zq26

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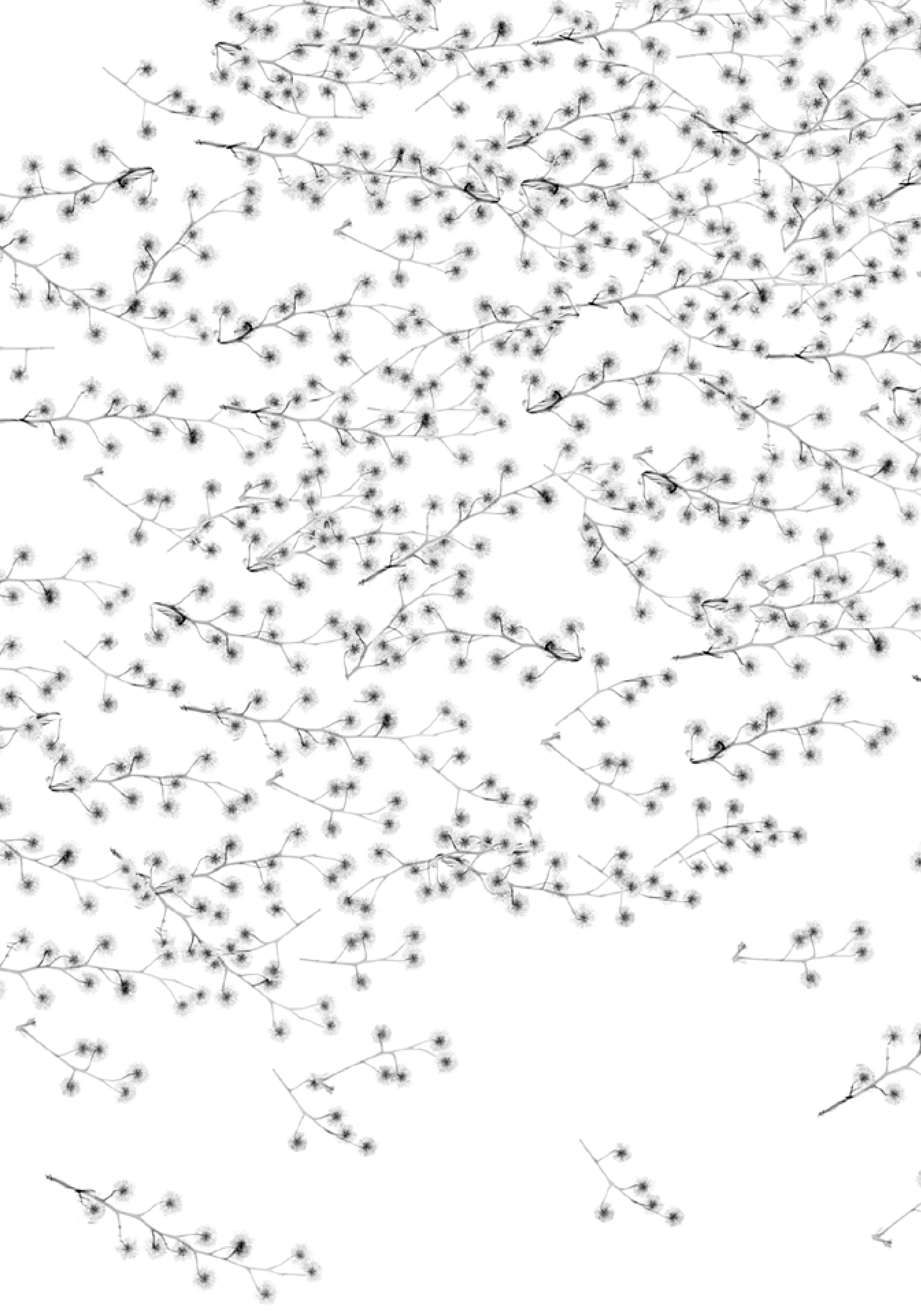

