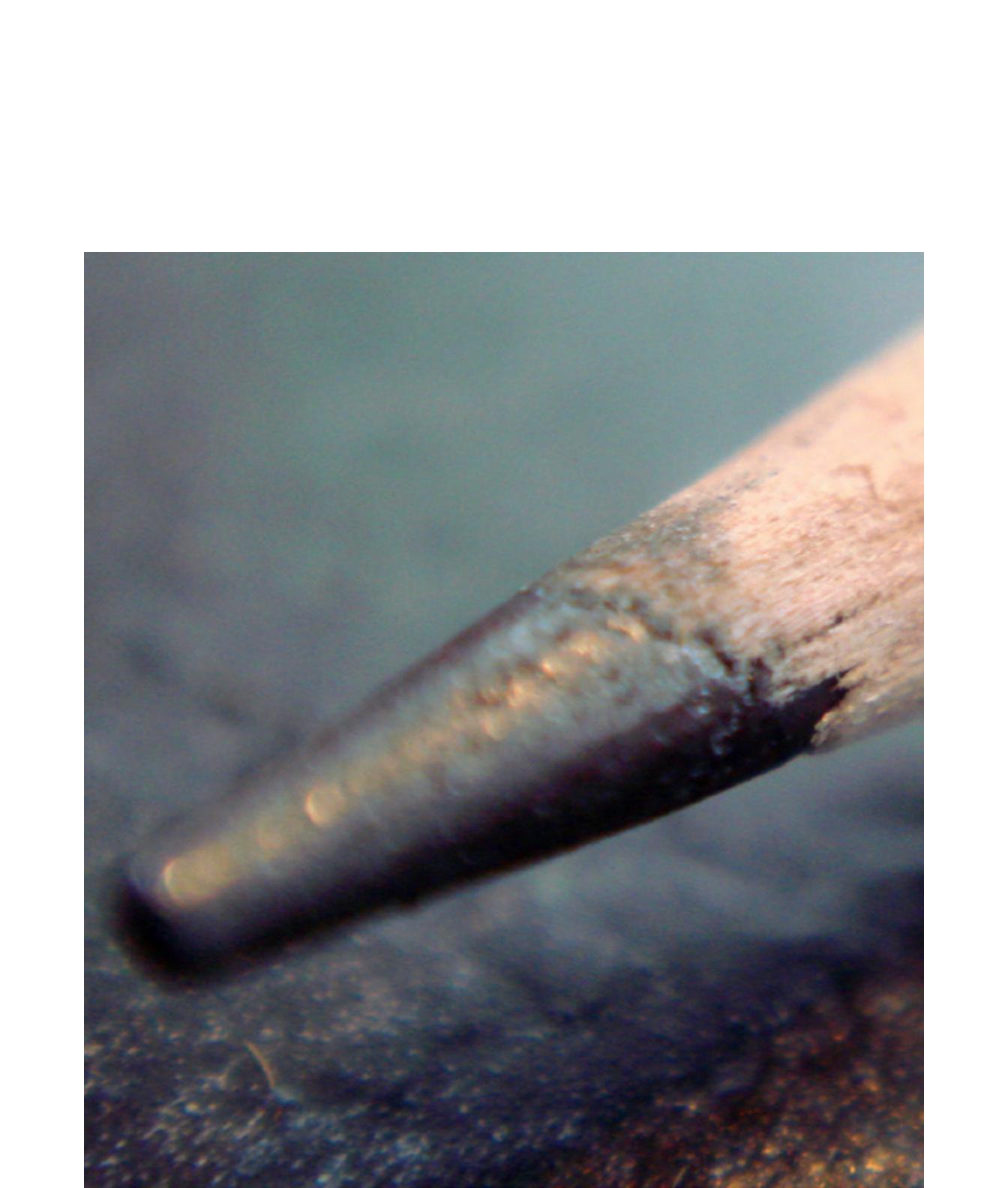
Each of these allotropes, despite being made of the same material, has wildly different properties. Consider the “lead” in a graphite pencil versus a diamond. This is because graphite’s atoms are arranged in sliding sheets, while a diamond’s atoms are arranged in the pyramid-like and ultra stable tetrahedron formation. Carbon has been called “the king of the elements” since nearly ten million compounds of this highly linkable element have been described. Many more are possible.

Carbon owes its collaborative nature to its basic structure, offering four electrons that can bind covalently with other elements like hydrogen or other carbons. Long chains of carbon and hydrogen form the hydrocarbons that fuel, lubricate, fertilize and plasticize our world. Although carbon binds readily in any number of combinations, the resultant materials are



Harry Kroto

Photo: Wikimedia Commons, 2010



Pencil

Photo: Cubosh, 2009 | Flickr cc

Case Study

Harry Kroto and the Shape of Things to Come

Author:

Tom McKeag

typically thermodynamically stable due to the strong covalent bonds. For example, carbon remains a solid at very high temperatures, higher even than metals like tungsten. The strong bonds mean that, once formed, carbon-based materials take a lot more energy to break apart. This characteristic makes so-called organic life possible and durable.

Indeed, carbon is found throughout the living world and defines the field of organic chemistry. Bound to oxygen and hydrogen, it forms the food and building materials of our living world: sugar, alcohol, fat. Chitin, lignans, esters, carotenoids and terpenes are made of these carbon/oxygen/hydrogen molecules. When carbon is combined with nitrogen it forms alkaloids, and with the addition of sulfur forms antibiotics, amino acids. Add again phosphorus and the basic information guides to life, DNA and RNA, emerge, along with ATP (adenosine triphosphate), without which energy could not be extracted from food.

When discovered, fullerenes were found to be a previously unknown shape of pure carbon with unique properties. Fullerenes are a fundamental part of nanotechnology, the study of the very small and how tiny structures and devices might be put to use. A nanometer is a unit of measurement that is one billionth of a meter, or 10^{-9} . This is the scale of molecules, DNA, viruses, and the wavelength of the optical spectrum. Human hair has a diameter three orders of magnitude greater.

Famously predicted by physicist Richard Feynman in a 1959 talk at Caltech, *There's Plenty of Room at the Bottom*, nanoscience has become an inextricable part of national economies and scientific advancement. Nature has been the

fundamental and almost exclusive model for this sector of research and development; the tiny machinery that operate within a living cell the most studied templates. Applications are diverse and include optics, superconductors, antibiotics, energy and strong materials.

Our tale of discovery, however, begins not at the infinitesimal, but in the vastness of interstellar space. Kroto was initially interested in the origins of long linear carbon molecules that he and Canadian scientists had discovered there. Working with microwave spectroscopy at the University of Sussex in the UK in the early 1980's, Kroto theorized that these unusual chains had been created from red giant stars, but he lacked the means to test his theory.

A fortuitous meeting with Robert Curl in 1984, led to Kroto's collaboration at Rice a year later. Curl and Richard Smalley had been studying atom clusters using their custom-made instrument called an AP2 which enabled them to study clusters of any element. The device bombarded material with lasers at specific pulse rates, exploding and then measuring the resultant elements. Typically, a sample would be placed inside a hollow steel block in a vacuum chamber and then shot and vaporized with a laser. The resultant material would be mixed with helium gas and shot again with a laser to ionize or strip away its electrons. The stripped out atom clusters would then be measured in a mass spectrometer.

Kroto could see that this was a way to test his idea about the formation of his carbon chains; the intense heat of the device seemed to replicate the fiery furnace of expanding red giant stars and in late 1985 the three scientists con-

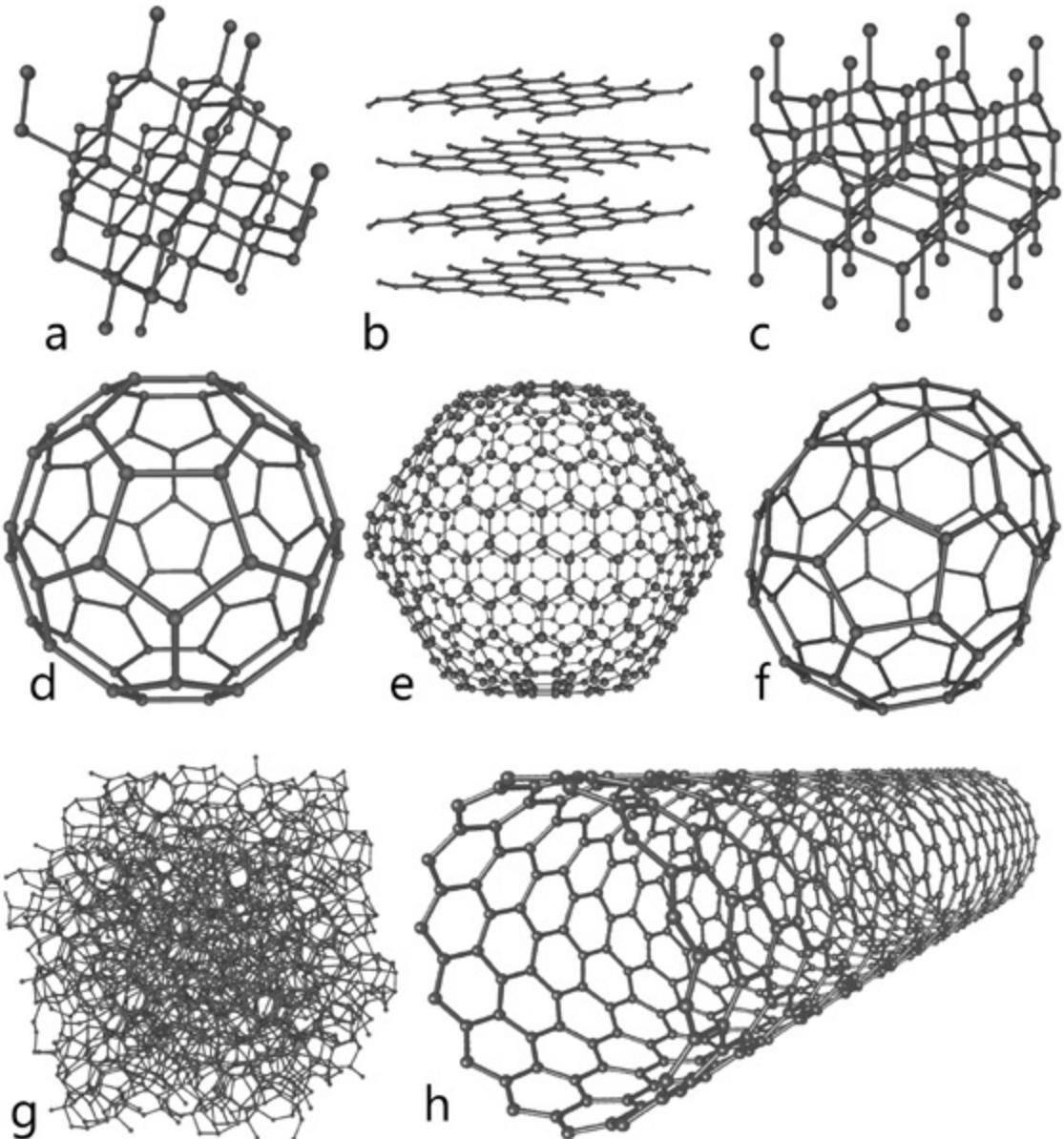


Illustration of the eight allotropes (different molecular configurations) that pure carbon can take:

- a) Diamond
- b) Graphite
- c) Lonsdaleite
- d) C₆₀ (Buckminsterfullerene)
- e) C₅₄₀
- f) C₇₀
- g) Amorphous carbon
- h) single-walled carbon nanotube

Illustration: Michael Ströck, 2006 | Wikimedia Commons



Montreal Biosphere at night

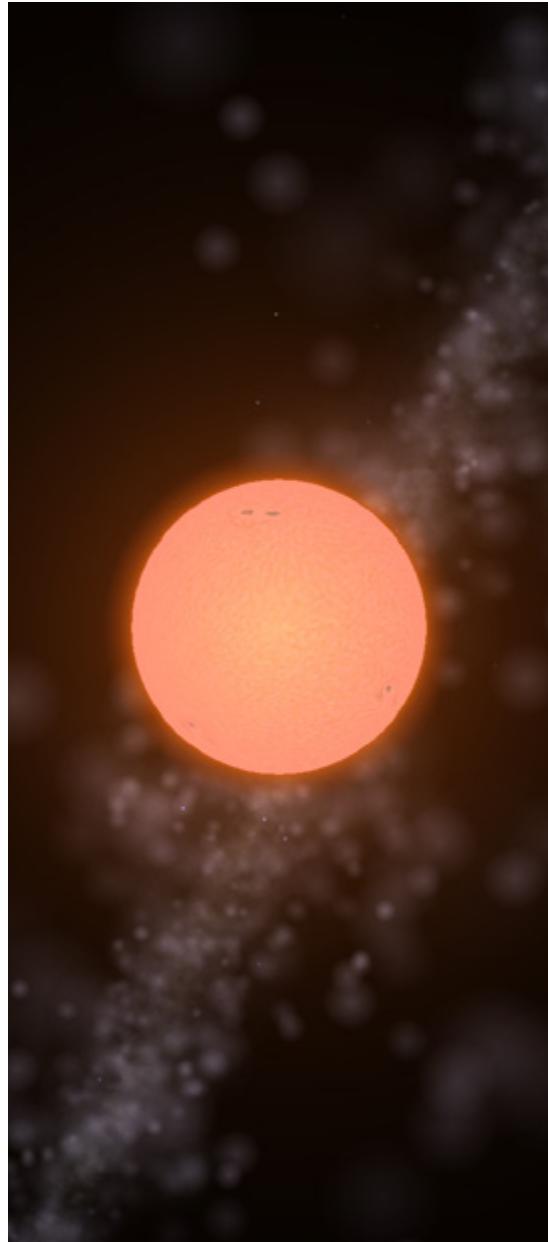
Photo: Hamidreza, 2012 | Flickr cc

ducted the study. In a matter of days, the team had found not only Kroto's predicted long chains, but something new. Its characteristics were breathtaking: not a cluster of carbon atoms but an entirely new molecule made completely of carbon.