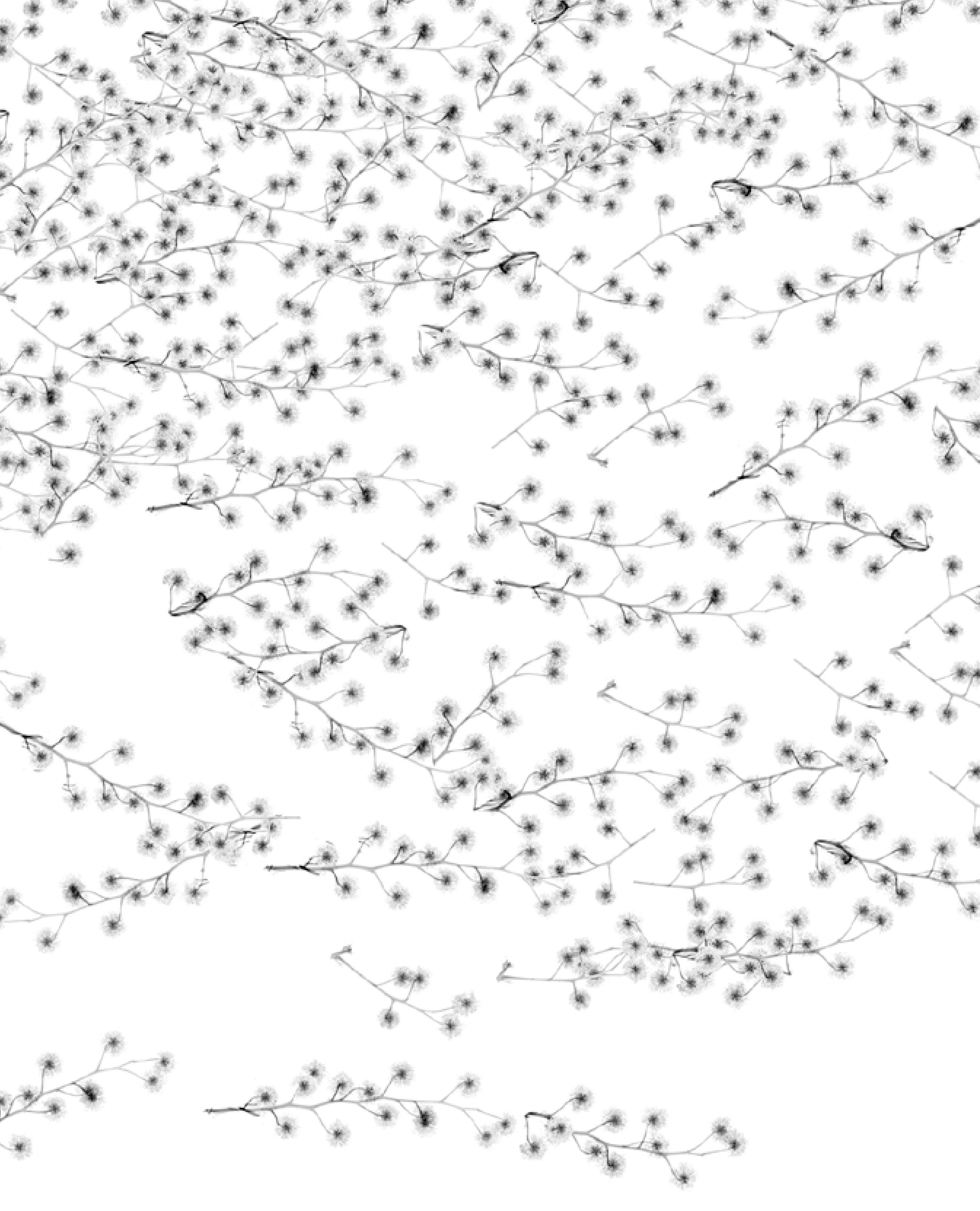

About Zygote Quarterly

Contact
info@zqjournal.org

Cover art
Cover: Dornith Doherty | *Eucalyptus IV* (detail) | Archiving Eden 2008 - ongoing | pp. 2-3 & pp. 106-107: *Pycnantha* (detail)| Archiving Eden 2008 - ongoing

Design
Marjan Eggermont
Colin McDonald

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Close-up of an incurve chrysanthemum | Photo: Fred Dunn, 2012 | Flickr cc

Editorial

From the depths of the ocean to the bowels of an Arctic mountain, our issue explores the survival techniques of deep-sea thermophiles and the form of those time capsules of genetic information, seeds. Dornith Doherty travels the world recording the preservation of specimens in 20 global seed banks, often using the x-ray equipment of the conservationists to create her art. Another portfolio artist, Ruth Cuthand, creates bright beaded works depicting microscopic images of viruses; compelling for their brilliant colors and their historical significance to the cultures of the new and old worlds.

We discuss the techniques of bio-inspired innovation in three articles. Jeremy Faludi shares his results from surveying designers about a range of sustainability tools, including biomimicry, and tallies some surprising results. Jorge Rodriguez and Jacques Chirazi respond to our recent series, Stories from the Trenches, with two perspectives pieces, bringing their professional opinions in business entrepreneurship and engineering to the debate about how best to apply this innovation technique.

Happy reading! ×

Tom Norbert Marjan

Tom McKeag, Norbert Hoeller and Marjan Eggermont

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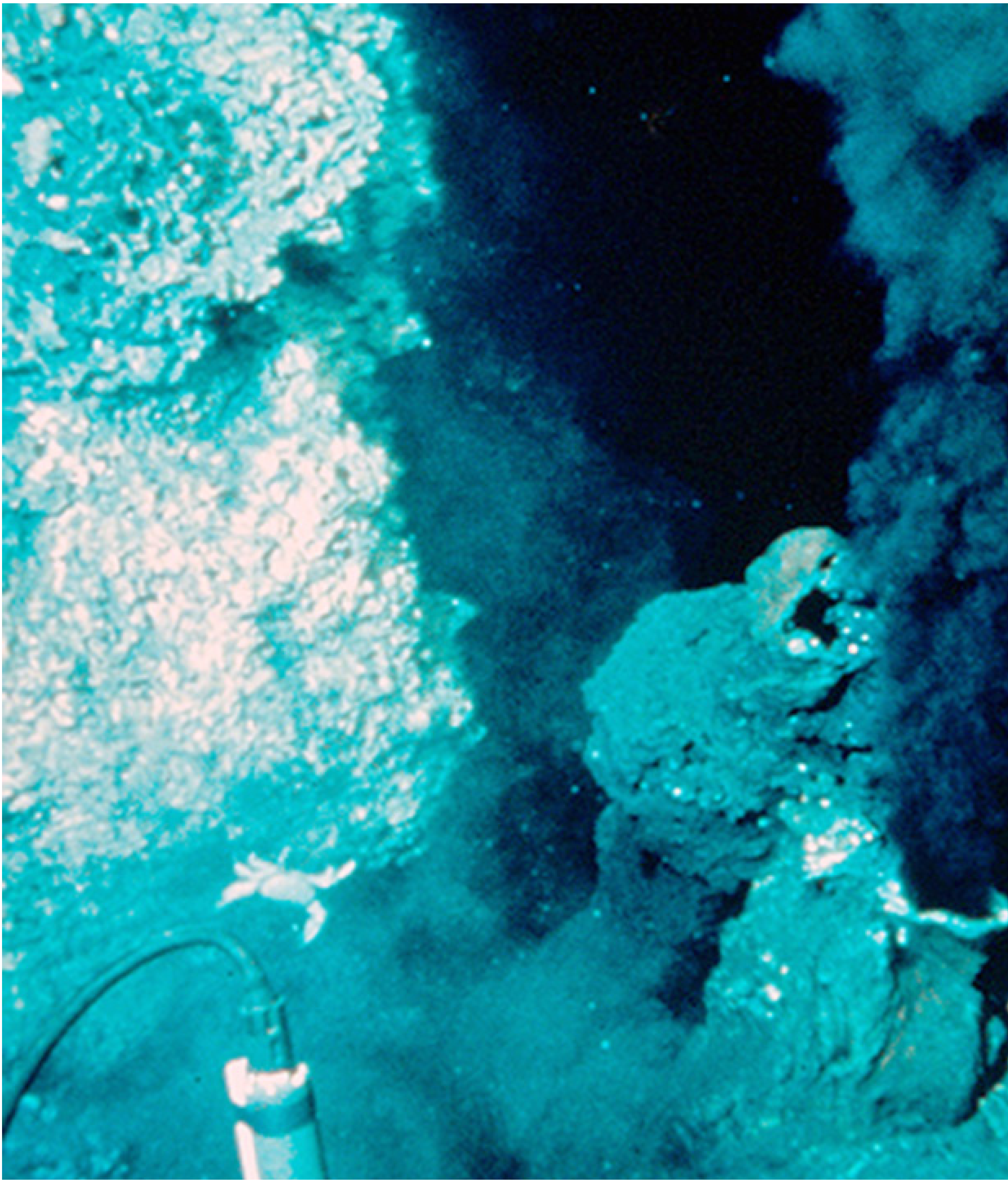
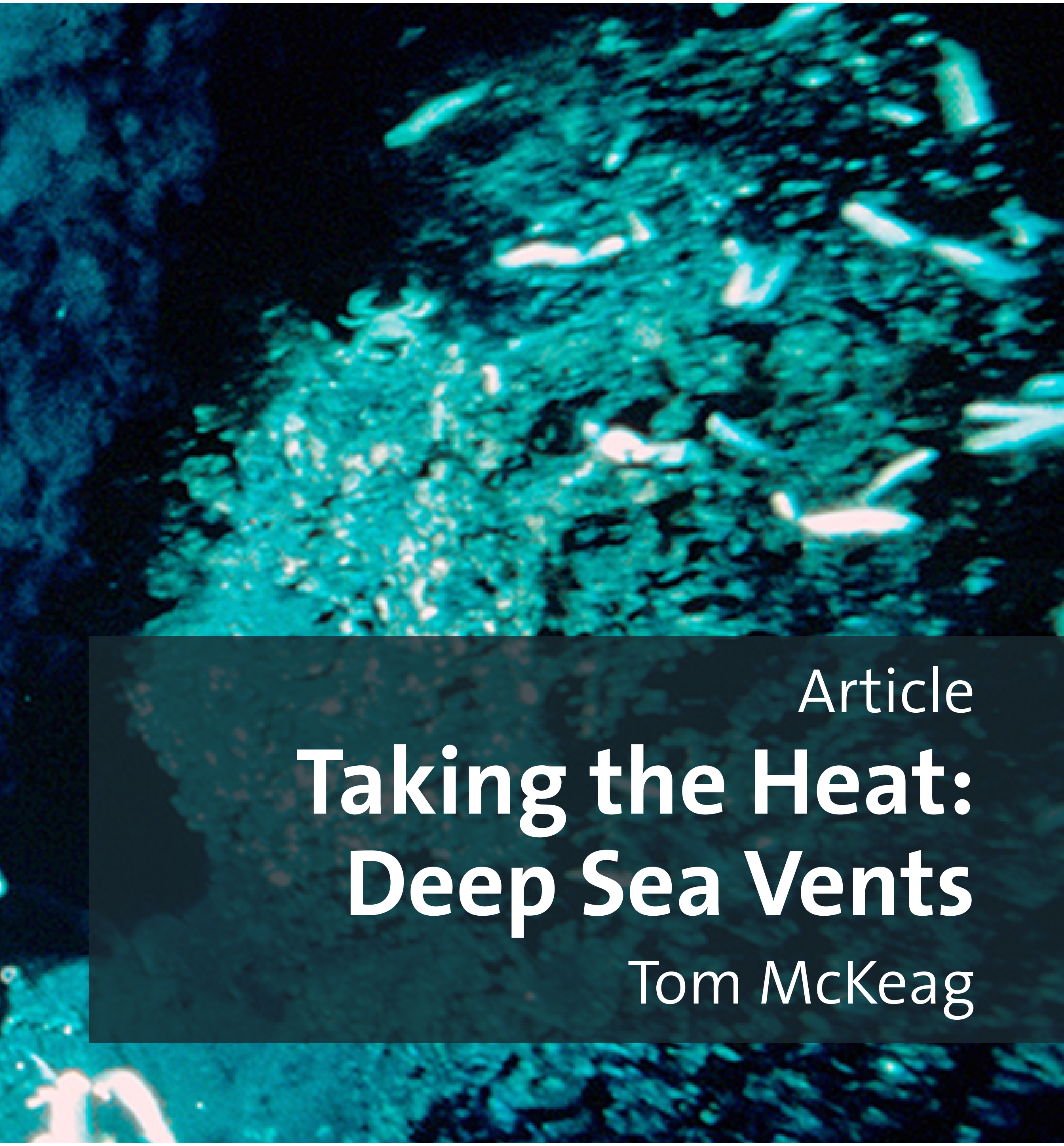