They had found this new molecule using a mass spectrometer which had its measurement limits. A mass spectrometer ionizes a material and then sorts the ions based on their mass-to-charge ratio. While it can indicate mass and what molecules comprise a material, it does not reveal the structure of these molecules. The scientists did know that the material was extremely stable, always had 60 carbon molecules, and did not react with other elements. This suggested that, unlike all other known forms of carbon, this one did not have dangling edges that cross-linked with other elements, like, for example the hydrogen found in hydrocarbons.

If this carbon molecule consisted of only carbon bonds, what shape would that mean? Would it be cross-linked sheets or something more spherical that closed in on itself? In the discussion, Kroto recalled his 1967 visit to the World Exposition in Montreal, where a radical architect, R. Buckminster Fuller, had created a large 76 meter diameter by 62 meter high geodesic dome for the U.S. pavilion. The Expo dome was a $\frac{3}{4}$ sphere, based on the icosahedron, a Platonic solid known to the ancient Greeks and documented since circa 360 BCE.

Platonic solids are three-dimensional convex shapes that are composed of congruent regular polygons with the same number of faces meeting at each vertex or point. Only five solids meet



VX Sagittarii Red Supergiant Star

Photo: PlanetUser, 2012 | Wikimedia Commons

this test: cube, tetrahedron, octahedron, dodecahedron, and the icosahedron which formed the basis of Fuller's dome.

The Rice research team broke up to ponder the results of their experiments and solve the riddle of the 60-carbon structure. Richard Smalley pursued the spherical option, first unsuccessfully on his computer, and then resorting to paper, scissors, and tape using the hexagons they believed the molecules to be forming. Without pentagons, however, he was not able to get the shape to close upon itself. Once these were interspersed with the hexagons, the model came together with ease. What emerged was the familiar shape of the football (soccer ball): 12 regular pentagonal faces, 20 regular hexagonal faces, 60 vertices and 90 edges.

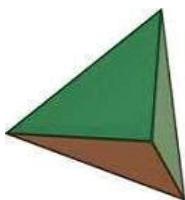
At the molecular scale, atoms of carbon corresponded to vertices, and so the team realized that the sixty carbon atoms could form a perfect sphere. They were ecstatic: the first known one-element molecule formed in a sphere, and that element was carbon, the "king of elements". At the time, graphite and diamond were the only

known forms of pure carbon, and this was an entirely new fundamental shape. Smalley likened its application possibilities to the discovery of the hexagonal benzene ring in 1825, from which countless permutations had led to products as diverse as aspirin, paints and dyes, and plastics.

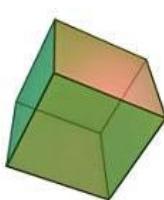
A soccer football is more precisely described as a truncated icosahedron. If one constructs an icosahedron of 20 faces of triangles and then snips off all the points or vertices a third of the way in, they present pentagonal faces in addition to the hexagons formed from the initial triangles. The shape is now a semi-regular polyhedron as it mixes two basic panel shapes. Carry this truncation to finer and finer scale, snipping off points created in the previous iteration and the shape gets rounder, eventually reaching the type of elegance shown in Fuller's Expo dome.

Both Euler and Descartes had explored the geometry of making spheres out of geometric flat panels, resulting in independent conclusions circa 1752 now referred to commonly as the Euler

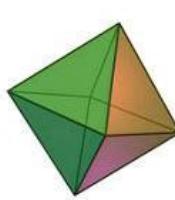
Tetrahedron
V=4 E=6 F=4



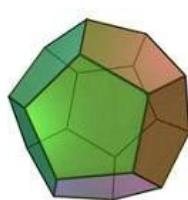
Hexahedron
V=8 E=12 F=6



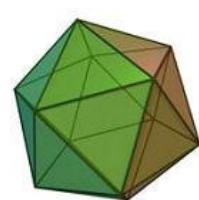
Octahedron
V=6 E=12 F=8



Dodecahedron
V=12 E=30 F=20



Icosahedron
V=20 E=30 F=12



Leonard Euler's polyhedron formula: Vertices - Edges + Faces = 2
Illustration: Adapted from Lwphillips, 2014 | Wikimedia Commons

Polyhedral Formula. Add the number of vertices and faces of the regular polyhedron and subtract the edges and you will always yield two ($V+F-E=2$). Fuller had studied these geometries in order to give them form in the built world, branding his system as 'geodesics'.

It is perhaps fitting, then, that a polymath like Kroto would be key to this important discovery from both a scientific research and conceptual design perspective. In addition to his knowledge and passion for science, he also was a talented artist and designer, and continued a brisk sideline of poster and logo design. His interest in design had made him aware of Fuller's work, and without this awareness, the discovery of fullerenes would have been long delayed.

The team called their new discovery Buckminsterfullerene, with a designation of C₆₀ in their seminal paper in the journal *Nature*. These hollow, durable spheres, later called buckyballs or fullerenes, were only the beginning, as research into this exciting phenomenon widened. Other shapes were subsequently discovered and over a thousand new compounds incorporating the fullerene structure have been synthesized since.

It took another six years before researchers at the University of California Berkeley, led by Joel Hawkins, published the first x-ray pictures of the molecule's crystal structure in 1991, confirming without a doubt the shape of the molecule predicted by research results, mathematics and the crossing of design and science. Smalley, Curl and Kroto were awarded the Nobel Prize in Chemistry in 1996, recognizing their mark in science and the opening of a whole new world of the very small. X



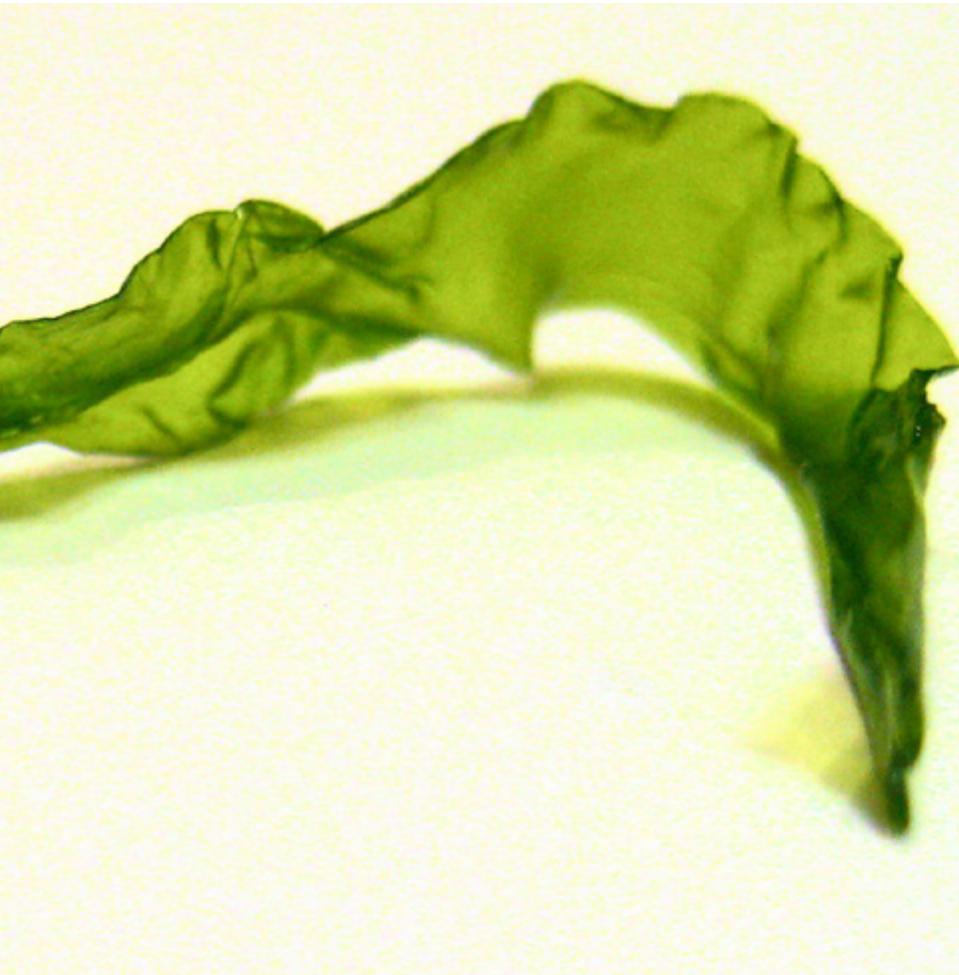
Chemistry at Sussex poster

Design: Harry Kroto | <http://www.kroto.info/graphics/>



Seaweed strand

Photo: robanhk, 2008 | Flickr cc



Interview

Thierry Chopin

Dr. Thierry Chopin was born and educated in France. He obtained his Doctorate from the University of Western Brittany, Brest, France. He moved to Canada in 1989 and is presently a Professor in the Department of Biological Sciences at the University of New Brunswick in Saint John, Canada. He is the Scientific Director of the Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN) (<http://www2.unb.ca/chopinlab/index.html>). Integrated Multi-Trophic Aquaculture (IMTA) is the practice which combines, in appropriate proportions, the cultivation of fed aquaculture species (e.g. finfish) with inorganic extractive aquaculture species (e.g. seaweeds) and organic extractive aquaculture species (e.g. shellfish/other invertebrates/herbivorous fish) to create a balanced ecosystem management approach to aquaculture for environmental sustainability (nutrient biomitigation and other ecosystem services), economic stability (product diversification, risk reduction and job creation in coastal communities) and societal acceptability (better management practices and improved regulatory framework).

Dr. Chopin is Past President of the Aquaculture Association of Canada, the Phycological Society of America



Thierry Chopin with dried samples of sugar kelp (*Saccharina latissima*)

Photo: Amélie Gosselin

and the International Seaweed Association. He is an advisor to the International Foundation for Science, in Stockholm, and a member of the Editorial Boards of the journals *Aquaculture International*, *Perspectives in Phycology*, *European Journal of Phycology*, *Journal of Applied Phycology* and *Aquatic Living Resources*. Dr. Chopin is also Honorary Consul of France and was awarded the distinctions of Chevalier in the Ordre National du Mérite and in the Ordre des Palmes Académiques.

How did you get started in integrated aquaculture?

My specialties are the physiology and biochemistry of seaweeds, which are the large marine algae. There are approximately 10,500 species of seaweeds, distributed among the red, brown and green algae. In Brittany, France, my doctoral dissertation was on the impact of phosphorus and nitrogen in seawater on the production in red algae of carrageenans, which are sugars used in the food, pharmaceutical and many other industries. I came to New Brunswick in 1989 and continued to work on seaweeds. I got progressively involved with aquaculture in the Bay of Fundy. Salmon aquaculture was in full development and fish excrete large quantities of inorganic dissolved nitrogen and phosphorus, which could have a significant impact on the marine habitat. Seaweeds feed off these nutrients, suggesting that integrating seaweeds with salmon aquaculture could create a bioremediation system to help balance nutrient cycles.

Dr. Shawn Robinson of Fisheries and Oceans Canada, in St. Andrews, was also interested in exploring how shellfish and other invertebrates consumed organic solid salmon farming by-products, recreating trophic cycles found natu-



Low tide along the shore of the Bay of Fundy, Canada: the brown kelps and red dulse are covering the lower intertidal zone | Photo: Thierry Chopin

rally in the environment. We learned that mussels, suspended in the water column, preferred small organic particles, while sea urchins, sea cucumbers and lobsters on the ocean floor preferred larger particles.

What do you see as the major opportunities for aquaculture?

We face major challenges feeding a human population that is not only growing but is also seeking greater dietary diversity. At the same time, we need to reduce the pressure on remaining fish stocks. Aquaculture has been growing rapidly, delivering almost half the world's seafood, but has developed a controversial reputation in some parts of the world due to high density operations, environmental degradation, algal blooms, and the increased risk of disease. IMTA can help address many of the environmental impacts of aquaculture.

In addition, IMTA can diversify and broaden the salmon aquaculture industry away from a monoculture model, improving business cases, increasing resilience and improving the societal acceptability of this industry. Farmed shellfish already has an established market in the western world. Seaweeds, mostly cultivated and used in Asia for human consumption, can be used in many applications from feed for sea urchin, abalone and fish farming to a source of high-value products in the pigment, cosmetic and nutraceutical industries. Seaweeds can also have an impact on climate change by sequestering carbon dioxide and decreasing coastal acidification. Shellfish hatcheries are noticing increased mortality in larvae which cannot properly calcify their shells. It would be interesting to combine

seaweed and shellfish aquaculture operations where seawater would go through seaweed tanks first to reduce acidity, before being piped into the mussel tanks where it would help larvae calcify properly. The IMTA multi-crop diversification approach (fish, seaweeds and invertebrates) could be an economic risk mitigation and management option to address pending climate change and coastal acidification impacts. To give seaweeds and IMTA their full value, extractive species must be valued for not only their biomass and food trading values, but also for the ecosystem services they provide (circular economy approach). The value of these ecosystem services should be recognized, accounted for and used as financial and regulatory incentive tools (for example, the development of a nutrient trading credit system).

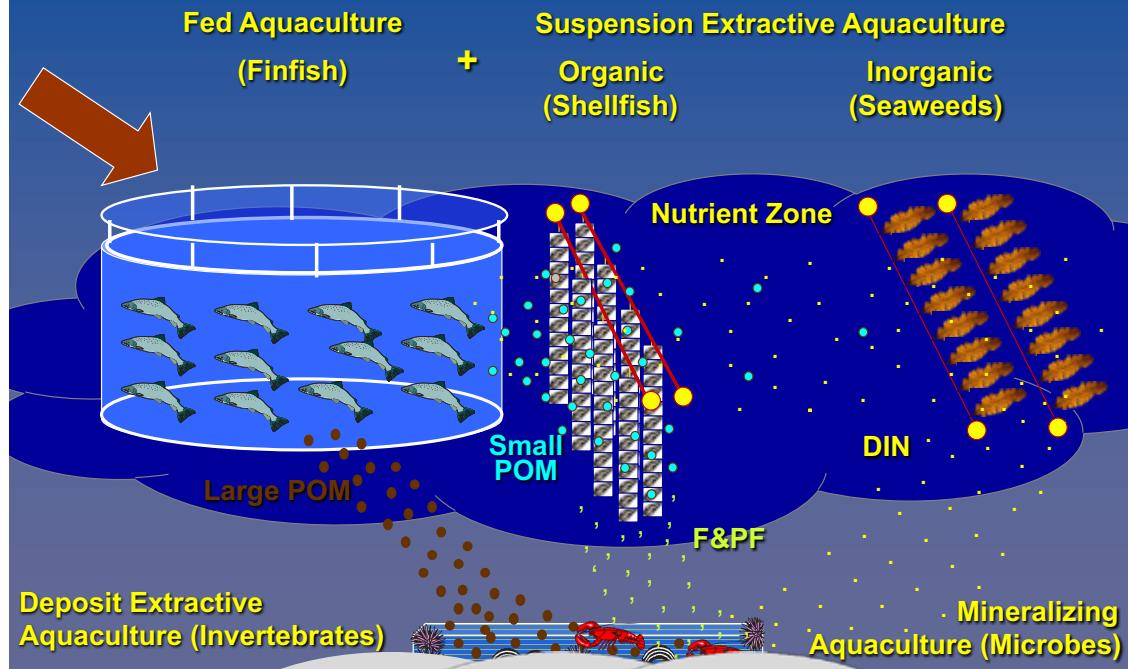
IMTA could also be a model of benign aquaculture practices compatible with activities in Marine Protected Areas, where local human populations could find sustainable employment, instead of being uprooted to allow development of reserves for well-off tourists. Aquaculture eco-tourism would go a long way toward helping the aquaculture industry gain societal trust.

IMTA systems could also be associated with offshore wind farms for a combined, reduced footprint.

What are the major challenges facing IMTA?

Aquaculture tends to be highly specialized. Western marine biologists tend to focus on animals - few are familiar with seaweeds and their benefits. Implementing IMTA requires collaboration across a wide range of disciplines and in-

Integrated Multi-Trophic Aquaculture (IMTA)



IMTA concept: Conceptual diagram of an integrated multi-trophic aquaculture (IMTA) operation including the combination of fed aquaculture (e.g. finfish) with suspension organic extractive aquaculture (e.g. shellfish), taking advantage of the enrichment in small particulate organic matter (POM), inorganic extractive aquaculture (e.g. seaweeds), taking advantage of the enrichment in dissolved inorganic nutrients (DIN), and deposit organic extractive aquaculture (e.g. echinoids, holothuroids, decapodes and polychaetes), taking advantage of the enrichment in large particulate organic matter (POM) and faeces and pseudo-faeces (F&PF) from suspension-feeding organisms. The bioturbation and microbial mineralization on the bottom regenerates more DIN, which becomes available to the seaweeds.

Illustration: Thierry Chopin

dustries, but inter-disciplinary collaboration can be inhibited due to differences in language and experimental methods.

Funding inter-disciplinary research can be challenging. The Natural Sciences and Engineering Research Council (NSERC) does not generally support social scientists, while the Social Sciences and Humanities Research Council (SSHRC) does not support natural scientists. Although I have found that novel solutions frequently appear at the interface between disciplines, universities are also often internally structured into silos. Early career natural scientists may also be concerned that publishing papers with economists and social scientist could affect their CV when the time comes for a promotion.

Regulations governing aquaculture are often designed with a single species/group of species in mind, just like fishery regulations, and can inhibit a more holistic approach by not considering species interactions and an ecosystem-based management approach. For example, we were told early on that our IMTA project would be a nice academic project, but would not be allowed to go commercial. What, then, would be the incentives for the aquaculture industry to get involved with IMTA, or change its practices, if the products could not go to market? We were inheriting an unrelated regulation that would not allow growing any species closer than 125 meters from a wharf or a sewage effluent. Consequently, we would not be able to grow one species closer than 125 meters from another. It took us eight years of accumulating data to reverse 12 lines banning polyculture in the Canadian Shellfish Sanitation Program and now have two

pages allowing Integrated Multi-Trophic Aquaculture, if the proper monitoring program is in place.

We need other regulatory changes if we want to implement IMTA at the appropriate scale. We need enabling and flexible regulations for the development and implementation of innovative aquaculture practices, using an integrated coastal area management (ICAM) strategy.

How have you overcome these challenges?

In 2009, we founded a structure, the NSERC Strategic Network program, that, while mostly supporting natural science research, allows around 20% joint efforts with economic and social scientists. We were successful with our funding request that supported the Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN) from 2010 to early 2017 - 28 scientists in eight universities, six federal laboratories, one provincial laboratory and four industry partners on the east and west coasts.

Based on my experience with the Atlantic Innovation Fund from the Atlantic Canada Opportunities Agency from 2006 to 2012, and with NSERC from 2010 to 2017, very small players struggle to implement the necessary systems, while large players, who need IMTA the most, prefer to focus on their core business, typically salmon. Small and medium-sized enterprises (SMEs) seem to be the most interested – they are flexible and innovative and want to differentiate themselves, particularly as their industries are affected by consolidation.

We were also fortunate because we attracted innovative students. We wanted to cultivate sea

cucumbers that would be among the species recycling the large organic particles falling to the sea floor. However, sea cucumbers are famous for being “Houdinis of the sea” and can easily escape from cages. If you make the cages with a very fine mesh material, they do not receive the food they are supposed to process. A student from British Columbia thought literally outside the box and designed one with an open top with lids that flapped from the weight of the sea cucumbers, discouraging them from getting out.

Training highly qualified personnel (HQP: undergraduate, Master and PhD students, post-doctoral fellows, technicians and research scientists) was a very high priority for CIMTAN. The initial and ambitious target of training 114 HQP over the entire life of the Network was exceeded, as 137 HQP were trained. Our CIMTAN HQP have either pursued higher academic degrees or found jobs in a variety of sectors (academic institutions; federal/provincial departments and laboratories; aquaculture and feed companies; engineering, consulting and financial companies; renewable and power networks; non-governmental organizations, museums and municipal authorities), where they are appreciated for their inter-disciplinary training and approaches to problem solving.

Our HQP are also fantastic ambassadors of IMTA at their workplaces and will gradually change some attitudes, especially in regulating agencies. For IMTA to be implemented and scaled up, we still need to address some serious regulatory hurdles. We need a major rethinking regarding the functioning of an “aquaculture farm”. It does not work only within the limits of a few buoys on the water, but should be managed using an in-

tegrated coastal area management (ICAM) strategy, according to the movement of the different elements considered:

- large particulate organic nutrients should be managed within the site;
- small particulate organic nutrients should be managed within the site or around its immediate vicinity;
- dissolved inorganic nutrients should be managed at the ICAM scale (as is already accepted for managing disease vectors and parasites).

This means that different strategies (in space and time) will be needed to recover these different nutrients, and that entire bays/coastal areas/regions should be the units of IMTA management. It is, indeed, opening the Pandora’s box of regulations. Harmonization and coordination between provincial and federal regulations and between departments and agencies will also be needed.

How has your work developed?

In September 1995, I gave a presentation entitled “Mixed, integrated, poly-, or multi-level aquaculture - whatever you call it, it is time to put seaweeds around your cages!” at a conference. I could see several faces in the room saying “What is this guy talking about?”

From 1995 to 2000 was the period of “preaching in the desert”. We started to be taken seriously when we joined AquaNet, the Network of Centres of Excellence for Aquaculture in 2001. In March 2004, at a workshop in Saint John, New Brunswick, we gave a name to what we were doing. I came up with “Integrated Aquaculture”



A line of sugar kelp (*Saccharina latissima*) at an IMTA site in the Bay of Fundy, New Brunswick, Canada | Photo: Thierry Chopin





The principles of marine IMTA (MIMTA) can also be applied to land-based, freshwater systems (FIMTA), also called aquaponics. Yarrow, mint, lettuce, chamomile and nasturtium after six weeks of growth at 13-15°C in effluent collected at a commercial salmon hatchery. | Photo: Thierry Chopin

and Jack Taylor (Fisheries and Oceans Canada) with "Multi-Trophic Aquaculture". By combining the two, "Integrated Multi-Trophic Aquaculture", or "IMTA", was born and in 12 years more than 1,300 publications referring to IMTA have been published worldwide.

Over the years, we have been progressing along the continuum from R (Research) to D (Development) to c (small scale commercialization), hoping to soon enter C (larger scale commercialization). Here too, we need to think outside the box. We need to change our attitudes and business models to evolve from the linear approach (one species – one process – one product), used far too often with fishery and aquaculture products, towards the Integrated Sequential Biorefinery (ISBR) approach (one species – several processes – several products). This fits very well with the circular economy approach, in which by-products are no longer considered wastes but co-products, which can be valued in other applications. Seaweeds can be used in the production, on one hand, of a wide range of bio-based, high-valued products (food and feed products/ingredients/supplements, biopolymers, fine and bulk chemicals, agrochemicals, biostimulants, pharmaceuticals, cosmeceuticals, nutraceuticals, functional foods, biooils, botanicals, pigments) and, on the other hand, of lower-valued commodity energy carrying molecules for heat and power (biofuels, biodiesels, biogases, bioalcohols) and biomaterials.

I started my own company, Chopin Coastal Health Solutions Inc., in July 2016 to conduct consulting on IMTA in Canada and abroad and to develop some products, especially seaweed-based ones.

What insights have you developed?

IMTA was never conceived with the idea of being viewed only as the cultivation of salmon, kelps, blue mussels and other invertebrates, in temperate waters, and only within the limits of existing finfish aquaculture sites. That's how we started in Canada, to have access to conducting experiments at sea rather than extrapolating from small tank experiments in laboratory conditions, which is always dangerous. We know that IMTA systems will continue to evolve.

Because the IMTA concept can be applied worldwide to open-water and land-based systems, marine and freshwater environments, and temperate and tropical climates, there is no ultimate IMTA system to feed the world. Different climatic, environmental, biological, physical, chemical, economic, historical, societal, political and governance conditions will lead to different choices in the design of the best suited IMTA systems.

It is not enough to consider multiple species (like in polyculture); they have to be at multiple trophic levels based on their complementary functions in the ecosystem. They should also have an economic value.

Integration should be understood as cultivation in proximity, not considering absolute distances but, instead, connectivity in terms of ecosystem functionalities at the ICAM scale.

Regulators should be engaged early on as trends start to appear, rather than developing regulations that are not well thought-out at the last minute, as this will delay commercialization.

How has IMTA changed you?

It is interesting to note the evolution, over three decades, in the type of conferences I have been attending: from seaweed-oriented to aquaculture-oriented scientific conferences, and most recently, to conferences attended by decision-makers and influencers such as “Bacon and Eggheads Breakfast” on Parliament Hill in Ottawa, Capitol Hill Ocean Week in Washington, and the Monaco Blue Initiative (<http://www.monacoblueinitiative.org/>) under the auspices of H.S.H. Prince Albert II.

For me, it is time to make the “Blue Revolution” mature into the greener “Turquoise Revolution” where production activities are no longer in conflict with the environment but protect it. IMTA definitely has its place in the circular economy, in Canada and beyond.

What key messages do you have for the practice of bio-inspired design?

Take advantage of nature’s trophic relationships and reinforce the use of its ecosystem services within a circular economy approach.

Favour the inter-disciplinary approach because most problems can be solved at the interfaces of the various disciplines.

Demonstrate value at multiple levels (environmental sustainability, economic stability and societal acceptability) and for the long term.

Bring regulators to the table early on to develop open relationships that can work together towards effective regulations that enable new practices, new industries and establish new markets.

Nurture projects that combine pure and applied research to solve real-world problems and deliver meaningful results.

Explore trends to identify opportunities for diversification in a sector. Aquaculture production in Atlantic Canada has, historically, focused on finfish (mostly salmon and trout), which has been decreasing in recent years. Therefore, if we still want to talk about “aquaculture development”, the “development” will need to involve other species.

Be patient, determined and persistent. Science and society need time to think and evolve. IMTA will not happen overnight, especially in the western world, which presently prefers monocultures, linear processes, and short term profits.

Which work/image have you seen recently that really excited you?

A picture of a very simple and efficient freshwater IMTA/aquaponics system in a village in northern Brazil. These people are very ingenious with almost nothing; they really know how to recycle. I hope to spend part of my sabbatical leave next year with Dr. Janaina Mitsue Kimpara from the Brazilian Agricultural Research Corporation (EMBRAPA), who is supporting this project and others involving seaweeds and marine IMTA.

What is your favorite inter-disciplinary work of all time?

I was involved with a project in Senegal several years ago, where every winter large amounts of the red seaweed, *Hypnea musciformis*, washed ashore and decayed, which is not good for tour-

ism. To address the issue, we needed to find out where the seaweeds were coming from. I heard some strange hypotheses from academics at the University of Dakar suggesting that they originated from the Cape Verde Islands, which would mean that the seaweeds (still in very good shape) must have drifted some 700 km. Travelling along the Petite Côte, we stopped in a village with massive red seaweed biomass stranded on the village beach. Through a translator, I talked to an old fisherman who claimed that the red seaweeds were coming from “where the rocks change colours.” The academics had warned me that talking to these villagers would be a total waste of time. I suggested we arrange to have a fisherman take us to these rocks changing colours with a pirogue. After a few miles of shallow sandy bottom, the slope of the continental shelf abruptly changes and there are large rocky formations covered with seaweeds, which prefer to grow on stable substrates rather than unstable sandy formations.