East Pacific Rise, 21 degrees north. Base of "black smoker" chimney. Pacific Ocean.
Photo: W.R. Normark, Dudley Foster, 1980 | Wikimedia Commons



Article

Taking the Heat: Deep Sea Vents

Tom McKeag

Taking the Heat: Deep Sea Vents

Tom McKeag

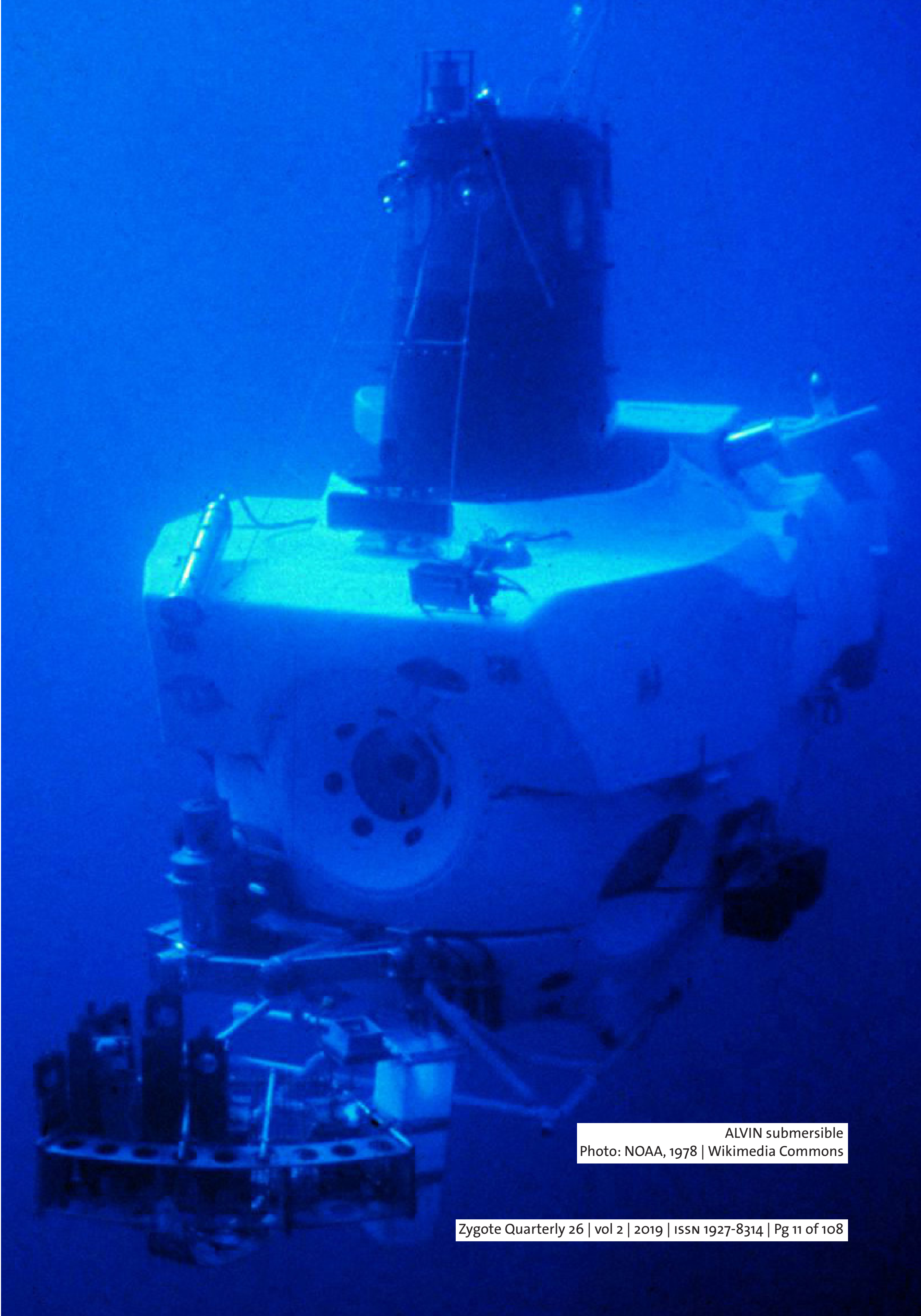
This is part of a continuing series on extremophiles, those organisms on our earth that thrive in environments that are beyond the normal range of factors critical to survival for most of the living world. Temperature, pressure, moisture, pH, and a range of chemical parameters all play a part in where life is able to exist, and scientists are continually discovering astounding new niches where life not only exists, but thrives. The mechanisms used to enable this life have been the inspiration for innovations in dozens of industrial processes, including food processing, pharmaceuticals, bioremediation, mariculture, antibiotics, and detergent production. Our last article was "Cure for the Uncommon Cold" (https://zqjournal.org/editions/zq21.html p. 8) about the Antarctic Ice Fish.