For me, it remains my best example of gaining an understanding of a “mystery” by an interdisciplinary approach and the rewards of some-

times leaving the ivory tower and accepting that traditional knowledge can also be valuable. Having worked on another red seaweed, Irish moss (*Chondrus crispus*), on Prince Edward Island, I had experienced ocean floors covered with purplish seaweeds in the winter that turn pale pinkish in the summer, due to the denaturation of the red pigments (phycobilins) by solar radiations in shallow waters.

What is the last book you enjoyed?

“*La fin des haricots & autres mystères des expressions françaises*” by Colette Guillemard. This book explains the origin, and the evolution through the centuries, of the meaning of 134 common expressions of the French language. Very interesting, intriguing, funny, and highly revealing of the period when they were created.

Whom do you admire? Why...

I wanted a profession close to the sea because I loved sailing. So, why not become a marine biologist? But what type of marine biology? I was interested in genetics but that field was just expanding into marine biology and it was difficult to find a supervisor. I took a phycology course (phycology is the study of algae) by Dr. Jean-Yves Floc'h at the University of Western Brittany. He was interesting, passionate, captivating and enjoyable and that's how it started.

When I moved to North America, I completed a postdoctoral fellowship at Harbor Branch Oceanographic Institution in Vero Beach, Florida. My supervisor there was Dr. Dennis Hanisak, who became my second mentor. Dennis Hanisak not



Irish moss (*Chondrus crispus*) with bleached parts due to the denaturation of the red pigments (phycobilins) by solar radiation.

Photo: Thierry Chopin



On the right, Steven Backman (owner of Magellan Aqua Farms Inc.) and, on the left, Thierry Chopin holding a spool with a twine covered with microscopic kelps being unwound around a rope to be put at sea. In six months, the rope will be covered with 2-3 m long kelps. | Photo: Caroline Longtin



only cultivates seaweeds; he inoculated deeper in me the bug to become active in associations, which I had started to develop in France with my involvement in the renowned sailing centre, the Centre Nautique des Glénans. That's how I became involved with the Phycological Society of America, the International Phycological Society, the Aquaculture Association of Canada and the International Seaweed Association, which has been a wonderful journey of work, responsibilities and fun!

My father was also a great source of inspiration. A dedicated pediatrician with a great humanist approach to education and life, a type of individual that will, unfortunately, soon be on the endangered species list.

What's your favorite motto or quotation?

My wife made a wonderful sign for me this last Christmas:

Eat fish, live longer

Eat oysters, love longer

Eat seaweeds, live and love even longer

I have another favorite, from the French writer Jules Verne: "Tout ce qui est impossible reste à accomplir" or "All that is impossible remains to be accomplished".

More than ever, the good old adages "what is waste for some is gold for others" and "don't put all your eggs in the same salmon basket" apply to IMTA and crop diversification.

What is your idea of perfect happiness?

A world where common sense would be common and an 11th beatitude would be added:

"Blessed are those who can laugh at themselves, for they will not stop laughing."

If not a scientist/designer/educator, who/what would you be?

A scientific writer/translator. I have always thought that my two most important publications would be a children's book and a coffee table book on seaweeds, adapted to the respective audience, to show how beautiful these organisms can be, why they are so important in many respects, why we should not continue to ignore them, and what they can do for us and the planet. But, I need to find the time to write these books... maybe a retirement project! ×



Eat seaweeds: Maybe the new motto of the company created by Thierry Chopin, Chopin Coastal Health Solutions Inc.

Photo: Thierry Chopin

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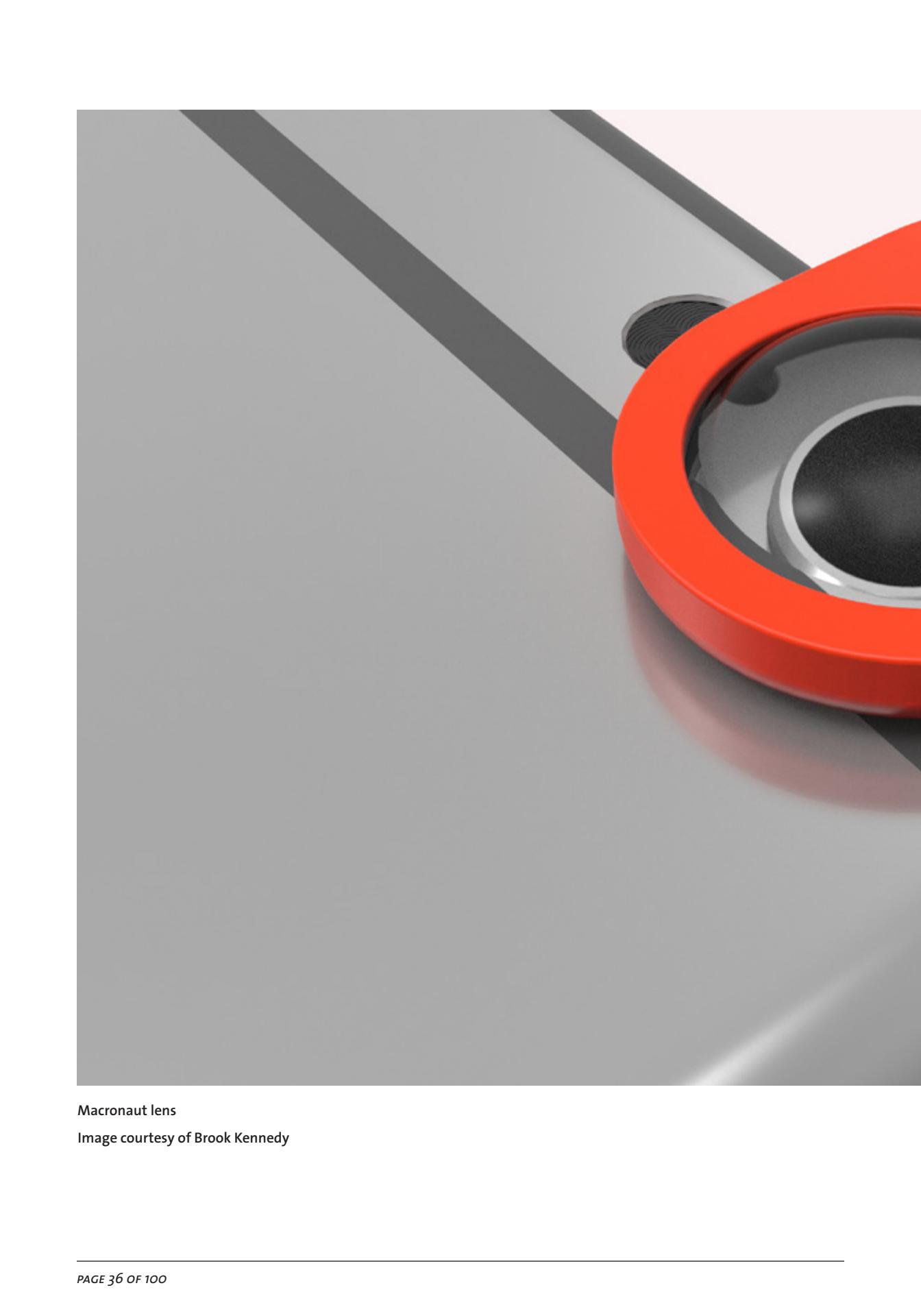
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Macronaut lens

Image courtesy of Brook Kennedy



Product Design

Macronaut

Brook Kennedy

Brook S. Kennedy (<https://www.brookkennedy.com/>) is an industrial designer with the soul of an inventor and a desire to make the world a better place through design. He received a BA in Art from Reed College in Portland, Oregon and an MFA at Stanford University from the Joint Program in Design where he was a teaching assistant for David Kelley, one of the thought leaders behind Design Thinking and cofounder of IDEO and the Stanford D. School.

With more than a decade and a half of award-winning product design and innovation experience serving some of the world's most respected brands (including seven years as Associate Director of Industrial Design at Smart Design in New York), his current focus is on finding new, better pathways for design in the name of health, sustainability, and quality of life. As an Associate Professor in the Industrial Design program at Virginia Tech, he pursues research collaborations with scientists and engineers, teaches his students to use Human-Centered Design to help solve real problems and create lasting value, and consults

for companies and startups internationally. He loves the serene beauty of the Blue Ridge Mountains and enjoys being a pedestrian in a small college town.

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

Most everyone familiar with the field of bio-inspired design (BID) is aware of the story of VELCRO®, a now widely used industrial material invented by Swiss electrical engineer Georges de Mestral in the 1940s-50s. VELCRO® has found its way into industrial products across categories: shoes, luggage, medical devices, space suits, and many others. It is said that de Mestral was hunting with his dog in rural Switzerland during which time his dog's fur and his trousers became covered with burdock seed burrs, an outcome of bushwhacking through backcountry wilderness. Upon closer inspection, de Mestral realized there was something unique about the seeds that were otherwise a nuisance. They would attach easily to fur, yet without much resistance they would detach as well. Later, after examining the seeds with a magnifying glass, de Mestral discovered the important "hook" geometry that entangles itself in furry "loops" (or sweaters and other clothing) and enables the mechanical phenomenon that became widely known as "hook and loop," later commercialized as VELCRO®.

This example still captivates audiences new to the field while probably garnering some level of eye rolling to those more familiar with bio-inspired design. This is driven, in part, by the example's persistence as one of the few iconic examples of successful BID. While publishing of potential bio-inspired science and technologies has been on the rise in the past decade, many in



Brook Kennedy

the BID community are dismayed that there are not more commercial success stories with such measurable impact as VELCRO®.

The main process or technique that seems to have enabled de Mestral to discover the “hook” was close examination of a mundane natural artefact, probably at a slightly increased magnification to discover the underlying geometry. Is this process repeatable? Are there other phenomena/inventions that could be discovered this way?

What if we could replicate the essence of de Mestral’s invention process more consistently? Not that invention is a predictable or linear process, but how could we at least increase the chances of discovering something similarly useful? Georges de Mestral’s discovery was right under his nose but needed a little bit of curiosity and magnification to see, analyze and re-conceptualize for intentional applications. How might keenly observed phenomenon lead to useful inventions and design opportunities right underneath our noses?

How did you get started?

I have been working on a university Industrial Design research project that has sought to create a process through which to search for design opportunities, at a slightly magnified scale, as de Mestral did. I have been testing this process over the last four years through a series of interrelated design seminars and workshops, and simple observation tasks conducted in the backyard. Central to these tests were magnifying lenses as de Mestral surely used. I am continuing to pilot

and improve the de Mestral project in university environments to see what additional design possibilities may result.

What kind of techniques do you use for your work?

I use the ‘Macronaut,’ a custom macro lens I designed that complements smartphone photography and allows me to look more carefully at my surroundings. The act of looking at the most mundane local natural phenomenon in a new way gave me a new appreciation for the outdoors and got me to pay closer attention to the inner workings and behaviors of the natural world around me.

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

The quality and novelty of the Macronaut photos themselves. Many of the photos have been exhibited in local photography exhibitions or posted on my Instagram site (<https://www.instagram.com/biodesign14/>). Also, the numerous hiking trails in the Appalachian Mountains.

How has the Macronaut developed?

The Macronaut has evolved into a model that fits most smartphones and some tablets, with or without cases. The compact size proved superior to other models available for purchase that were too big to fit into the pocket. Colored frames were developed to keep the small lenses from getting lost if dropped outside: orange seemed to contrast best with natural color tones



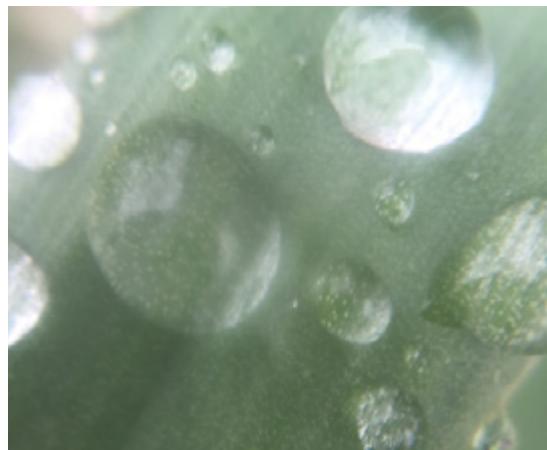
Bicycle seats after a rain shower; Macronaut photo of water on a leaf

on nature trails. By year three the design incorporated 15x magnification which produced the best results. 10x was too little to produce surprising details and 25x provided so much magnification that sometimes you could not understand what you were seeing.

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

Folium

Wet bicycle seats are a common problem for cyclists. Even in cases where the seat fabric doesn't



Macronaut photo of hydrophobic leaf surface; illustration of Folium bike seat with hydrophobic seating fabric. Close-up detail of fabric performance.

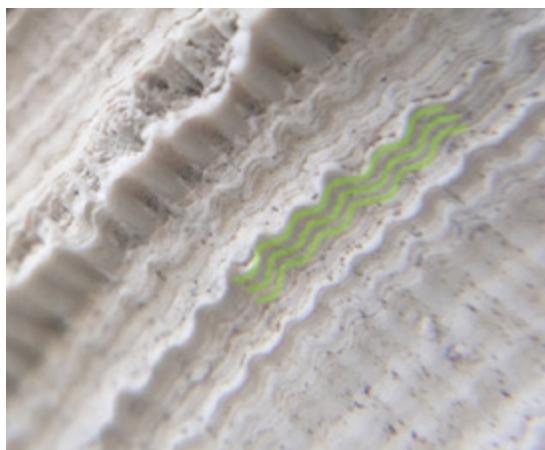
absorb water, the water droplets won't roll off. Current solutions include custom seat covers or more commonly, plastic grocery bags.

In contrast, many images of leaves taken in the spring of 2013 showed how they repelled water droplets, leading to the exploration of the microstructure of leaf surfaces with the help of a botanist and microfluidics engineer. The result was "Folium", a bicycle seat that would be hydrophobic through a micro-scale material texture. In conversations with FLEXcon (<https://www.flexcon.com/>, makers of roll to roll thin films with micro textures such as the antibacterial Sharklet™ material), the team determined that a thin film with hydrophobic micro structures could be applied and would be satisfactorily durable as current bike seat surfaces. The final design proposed a tested, comfortable ergonomic form matched with a FLEXcon produced film. The seat surface would also have leaf-like channels to lead water droplets off the seat as observed using the Macronaut.

Corlayer3d

The Macronaut can not only explore natural structures but also provide insights into natural processes. Mollusks create their hard ceramic shell material mostly of calcium carbonate and protein with relatively low energy expenditure compared with industrial and craft ceramics. Many shells have corrugations that led me to explore whether these corrugations could be reproduced using a 3D printer.

Most 3D printers control the nozzle in the X- and Y-axis, lowering the table (the Z-axis) once a layer of plastic has been laid down. I hired a computer science student to write custom programming in G-Code (the language used to control the 3D printer nozzle) that allowed plastic to be deposited in all three axes simultaneously on fused deposition modeling (FDM) 3D printers such as the Mass Portal Delta Bot.



At left, a close-up photograph of corrugated layering in a clam shell. At right, a Mass Portal Delta Bot 3D printer.

Initial test showed that not only could plastic layers be applied in a corrugated manner, they potentially could be gradually corrugated from straight line deposits.

As a practical example, my team explored how Gerolsteiner glass bottles could be upcycled to use as refillable water bottles by custom 3D printed caps. We hypothesized that incorporating corrugations would strengthen the bottle cap to diminish chances that the layers would shear and break when twisted hard. Prototypes are being evaluated in a stress test lab on campus in the Mechanical Engineering department.

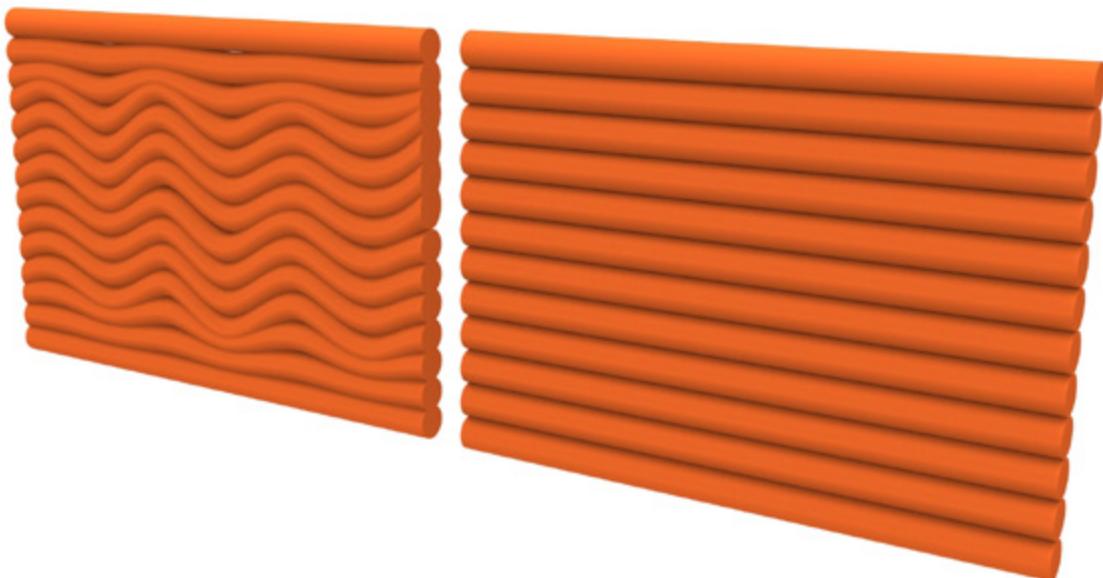
Experiments are underway to explore the different kinds of potential that manipulating layering geometry can bring in 3D printed part properties including strength, flexibility, aesthetics, and others. The Corlayer3d process that I invent-

ed along with Ed Coe is a patent pending additive manufacturing process that could be implemented in software driving roughly 60% of 3D printers. x

Additional information about these projects and contact information can be found at <https://www.brookkennedy.com/>.

Endnotes

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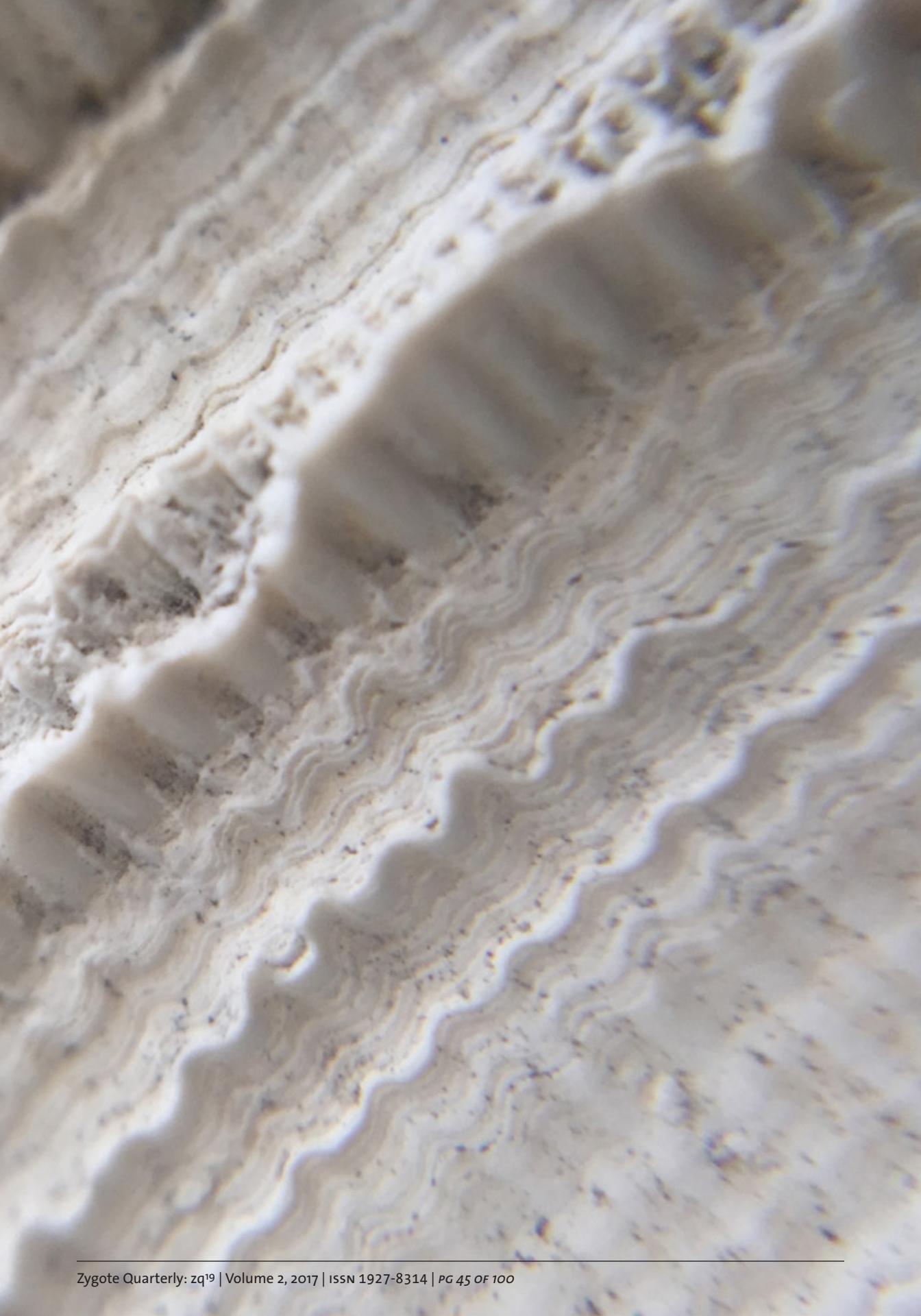
Illustrations of differences in layering approaches from a CAM slicing program. Corrugated on left, conventional straight deposits at right.



At left, potential benefits of corrugating Z-layers in an FDM 3d printed bottle cap design (for upcycling glass water bottles). At top right, corrugations would prevent twisting shear over parallel layer deposits shown at bottom right.



Magnified view of ocean clam shell construction | Brook Kennedy





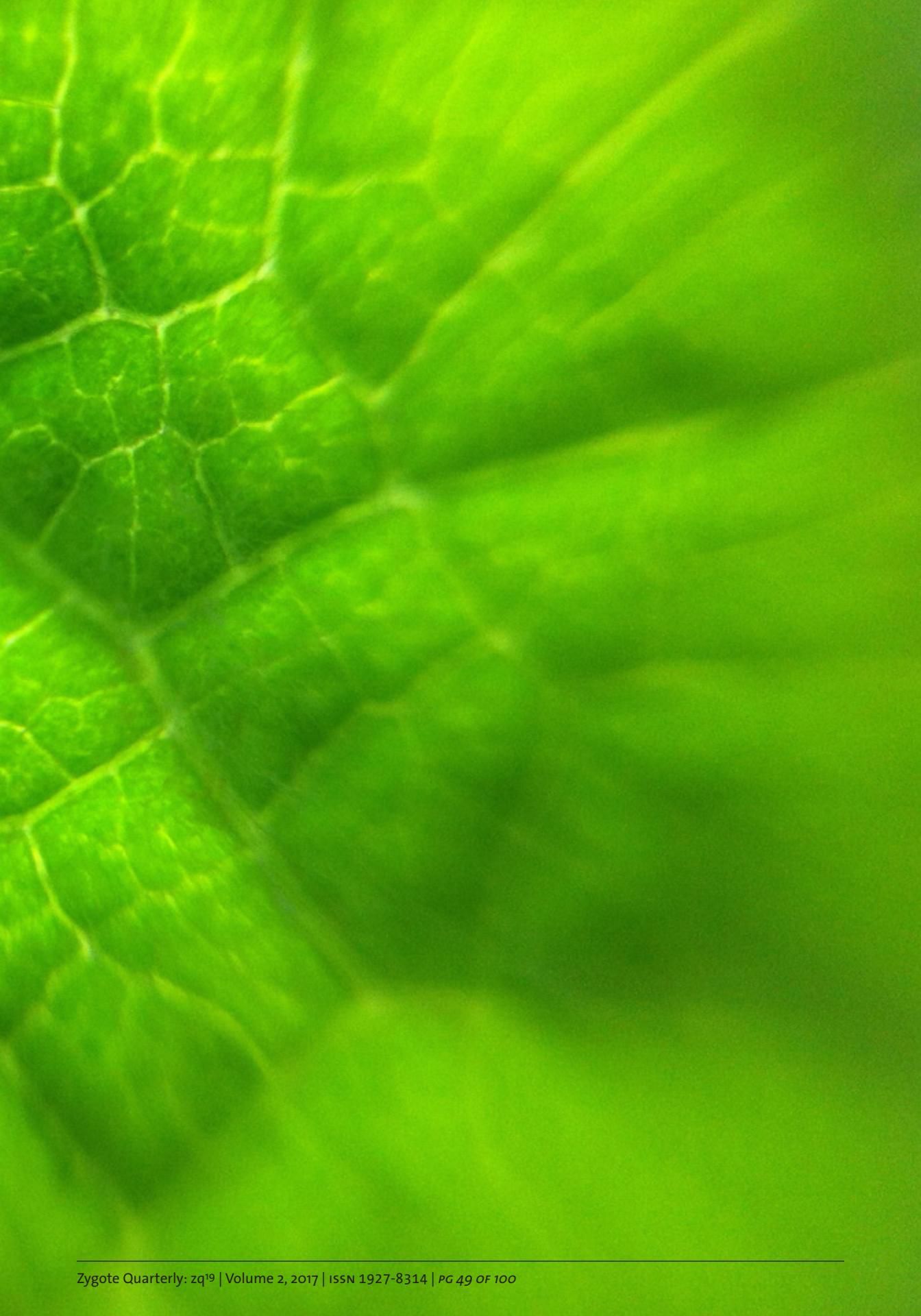
Magnified view of water droplet on leaf | Brook Kennedy