The discovery

Off the coast of South America, 2600 meters deep at the ocean floor of the Pacific, plumes of black minerals pulsate up toward a surface that seems too distant to be real. In the darkness, cold and great pressure, these plumes are emanating from high temperature vents of 380 degrees C called "black smokers". These underwater geysers are one of three broad types of deep-sea hydrothermal vent (black, white and clear) and they sit on the crest of the East Pacific Rise, a crack in the tectonic plates, where the earth's geothermal energy leaks out from the containment of its crust. Their color comes from the mixing of iron and sulfide to make monosulfide, a truly apt emissary of the underworld.

In 1979, three men in a tiny manned submersible, the *Alvin*, slowly descended through the mile and a half of darkness to this jagged seam between continent-spanning tectonic plates. Their mission was to detect and map the sub-seafloor magma chamber that feeds the lavas and igneous intrusions that create the oceanic crust and lithosphere in the process of seafloor spreading (National Oceanic and Atmospheric Administration, 2019). The edges of these plates are where most seismic activity on the planet occurs; the San Andreas Fault in California is the most well known example. It is here also where the earth's deep geothermal energy leaks out from containment.

While the team from the Scripps Oceanographic Institute was there to study and map geology, what they found at the bottom of the sea would rock the world of biology. Rather than desolation, they found abundance. The volcanic conditions spewing from the earth hosted an amazing ecosystem of life: clams, limpets, tube worms and crabs were all found at the four



ALVIN submersible
Photo: NOAA, 1978 | Wikimedia Commons

vents that the mission explored. The argonauts, like their astronaut brethren, gave domestic names to the mare incognito they were exploring: Garden of Eden, Clambake, Dandelions and Oyster Bed. Many of the organisms subsequently identified would be completely new discoveries.

The physical conditions

The water surrounding the vents explored by the *Alvin* crew ranged in temperature from 7-17 degrees C compared to 2 degrees in the ambient ocean (Corliss et al, 1979). Hot water from the vents swirled in complex geometries with the cold, creating a shimmering effect. Water was flowing upward from the vents from breaks in pillow basalt and sheet lava, or through piles of talus. Its rate of flow at the time was hard to calculate precisely, but estimated to be about 2-10 liters per second. This water was being mixed first beneath the rock surface where it is heated to as much as 400 degrees C and picks up metals like zinc, copper, and iron as well as hydrogen sulfide and loses its free oxygen. When ejected out the vent, it then mixes with the ambient ocean water. This mixing brings more acidic subsurface water and new elements into the more alkaline seawater, with complex resulting chemistries. Most importantly is the presence of elemental sulfur, first observed as a milky precipitate or “snow” around many of the vents. The sulfur is being oxidized out of the hydrogen sulfide emanating from the earth.

High temperatures as exist in the subsurface vent areas present challenges to life. The solubility of gasses in water is correlated with temperature, creating problems at high temperature for aquatic organisms requiring O_2 or CO_2. Temperatures approaching 100 degrees C normally denature proteins and nucleic acids, and increase the fluidity of membranes to lethal levels (Rothschild and Mancinelli, 2001).

At this great depth and pressure, superheated water remains liquid and is not “boiled off” as a gas. One experiences the opposite effect when cooking at high altitudes; with less atmospheric pressure water boils at lower temperatures. The hydrostatic pressure present at the depth that *Alvin* went to is 260 times that of that of the ocean surface: humans experience 14.5 pounds per square inch (psi) or “one atmosphere” of pressure at the surface, but for every 10 meters of depth an additional atmosphere is added. At the bottom this kind of force would break our bones.

Sunlight does not reach these depths and therefore no photosynthesis takes place. This means that the more common autotrophs of surface water, the sun-loving and sugar-making bacteria and algae of the phytoplankton, do not form exclusively the basis for an ecosystem. And yet, the ecosystem is there — and thriving.

The life found there

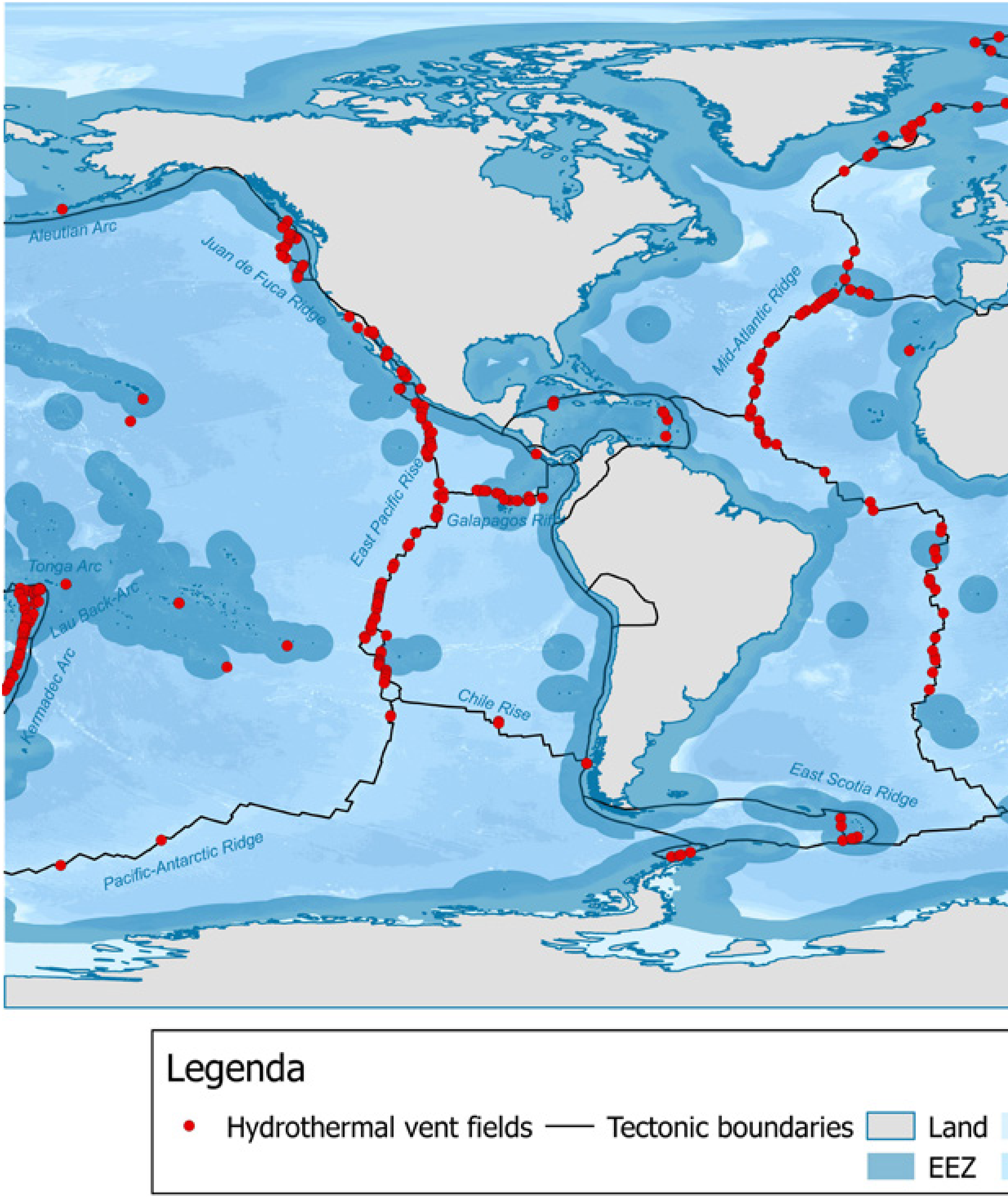
The ecosystems found at the deep-sea vents are formed not by tiny organisms converting the energy of the sun to make carbohydrates, but by scavenging the detritus that falls from above and by oxidizing sulfur. Indeed, subsequent to the *Alvin* voyage such chemolithotrophic bacteria and archaea have been confirmed and found in the waters around and in the rocks beneath the vents. These primary producers are in turn consumed and converted by the dense and highly productive colonies of filter feeders, invertebrates like the mollusks and worms, and top consumers like crabs and octopus.

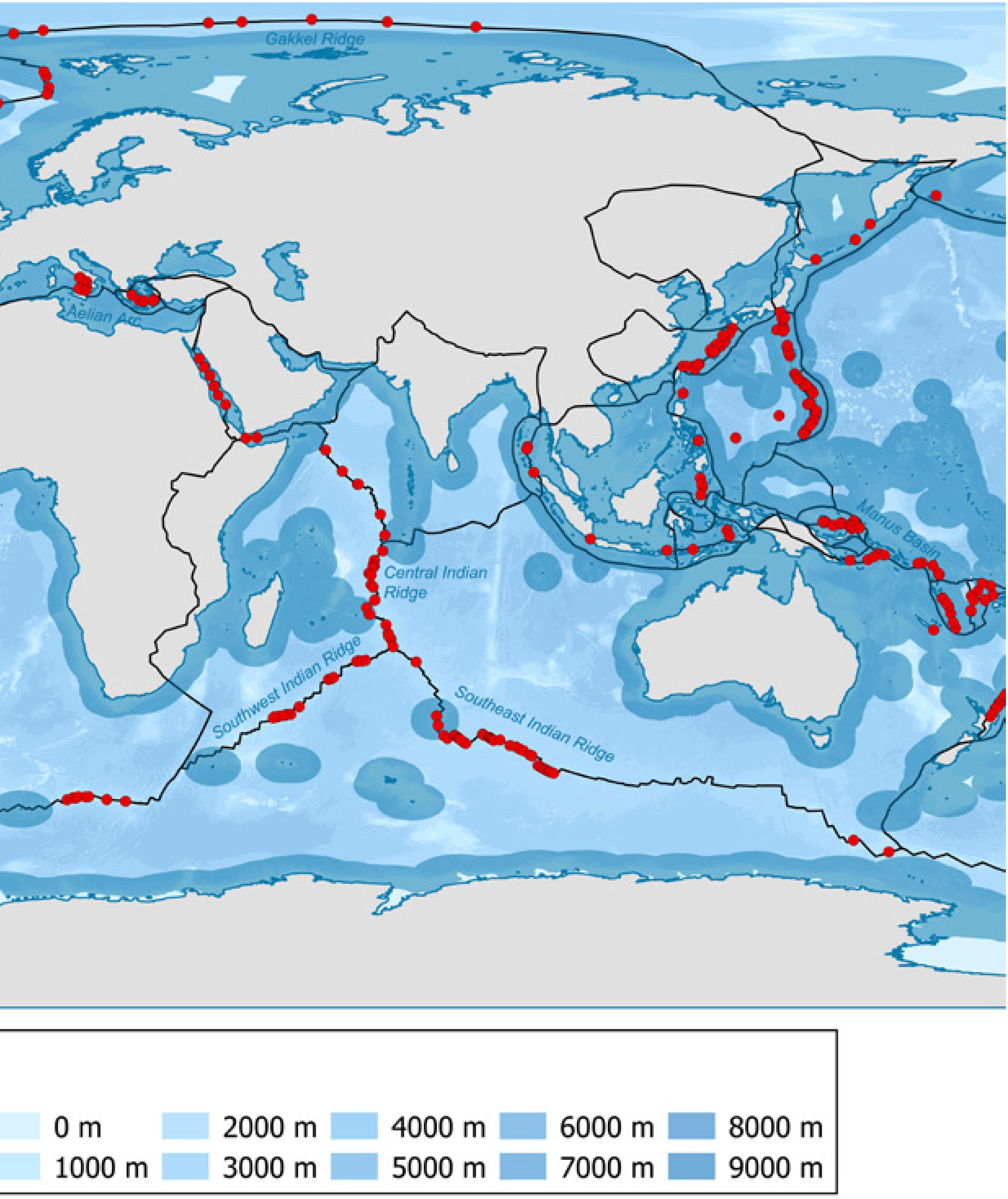
This is, in part, a sulfur-based society, as rich and as complex as any fully dependent on the sun. The organisms within this web survive because of the ability of bacteria and archaea to convert this sulfur to carbohydrates. Carbon dioxide (CO_2), water (H_2O), hydrogen sulfide (H_2S), and oxygen (O_2) are converted to these carbohydrates (CH_2O) and sulfuric acid (H_2SO_4). Sea vent creatures also depend on the organic matter detritus that drifts that long way down from the sunlit region. Finally, and importantly to our story, there are organisms that serve as energy links between the chemosynthetic bacteria and the rest of the food web.