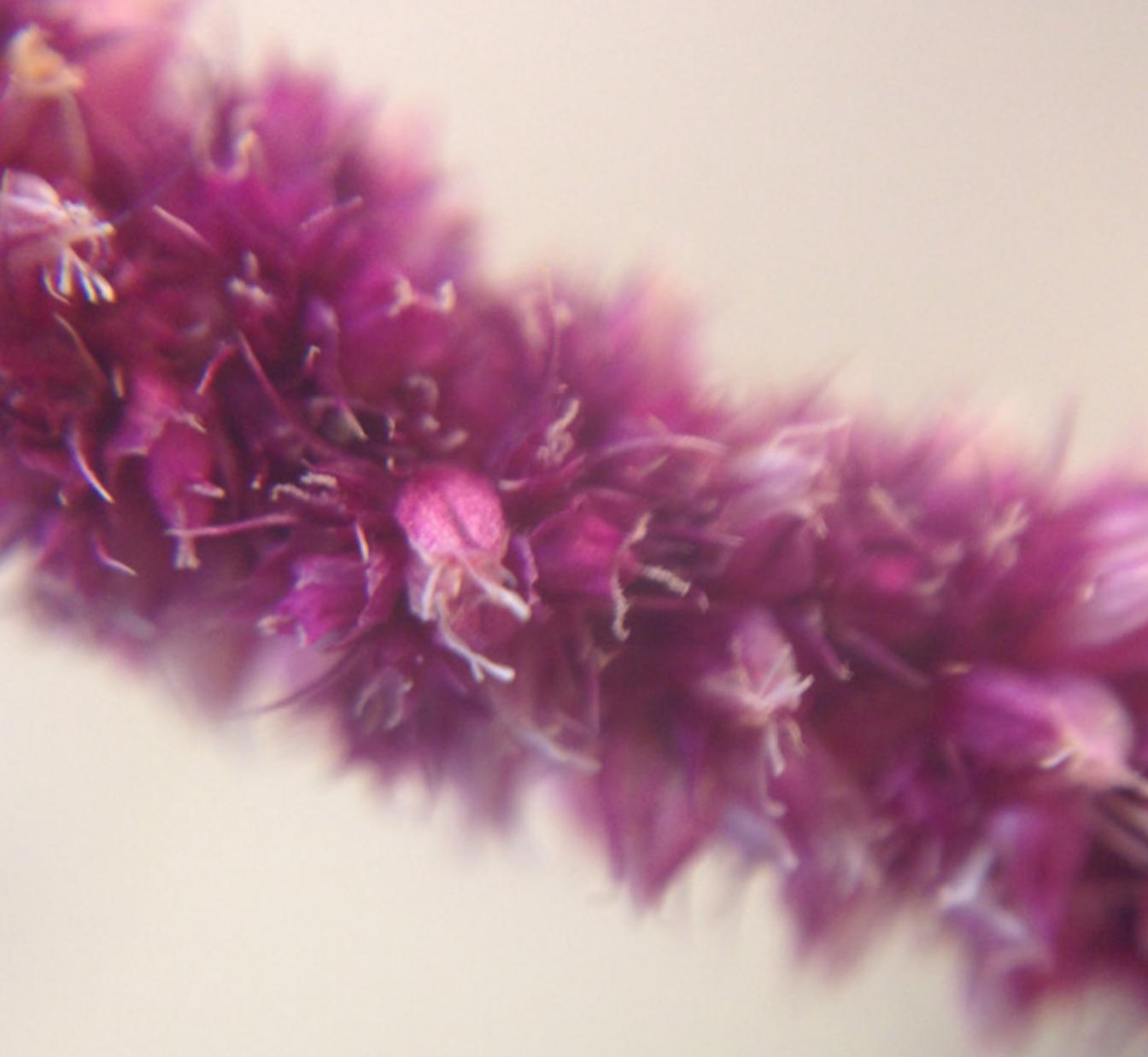


Magnified view of water droplet on Tulip Tree leaf | Brook Kennedy



Magnified view of water droplet on leaf structure | Brook Kennedy





Magnified view of reed | Brook Kennedy

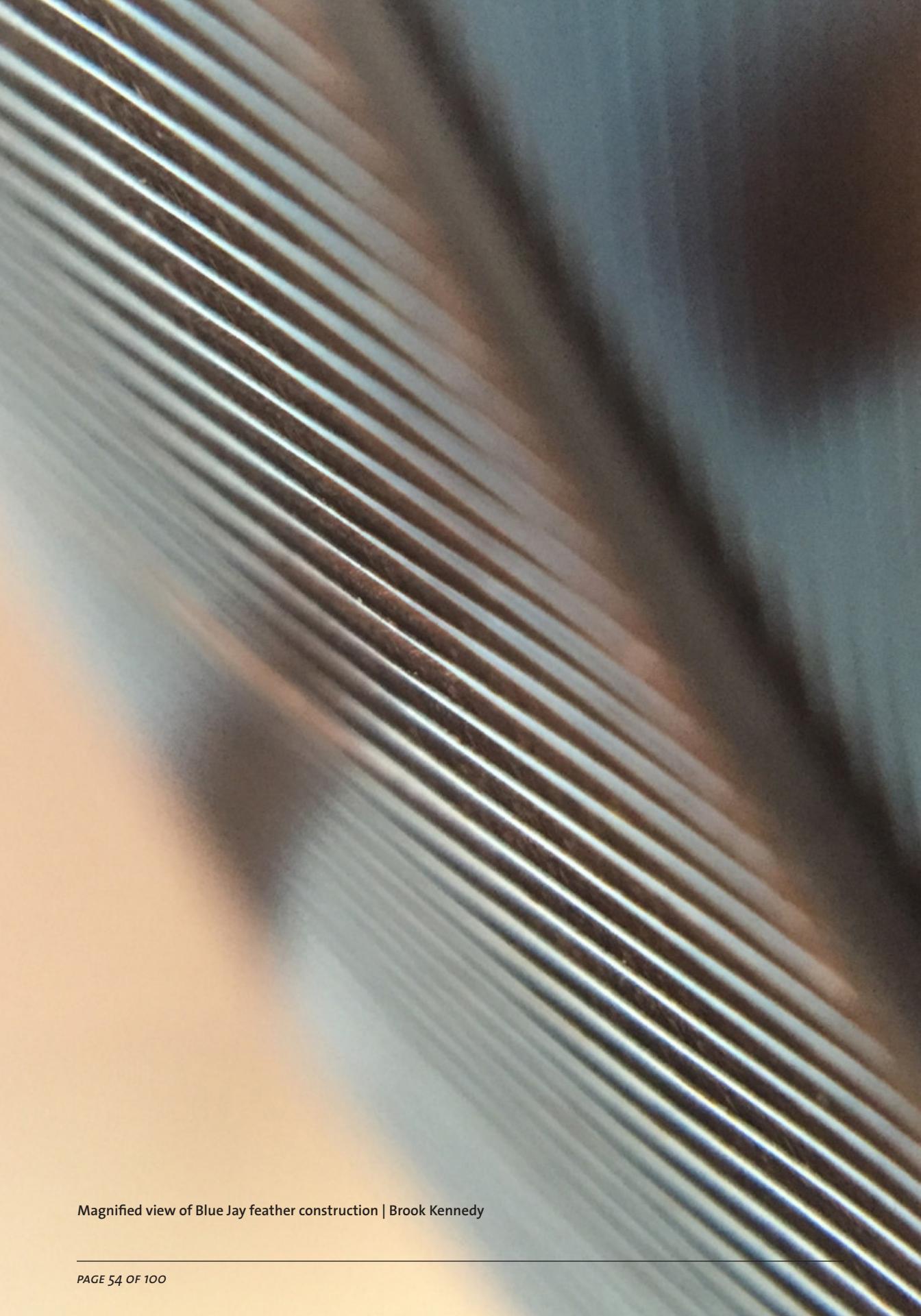


Magnified view of Trichomes | Brook Kennedy



Magnified view of water droplet on Tulip Tree leaf 2 | Brook Kennedy





Magnified view of Blue Jay feather construction | Brook Kennedy

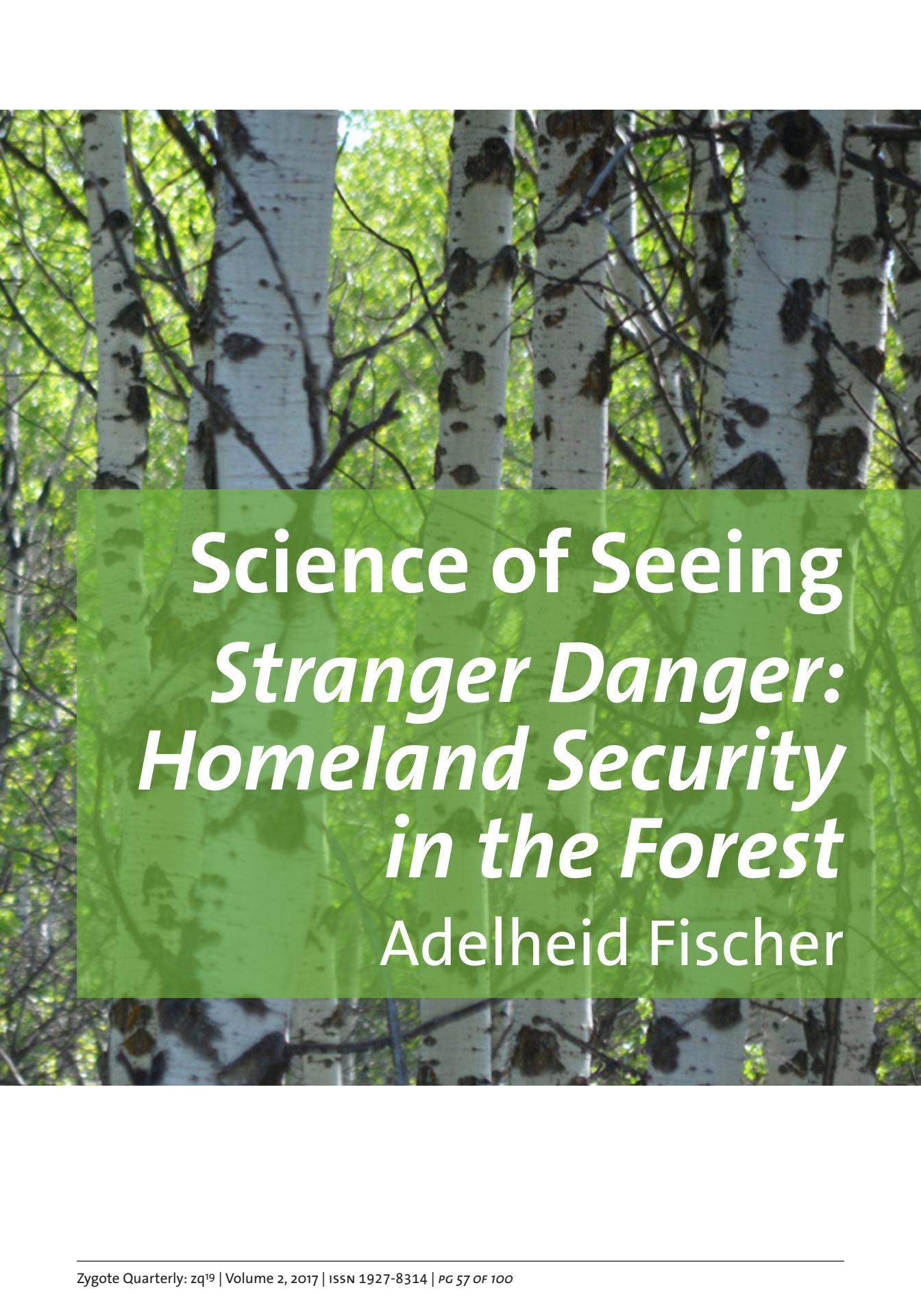


Magnified view of Dandelion pod attachment | Brook Kennedy



Aspen

Photo courtesy of Prasad Boradkar



Science of Seeing *Stranger Danger: Homeland Security in the Forest*

Adelheid Fischer

Stranger Danger: Homeland Security in the Forest

This is the second in a two-part series of essays on listening in nature.



About 10 miles south of the college town of Missoula, Montana, is a remnant of the old West that is so rare you might be tempted to dismiss it as a figment of your imagination. “Every time I walk in here, I always stop and soak it in because it’s so special,” says Erick Greene, professor of wildlife biology at the University of Montana, Missoula.

Greene is referring to a centuries-old forest with magnificent stands of cottonwood, aspen and ponderosa pine that stretch a full 100 feet toward the sky. As if this weren’t magical enough,

running through it is the Bitterroot River, one of America’s blue-ribbon trout streams. Somehow this patch was spared the fate of many riparian woodlands throughout the West in which river banks were logged to their edges and then converted to cattle pastures and alfalfa fields. Here, the Bitterroot was allowed to switchback across the land, carving oxbows that now form slack-water sloughs where harlequin-patterned wood ducks paddle. Moose, elk, mule deer, bear, mountain lions and wolves roam these forested reaches. Especially valuable to wildlife are the many snags. The dead standing trees serve as pantries, housing and nurseries for a wide range of wildlife, in particular, cavity-nesting birds. Greene and his students once sampled a random location in these snags and, within a 360-degree radius of where they stood, they counted about 60 nest cavities. “When I first came here,” Greene recalls, “I was like, Oh my goodness. Look at all these dead trees. This is great. This is what riparian forests should be like, but you don’t see many like this anymore.”

For more than a decade, the forest has served as a laboratory for Greene’s field work. But it’s much more than that. Touring the site with him, as I did on a sunny morning last May, is like taking a stroll through a village in Italy with the resident mayor. He knows everyone’s back story. At one point, Greene points to a bald-faced hornet and advises caution. In South America,



Erick Greene

Photo courtesy of Prasad Boradkar



Bald-Faced Hornet | Photo: PiccoloNamek, 2005 | Wikipedia, CC BY-SA 3.0

he says, its painful sting has earned it the nickname *ventiquattro horas*, translated as “you’ll be screaming for 24 hours.” When asked if he’s ever been stung, he answers with a nervous chuckle. Then Greene suddenly drops down on one knee to greet an old friend: *Phidippus*, a large jumping spider in the Salticidae family. “Look at that,” he exclaims, admiring its saffron-colored back and abdomen. “That’s a gorgeous spider. What a beauty.” In 1987 he and his colleagues published a paper in the journal *Science* showing that the spider’s prey—a tephritid fruit fly—had evolved an ingenious way to fend off a lethal attack. The fly’s wings bear the lookalike pattern of the spider’s legs. When stalked, the fly simply flicks its wings to imitate the territorial display of a spider rearing its legs. It’s code for “You’re trespassing. Back off or else.” Although the spider possesses a bank of eight eyes, which Greene says gives it the best eyesight in the arthropod world, it is fooled by the fly’s clever mimicry and instantly retreats. This work became a kind of scientific milestone, providing unusual documentation of an insect masquerading as its predator to avoid being eaten. Thanks to Greene’s work, such biological ruses, once thought to be rare, are causing scientists to take another look at other similar cases.