At the base of this society are the Chemo-Autotrophs, and as in the coral reef ecosystems at the surface, many of these organisms cannot go it alone but need to host and nurture the essential bacteria. This endosymbiosis allows the red-gilled tube worms (*Riftia pachyptila*), for instance, to absorb and use the hydrogen sulfide coming up through the vents. Mussels and zooplankton also form the base of this food web.

Primary Consumers include the Brachyuran Crab (*Bythograca thermydron*) which feeds on mussels, microbes, tubeworms sometimes crabs; the Galatheid Crab (*Munidopsis curvirostra*) which consumes microbes and zooplankton; the Vent Shrimp (*Rimicaris hybrsae*) and the Pompeii Worm (*Alvinella pompejana*) that feed on microbes and bacteria.

Primary Consumers are in turn eaten by Secondary Consumers. Vent Ratfish (*Hydrolagus collilei*) prowl for crabs, clams, sea stars, fishes, worms and shrimp. Dandelion siphonophore (*Thermopalia taraxaca*), related to jellies, are mostly scavengers existing on dead organisms and vent shrimp. A large colony usually indicates that the vent is declining and the ecosystem is dying out. Zoarcid Fish (*Thermarces cerberus*)


Aleutian Arc
Juan de Fuca Ridge
Mid-Atlantic Ridge
East Pacific Rise
Galapagos Rift
Tonga Arc
Lau Back-Arc
Kermadec Arc
Chile Rise
East Scotia Ridge
Pacific-Antarctic Ridge
Legenda
Hydrothermal vent fields
Tectonic boundaries
Land
EEZ



Distribution of hydrothermal vent fields.
Map: DeDuijn, 2016 | Wikimedia Commons

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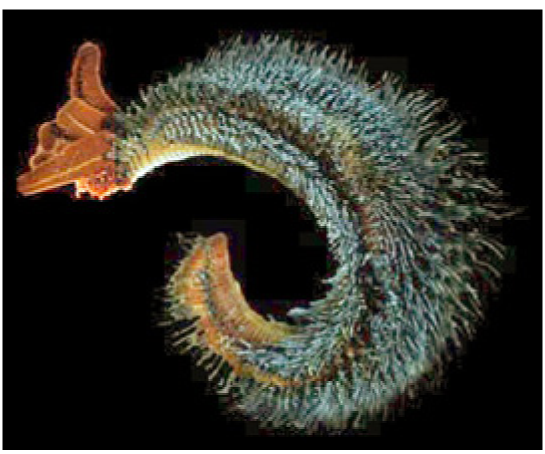
prey on Galatheid crab, and zooplankton. The Tube dwelling Anemone (*Cerianthus sp*) also eats Vent Shrimp and anything else it can catch with its stinging tentacles.

All of these larger creatures must be on constant lookout for the Top Consumers and two organisms are typical of this vent ecosystem. The Vent Octopus (*Vulcanoctopus hydrothermalis*) seems to prefer Zoarcid Fish and , Galatheid Crab, but will eat about anything else, and the Blind Crab (*Kiwa hirsute*) preys on the Dandelion siphonophores, worms, clams, mussels and anything else it can catch.

Within this community of organisms, all intriguingly adaptive, exists a humble worm that seems to not only defy the elements but appears to bridge the worlds of the primitive and volcanic and the complex and pelagic. It is the Pompeii Worm.



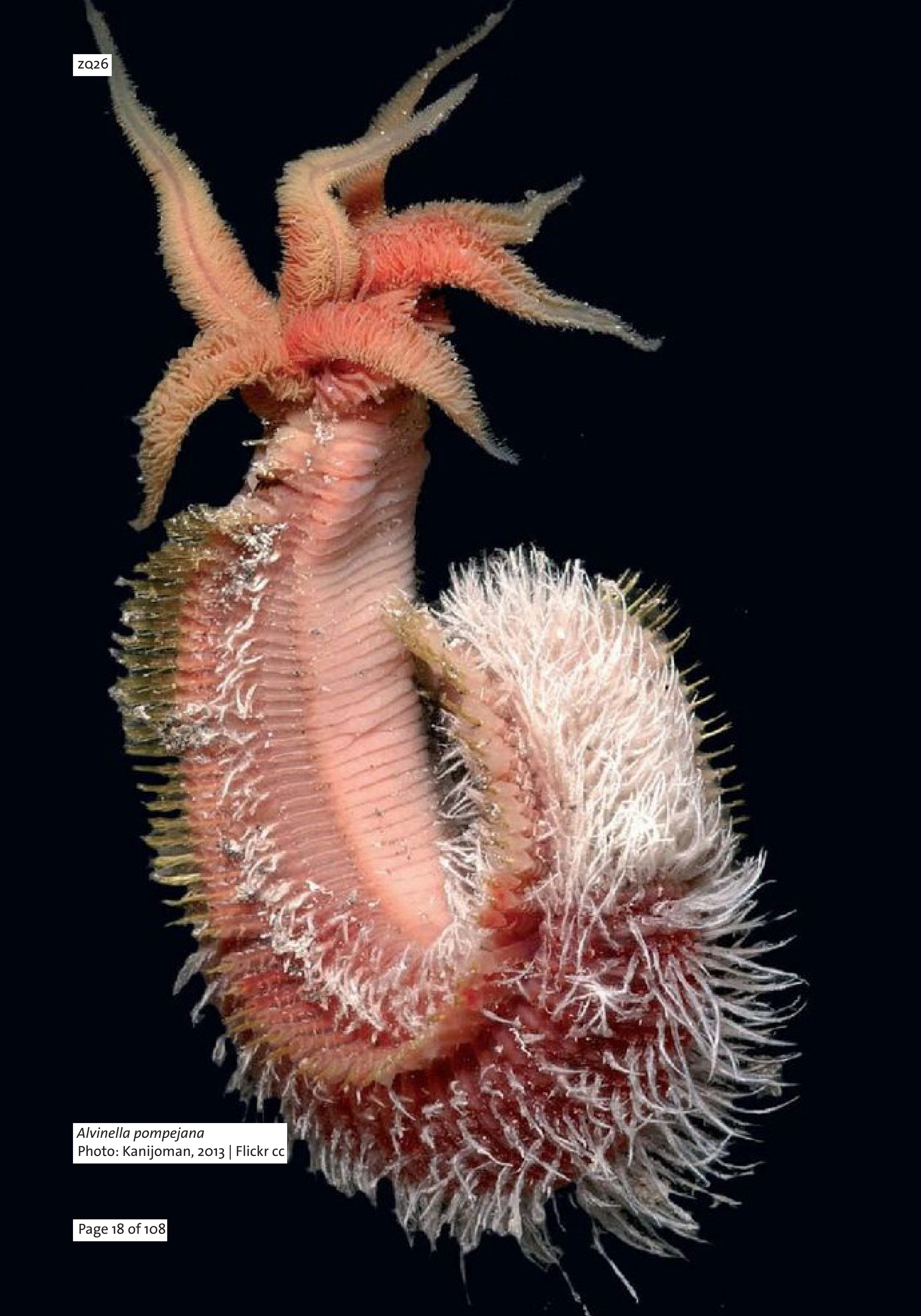
Alvinella pompejana or Pompeii worm, able to survive temperatures as high as 176°F. A coating of protective bacteria covers this deep-sea worm's back. | Photo: National Science Foundation (University of Delaware College of Marine Studies), 2001 | Wikimedia Commons