These days, however, it’s not the jousting between spiders and fruit flies that holds Greene’s attention. For more than a decade, he has been studying homeland security—from a birds-eye perspective. As in his previous work, it relies on

tuning in more closely to the ordinary world around him. And the scrutiny has produced results that are equally as groundbreaking.

Like humans, Greene points out, birds need to communicate danger, everything from the location and size of hazards to the urgency of the threats. His study site happens to be an ideal spot for eavesdropping on their intel. Although today’s riparian forests occupy only an estimated one percent of semi-arid western landscapes, he says, 80-90 percent of birds use them at some point during their life cycle, be it feeding, breeding, migrating or resting. Their occupation of these forests is especially important in winter as birds descend from the snowy mountains to the lower-elevation valleys where they concentrate in protected places like Greene’s study site. And that makes them especially attractive to a whole range of predators, from pygmy owls to sharp-shinned hawks, the fearsome F-35 fighter jets of the avian world.

So how do they evade the talons of hungry raptors? By listening in on each other’s conversation, Greene says. He notes that alarm calls and behaviors can sometimes be so subtle that even woods-wise birders and naturalists can miss them. Through sophisticated and painstaking analyses of spectrograms (graphical representations of sound), however, he has been able to interpret the communication of forest inhabitants. Study results demonstrate how nuanced and effective such forest chatter can be at protecting them from predators.

It takes a village to do this work. Greene recruits a small volunteer army of student workers who will swarm the study site on a calm winter day. The team mounts a collection of 16 synchro-

nized microphones at various heights on the trees, which he says is among the largest arrays ever erected for these kinds of behavioral experiments. When all is in place, Greene hits the record button to capture several minutes of ordinary forest sounds. Then he will issue a trigger that he says is designed to “piss the birds off.” For approximately two minutes, he will play several types of sounds: the call of a raptor, the alarm calls of different species of birds or a raucous audio recording of enraged songbirds mobbing an enemy such as a northern pygmy owl, a four-inch-tall owl with a voracious appetite for their kind. The faux distress calls will draw a wide range of curious birds—including black-capped chickadees, mountain chickadees, chestnut-backed chickadees, red-breasted nuthatches, white-breasted nuthatches, woodpeckers and Steller’s jays. Soon the live birds will join the fray with their own alarms. For the next five minutes, he will record their frenzied responses. In recent years, he has created even more ingenious triggers—robobirds. Enlisting the services of a taxidermist as well as those of a talented undergraduate physics student, Greene has created mechanized replicas of seven different species of hawks and owls. It includes a pygmy owl cyborg of feathers, motors and computer boards that even swivels its head like the real thing. The impersonators are hidden inside fake stumps that fall away at the touch of a button on a modified garage-door opener. The decoys are so convincing that they never fail to attract an angry horde of birds. Curiously, the smaller birds such as chickadees and nuthatches accost the pint-sized owl with greater vehemence than many of the larger predators, perhaps because small forest birds make up some 90 percent of the pygmy owl’s diet.

Each experiment may last only eight minutes, but it requires months of data crunching in the lab. Subsequent analysis of these field recordings—what Greene calls “decoding the info-scape”—has produced astounding insights. For starters, Greene has discovered that the language that birds use to communicate threat is highly specialized. To alert forest dwellers to the presence of a perched raptor in the neighborhood, for example, birds will use what Greene refers to as a “mobbing call.” These harsh, easily pinpointed signals utilize a wide bandwidth that can penetrate far into the forest. They are a flash mob alert for every bird within earshot. Indeed, studies have documented that such calls are capable of luring a whopping 50 different species of birds to a mobbing event. It seems counter-intuitive to draw birds to danger, Greene says, but perched raptors, since they are not flying and actively hunting, pose less threat to their smaller, far more maneuverable prey. The defensive recruits position themselves on branches around the stationary hawk or owl, forming a kind of halo of scolding, shrieking and dive-bombing birds. Their message to the raptor is clear, Greene says: “You’re busted. Time to get out of Dodge.”

By contrast, birds use a far different language to communicate the sighting of a raptor that is actively hunting in flight. Their Code Red alert, which signals the most extreme danger, has a dramatically different acoustical signature from the mobbing call. At 6 to 10 kilohertz, the call falls outside the sound-frequency interval that raptors are good at hearing. This short, thin, higher-frequency sound is known as a “seet” call. Birds instantly respond by either diving for cover or freezing in place. Most astounding,



Slough on the Bitterroot River | Photo courtesy of Prasad Boradkar



however, is his discovery that these high-alert calls are like batons passed along bird by bird in a sonic relay race. So speedy is this broadcasting system that Greene has clocked seet calls traveling through the forest at speeds of 100 mph, far exceeding the capacity of even the fastest forest flyers to keep up, including the top gun sharp-shinned hawk, which approaches velocities of 60 mph.

When birds speak, the forest listens. So important is this language, that even unrelated species have adopted some of its vocabulary. Greene notes that red squirrels and chipmunks, which also are vulnerable to attack from the skies, also give mobbing and seet calls similar to their avian neighbors, even though the anatomy of their voice structures couldn't be more different. "Squirrels understand 'bird-ease,' and birds understand 'squirrel-ease,'" he quipped in a 2015 *New York Times* article.

Given that forest animals collectively mount such a successful defense, how do raptors ever score a meal? It's a question that fills Greene with admiration for birds like hawks. "It's really hard to be a hawk," he observed in a 2016 interview on the Cornell Lab of Ornithology website. "You're hunting and flying around, trying to find your dinner, and yet there's this bow wave of information out in front of you faster than you can ever fly."

Greene cites anecdotal evidence suggesting that "a lot of the hunting strategies of raptors are designed to try to subvert this early warning system," he observes. A common ruse, according to a falconer he knows who flies a pair of Cooper's hawks for hunting, is for one of the pair to provoke a mobbing event by flying and perching in a

conspicuous way. While the attention of the agitated birds is diverted, the mate will sidle onto a nearby branch and then dive in for a kill.

Other raptors have honed stealth and surprise to a fine art, especially around backyard feeders. Greene has watched hawks take advantage of cryptic coloration by positioning themselves up against tree trunks at dawn to quietly await the early arrivals at feeders. Others have perfected an aerial artistry that leaves even veteran scientists like Greene wide-eyed and slack-jawed with wonder. "I once watched a Sharp-shin fly Mach 2, just scream down the alley behind my house, flying underneath parked cars and around garbage cans, doing everything he could to stay under the radar," he recalls. The hawk concluded these maneuvers by seamlessly vaulting an eight-foot-tall hedge to mount a surprise attack at a feeder on the other side.

Greene could be conducting any number of controlled experiments from the warmth and comfort of a university office, but these kinds of episodic encounters are central to his scientific inquiries, even if it means regularly venturing into the freezing temperatures of a Montana winter. "It's more difficult, and it's messier," he observed in the *New York Times*. "But it's glorious nature." x

Suggestions for Further Reading

Greene, Erick, Larry J. Orsak and Douglas W. Whitman. 1987. A Tephritisid Fly Mimics the Territorial Displays of its Jumping Spider Predators, *Science* 236: 310-312.

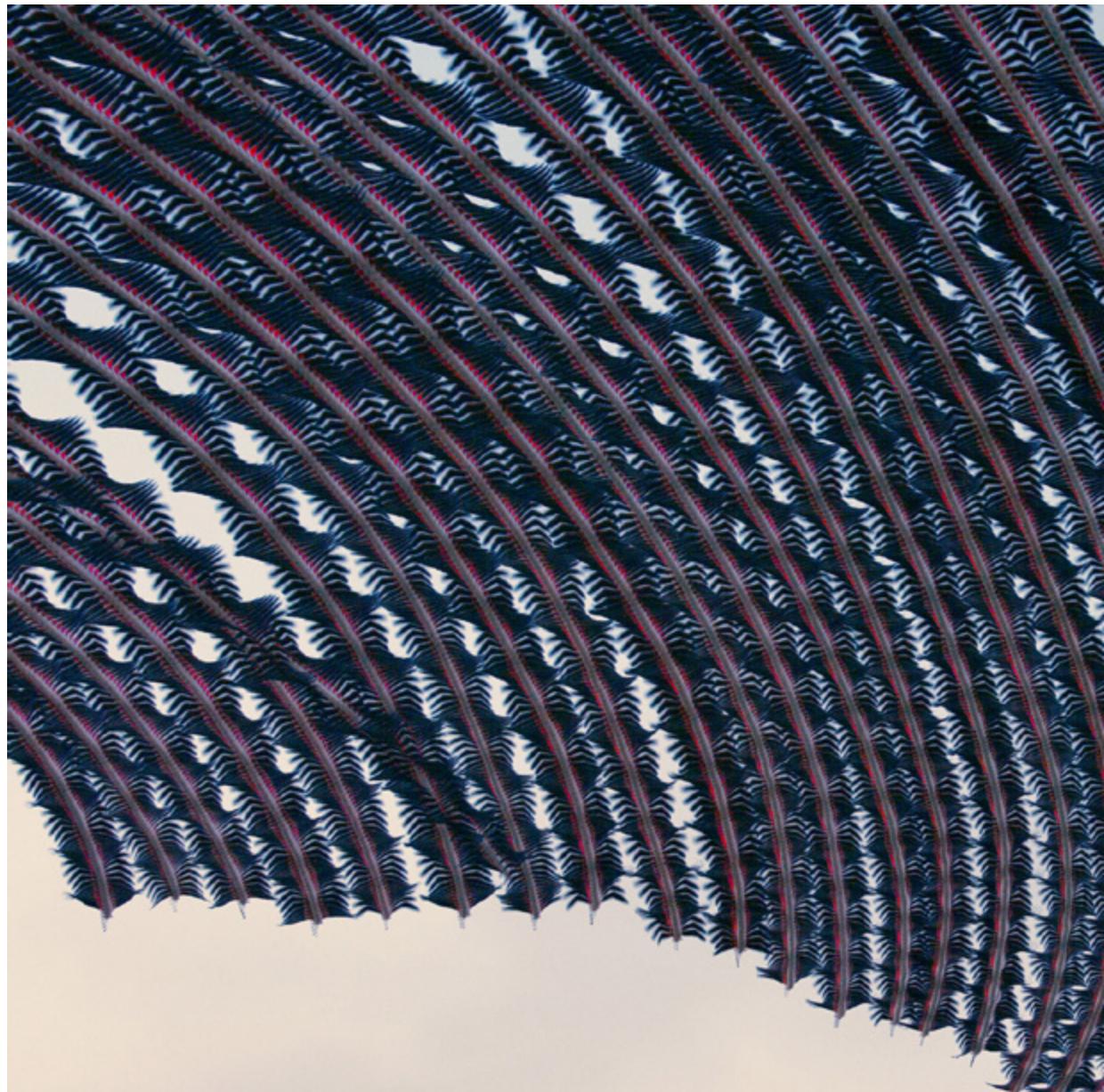
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Templeton, Christopher N. and Erick Greene. 2007. Nuthatches Eavesdrop on Variations in Heterospecific Chickadee Mobbing Alarm Calls. *Proceedings of the National Academy of Sciences* 104: 5479-5482.



Sharp-shinned Hawk - Juvenile

Photo: Len Blumin, 2016 | Flickr cc



Ornitography #18

Photo: Xavi Bou



Portfolio

Xavi Bou

Could you tell us about your background?

I earned a degree in Geology at the University of Barcelona, and at same time I took a three-year photography degree at the Grisart School. I finished my studies in 2003 and after that I dedicated myself to the world of fashion photography and advertising, starting as an assistant photographer with Jordi Farrus, Javier Vallhonrat, and Tony Kelly among others.

Since 2009, my partner Lacrin Studio and I have run a study of photographic retouch, working on campaigns for several major brands and magazines.

For the past 4 years, I have taught digital post-production in several courses at the Grisart School of Photography.

I dedicate my free time to my great passions: nature and travel - these are the subjects of my personal projects.

What kind of techniques do you use for your work?

Ornitographies arises from the concern for capturing unnoticed moments and from the interest in questioning the limits of human perception, in particular the perception of time. I achieved this by using a high-resolution camera to take dozens of images per second of the birds in front of my camera. Then I made a collage of all the hundreds of frames into one, revealing the shapes you see in front of you. Every single image is composed of anywhere between 150 and 1,000 individual pictures.

How has your art/style changed since you first started?

In the beginning I only saw this work as a photographic project. Nowadays I see it as a basis to explore many other formats like discovering the sounds produced behind the shapes of birds' flight.

I'm studying to be able to make a physical representation (sculpture) of some Ornitographies or audiovisual pieces.

How does your photography influence the way you see the world? Do you feel that you see things around you differently?

One of the things I'm thankful for in photography is the possibility of enjoying beauty that we are surrounded by in our daily life. Otherwise I wouldn't have realized how to enjoy the different sky we have every day, or the light which comes in through the window or some interesting reflection that is produced by accident in certain situations and places.

These are small things that appear day after day and it makes me happy to be aware of it.

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

I try to be inspired by nature's creativity and by artists like the great Andy Goldsworthy or Theo Jansen.

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

I keep exploring the possibilities of this project. Of course, I can't avoid my mind wandering with new ideas I have, but at the moment, I want to focus on developing even more of this work and work on the book I am hoping to have finished by the next year.

What is the last book you enjoyed?

I'm trying to get the habit of meditating every day, therefore the last book I read was *Sit like a Buddha: A pocket guide to meditation* by Lodro Rinzler

What are your favorite 3-5 websites?

- Vice (<https://news.vice.com>)
- <http://www.booooooom.com>
- <http://fotoroom.co>
- <http://www.itsnicethat.com/>

What's your favorite motto or quotation?

In Spain, we have a quotation which, translated, would read something like: "You won't ever swim in the same river twice." x



Ornitography #23

Photo: Xavi Bou





Ornitography #05 | Photo: Xavi Bou





Ornitography #01 | Photo: Xavi Bou





Ornitography #02 | Photo: Xavi Bou





Ornitography #16 | Photo: Xavi Bou





Ornitography #03 | Photo: Xavi Bou





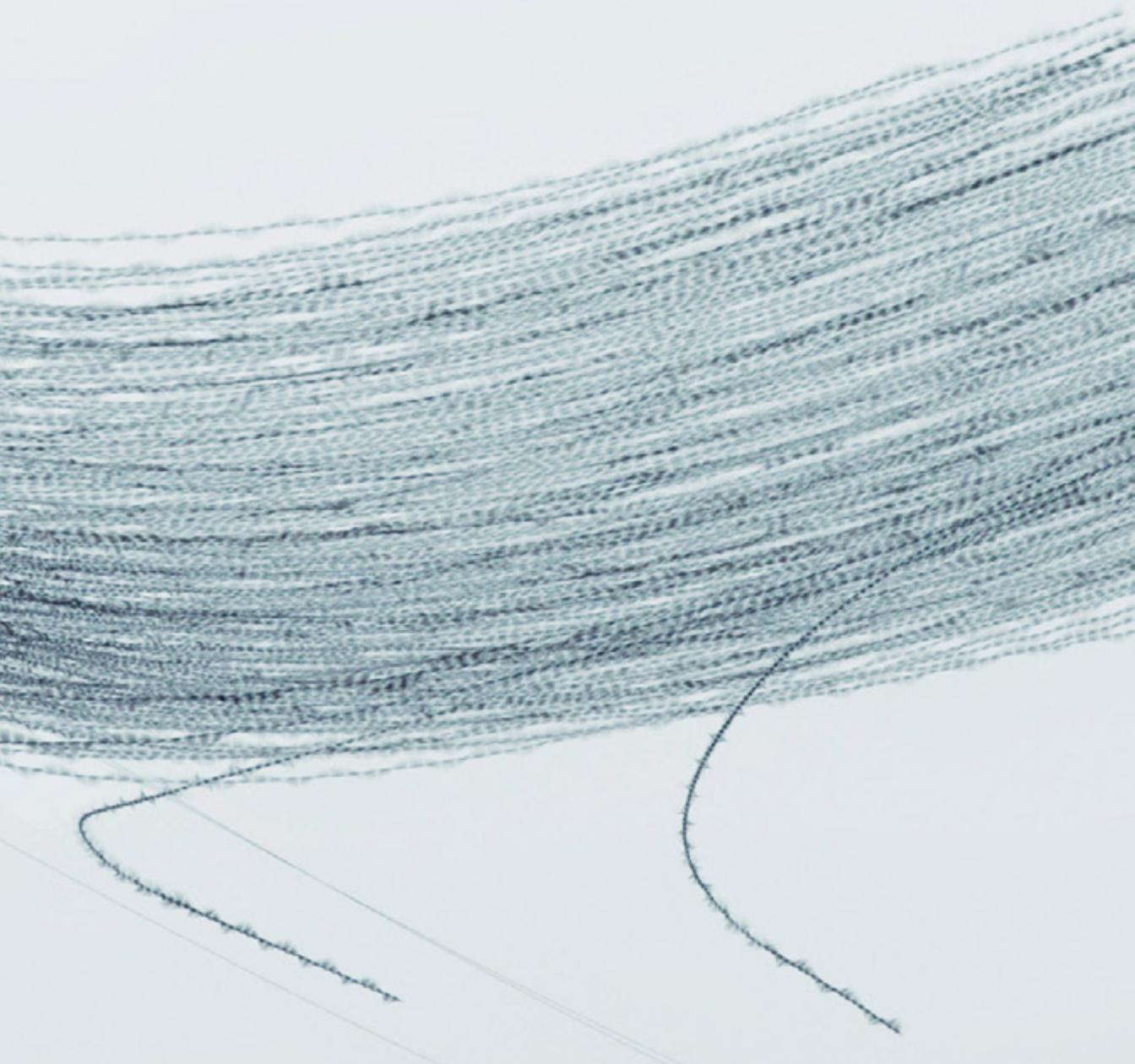
Ornitography #09 | Photo: Xavi Bou



Ornitography #04 | Photo: Xavi Bou







Ornitography #07 | Photo: Xavi Bou





Ornitography #06 | Photo: Xavi Bou



Sanderling (running)

Photo: Mdf, 2005 | Wikimedia Commons



World *Interview* Biomimicry Iberia

How did you get started?

In recent years, various individuals were engaged in parallel paths in biomimicry and related disciplines. Theresa Millard was the “glue” who connected us with each other when she moved to Spain. In 2013, we formalized with the legal name of Biomimicry Iberia and began to create collaborative relationships amongst ourselves and with our Portuguese neighbors.

What is your mission statement?

We aim to promote nature as a model, as a mentor, and as a measure for sustainable innovation and new technologies by bringing together a collaborative network of innovators, designers, biologists, engineers, architects, and educators.

Who is part of the group? How many members do you have? Are there different types of membership? Are you structured via a specific organizational model?

We are an international multi-disciplinary team using biomimicry as a creative tool from different perspectives. Our experience covers biology, architecture, business, communications, engineering, education, arts, consulting...

Our most active members/biomimicry practitioners are:

- Theresa Millard, UK/USA/Spain. Certified B3.8 Biomimicry Professional and Sustainability Project Manager at Kohler Company.

- Rafael Aparicio, Spain. “Out of The Box” thinker, technical engineer, philosopher, expert in disruptive innovation and problem-solving based in nature.
- Manuel Quirós, Spain. MSc, PhD biologist, well known, especially in South America for his blog *natureinspireus*. Teaches biomimicry at IED Design School in Madrid, and is very active in several initiatives such as contributing to the ZQ publication.
- Daniel Wahl, Germany/UK/USA/Spain. Marine biologist, turned holistic scientist with a PhD in Natural Design. He lives on Majorca and works as a consultant, educator and activist both locally and internationally. His recent book *Designing Regenerative Cultures* has gained international acclaim. Jonathon Porritt called it “an extraordinary intellectual and analytical resource, providing as good a picture of contemporary holistic, systems-based thinking as you’re likely to find.”
- Andrea Monge, Mexico/Spain. MA Environmental Conservation Education and B3.8 Biomimicry Specialist with a background in natural communication networks and passion for marine biology and sustainable development.
- Óscar Jimenez, Spain. Architect teaching at ESD Design School in Madrid where he practices with tireless curiosity, planting the seeds of sustainability in the DNA of future designers through the discipline of biomimicry.
- Agustín Falcó, Spain. Engineer in environmental issues, dreams to see a sustainable-natural world. Bringing biotechnical pro-



Egg of Red Knot *Calidris canutus* | Photo: Didier Descouens, 2012 | Wikimedia Commons



Egg of Bar-tailed Godwit *Limosa lapponica* | Photo: Didier Descouens, 2012 | Wikimedia Commons

fessional experience with deep knowledge based in hands-on learning from the human built world.

- **Carlos Sáez Comet**, Spain. Materials & Mechanical Engineer. Specialist in advanced structural materials & composites. Senior Product & Application Development at VELCRO Industries developing new uses and applications for the Velcro® product families. Associate professor of Advanced Materials- ELISAVA Design and Engineering school in Barcelona.
- **Carlos Rego**, Portugal. Design Manager and Biomimicry Specialist at Logoplaste Innovation Lab where he is dedicated to integrating Biomimicry.
- **Kevin Mamaqi**, Spain. Engineer in industrial design and product development. Discovered biomimicry attending Bionic Design at university. Now working between user experience, design for the masses and product development.
- **Damien Ollivry**, France. Consultant in international development and innovation. A social scientist with a Master's in Sociology.
- **Luisa Nunes**, France/Portugal. Degree in Forest ecology, PhD in insect ecology. Education in classical dance and scientific illustration. Teaches zoology, ecology, biomimicry.

Eight of us founded Biomimicry Iberia and we are growing. In the near future, we plan to increase our friends and practitioners from the region through a membership drive. Our group is decentralized and organizes organically, re-

sponding to emergent needs. We would like to add interns, students, corporations and institutions (NGO's, universities, schools...). This mix will support our vision, projects and future activity.

Biomimicry Iberia Association (BIA) is a non-profit association registered in Madrid. We are pioneers in Spain and Portugal beginning to make traction towards sustainability and a regenerative future. We hope through educating hearts and minds we can catalyze inspired innovative strategies that tackle our most pressing issues.

What other organizations are you linked to?

Several of us are aligned with the Biomimicry Institute and B3.8 in the U.S.A. and therefore the Global Network; we naturally are in the European Biomimicry Alliance. Recently, thanks to a generous invitation to Manuel Quirós, we joined the exciting new Red Biomimesis based mainly in the Spanish speaking community. The "Red" wants to establish an international biomimetic center in the heart of the Colombian Amazonia.

At the same time thanks to many members, we have great links with educational institutions such as IED Madrid, ELISAVA, Barcelona, ESD Madrid and UIB Balearic Islands, and with businesses such as Velcro, Logoplaste and Kohler.

All of these relationships create a symbiotic network which we know will promote future projects based in vision, deep knowledge, experience and collaboration.



Egg of Curlew Sandpiper *Calidris ferruginea* | Photo: Didier Descouens, 2012 | Wikimedia Commons



Egg of Grey Plover *Pluvialis squatarola* | Photo: Didier Descouens, 2012 | Wikimedia Commons

What initiatives are you working on? Can you highlight exciting Spanish research groups working in the area of bio-inspired design?

We have an active network of members with multiple projects:

1. Biomimicry for Entrepreneurs - EU funded project (€198,000) with Turkey and the Netherlands. This will create free-to-access e-learning that will make biomimicry broadly available. In early 2017 we will host an event in Madrid with the international partners to promote this project and to spread biomimicry to different sectors.
2. Red Biomimesis - in development are projects, fund raising and research with a view to designing a 2nd symposium, most likely in Bolivia.
3. IED Madrid will launch "Biomimesis" for 3rd year students of product design as the first official course totally based on biomimicry with 32 hours of teaching. In addition, an international postgraduate course based partially in the Colombian Amazonia and partially in Spain on sustainable and systems thinking is in the works.
4. Urban Biomimicry in Granada is Theresa's favorite project where she is working on snippets of biomimicry content that gets us outside in the city.
5. Rafa has participated as a finalist from over 500 entrants in an important entrepreneurship platform sponsored by Repsol S.A. (energy company) in association with Climate-KIC EU with his tidal turbine inspired by the beak of a red flamingo. More information at Biomival.

6. Manuel continues several initiatives including his unique Spanish blog with more than 60,000 visitors from over 50 countries at natureinspireus. As well, he is a scientific consultant for a publication on request of Chilean university and CICAT for scholars.

8. In November 2015, Theresa, Damien and Daniel collaborated with the European Biomimicry Alliance to support BIA in hosting the first European Biomimicry Practitioners Conference meeting on Majorca with over 45 participants from 11 European countries.

9. Daniel works through Gaia Education in community level capacity building in sustainable design and regenerative development. He has co-authored the curriculum for many of their courses which have been taught to more than 12,000 graduates from 96 different countries on 6 continents. He is currently working with the University of the Balearic Islands and Gaia Education to develop a new pilot program in 'Bioregional Design Education' focused on the island of Majorca.

10. Many team members are creating biomimicry workshops and courses for professionals and students alike and are bringing in partners from the European Biomimicry Alliance to foster further collaboration.

What are your plans for the future?

We need to improve the organization of our group and reach new members. We want to implement biomimicry in several industrial sectors helping others to see the power of this addictive discipline, while taking advantage of our multi-discipline backgrounds and the potential of new

members. We would like to integrate education, research and consultancy as a source of sustainable and regenerative innovation. The Iberian Peninsula is a hot spot of biodiversity and a place where over 70 million tourists visit every year. We can be leaders of this new approach if we appropriately integrate nature's wisdom.

What inhibitors to success have you experienced?

Although it is hard to believe, the innovation processes towards sustainability and regeneration are still very new and for many not yet reliable and poorly understood. It is a huge task to change this model and show that we are in a new era where nature and people matter. This simple sentence means we need a revolution and this takes time to become real on a daily basis. It is our duty to show that another world is not only desirable but also possible. Under existing educational paradigms, the multi-discipline nature of biomimicry makes it hard to establish a new normal since the current system is quite isolating.

How are you sustained financially?

The Biomimicry for Entrepreneurs EU project is the first funding that we have received as the BIA team. Individually we have achieved funding milestones along the way that are expanding our experiences as a group. We have to gain the trust of business and institutions who need disruptive solutions to their problems and the big challenge that we have is how to progress together from our decentralized positions. Some of us have full-time employment or are freelance professionals in the field but there is no financial

support yet through BIA. It can take a lot of free time and energy to make traction as a group, but we know that we are stronger together and are committed to becoming a team. We are beginning to initiate some annual fees for all members and will be able to spread the work of the EU project across all members to generate some internal cash flows.

What is your geographical "reach" within (and outside of) Iberia, and where are your members, meeting places, project locations?

We are truly dispersed all over the region. Some are based in Madrid, others in the Mediterranean areas of Valencia, Mallorca and Barcelona, as well, Zaragoza, Granada, Lisbon, Portugal and Paris, France. In the next months we will extend this map to several other regions for sure!

What is the best thing that you've done within the last year? Ever?

We are particularly pleased with having trained hundreds of undergraduate and post graduate students along with our own educational experiences and personal progress in the field. The workshops that we have developed with children represents not only a challenge but also a drop of hope. We are making an important contribution to spread the biomimicry meme among the Iberian community but much more needs to be done. The best is yet to come. ×

Contributed by Dr. Manuel Quirós and Theresa Millard both co-founders among others at BIA.





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