A remarkable worm

The Pompeii Worm (*Alvinella pompejana*) is one of the more fascinating of the higher order extremophiles, informally called metazoans, those eukaryote organisms possessing cells differentiated into tissue and organs. This group includes all animals but protozoans. It is a colonizing polychaete class worm discovered on the East Pacific smokers in 1980. The worms are typically 95 mm long and 12 mm wide reside in pale grey tubes and have red radiating tops that serve the function of gills. They form dense colonies living directly on the chimneys of the vents.

Alvinella holds the penultimate record for heat resistance in the upper tiers of the food web, second only to tardigrades in being able to withstand high heat. While tardigrades may hold the record for heat resistance (150 degrees C.), the Pompeii Worm can claim the overall prize for extreme tolerance: high pressure, a toxic soup of heavy metals and acid bombard this organism as well as a wide range of temperatures. Pompeii Worms sit with their bases anchored on chimneys reaching 80 degrees C, while their filtering tops float in the relatively mild 22 degree C water. While much is still unknown about the worms, there are several strategies for resisting the

Lamellibrachia sp. tube worms at a cold seep. Gulf of Mexico.
Photo: Aquapix and Expedition to the Deep Slope, 2007 | Flickr cc



Alvinella pompejana
Photo: Kanijoman, 2013 | Flickr cc

high heat, toxic metals and acid of the vents that have been investigated.

The tubes burrowed into the chimneys are made of proteins and minerals (Zbinden et al, 2000) and it is thought that the presence of metals in the tubes may mean that the worm is secreting them as a purging mechanism (Desbruyeres et al, 1998). The tubes may afford some physical shielding from heat surges as well. Likewise, its DNA is also more heat stable (Dixon et al, 1992). The worm incorporates special enzyme proteins like superoxide dismutase that are more thermally stable. These enzymes contain so-called interaction motifs, regions of the molecule that form bonds between each other (Shin et al, 2009). Finally, it is hypothesized that the red floating tops may serve as a heat dissipation strategy. Their bright color can be traced to the hemoglobin flowing through this tissue. The worm's particular brand of hemoglobin has a high affinity for oxygen, allowing the uptake and respiration to be maintained in highly variable environments. When CO_2 and acid conditions exist, as at the vents, oxygen is readily released into respiring tissues (Hourdez et al, 2000), hence the bright red color discovered in this world of no natural light.

The Pompeii worms achieve this all this durability, it turns out, with a little help from their friends. Like many of the filter-feeding sessile creatures living on the vents, they enjoy the benefits of a symbiotic relationship with chemolithotrophic bacteria; in this case *Nautillia profundicola*. The bacteria actually form a one centimeter thick mat on the back of the worm, nurtured by a regular secretion of mucus from the worm itself. This "gardening" appears to offer thermal insulation by the filamentous bacteria, as well as thermal regulation by the eurythermal enzymes possessed by the bacteria.

Research Relevance

The scientific community, as well as the public, has been intrigued and inspired by these relatively recent discoveries where the earth's outer core meets its great ocean depths. The ecosystems residing there are so novel (and sometimes bizarre), that they challenge us to re-think our assumptions about the nature of life and survival. The conditions that exist there are being studied as models for exploration of other harsh environments like other planets, as well as the conditions that probably existed at the beginning of life on earth. The organisms living there hold clues to our common ancestors as a result, and their interactions in mechanisms like symbiosis offer models of problem-solving at many scales. Within these communities, it is possible that a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Ring of Fire 2006 Expedition. The plethora of squat lobsters at Seamount X, disperse as the Jason II ROV comes in for a closer view. | Photo: NOAA Photo Library, 2010 | Flickr cc

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small annelid worm, named after a historical Roman volcanic eruption and a deep-sea submersible vehicle, could hold the key to the next great medical breakthrough of heat tolerant enzymes or the remediation of toxic metals, or the harvesting of energy from the earth. ×

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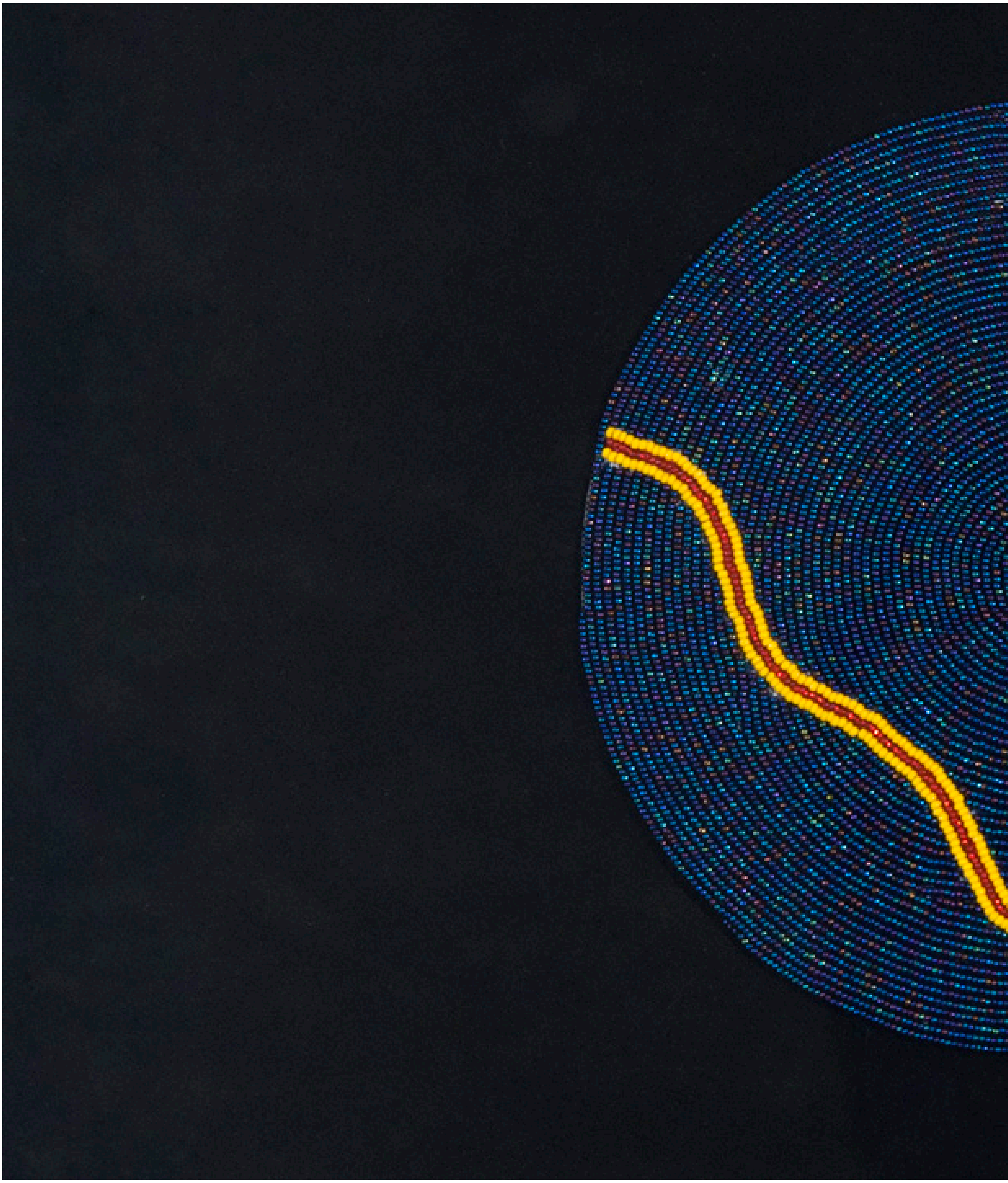
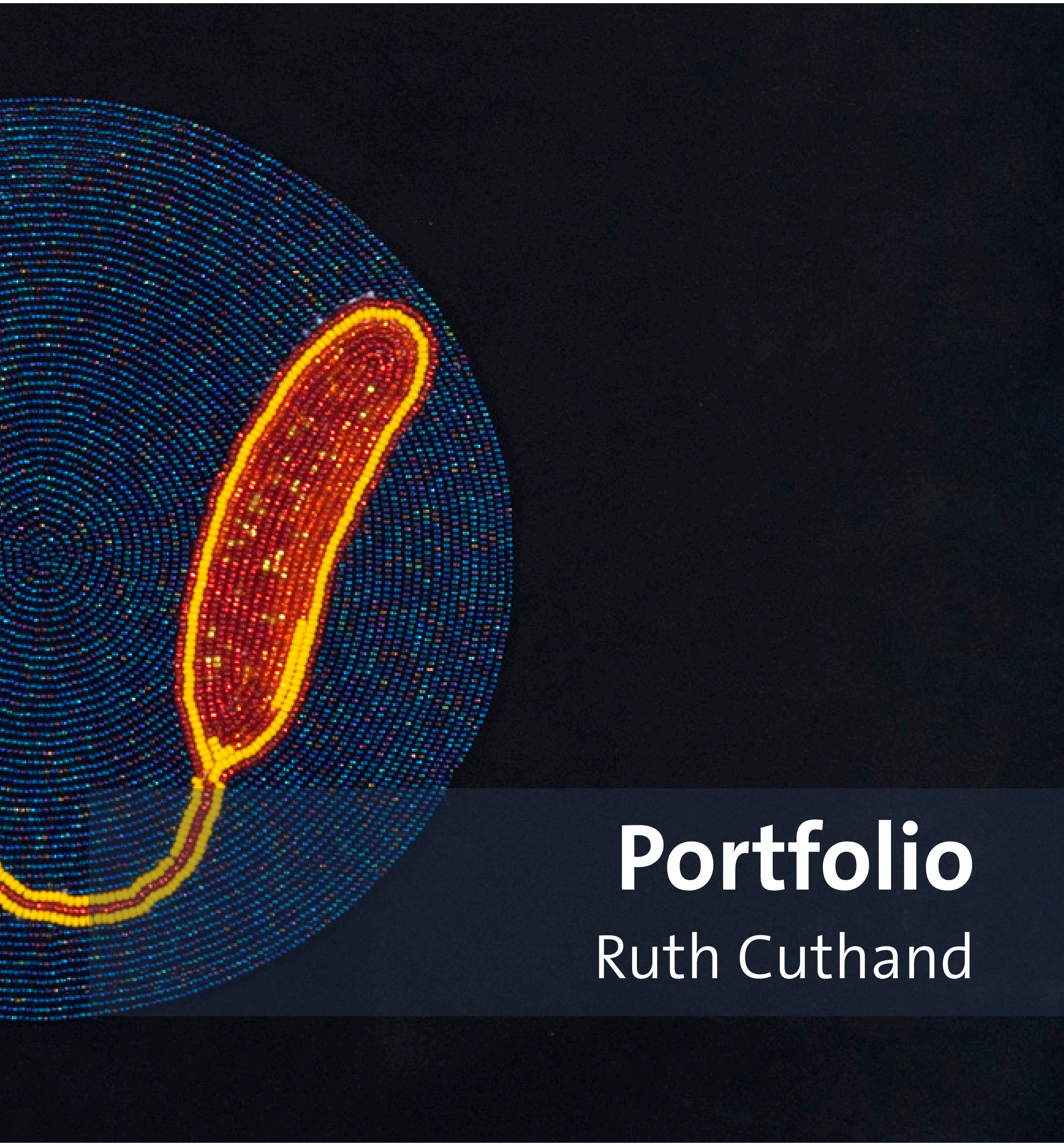
We would appreciate your feedback on this article:

A dense bed of hydrothermal mussels covers the slope of Northwest Eifuku volcano near a seafloor hot spring called Champagne vent. | Photo: Pacific Ring of Fire 2004 Expedition. NOAA Office of Ocean Exploration; Dr. Bob Embley, NOAA PMEL, Chief Scientist. | Flickr cc



Ruth Cuthand | Cholera (detail)
Image courtesy of The Mendel Art Gallery Collection at Remai Modern



Portfolio

Ruth Cuthand

Portfolio
Ruth Cuthand

Artist Statement

I'm Not The Indian You're Looking For

I was born in 1954 in Prince Albert, Saskatchewan, of Plains Cree, Scottish and Irish ancestry. I grew up in Cardston Alberta near the Blood Reserve, where at the age of eight I met artist Gerald Tailfeathers and decided that I, too, wanted to be an artist. As a child, my first art materials included the orange paper that was discarded in the processing of the Polaroid chest x-rays that we were subjected to annually as students in routine tuberculosis screenings; they collected the peculiar-smelling 18-inch squares of paper and gave them to my Anglican minister father for use in Sunday school. Early fascination with disease, First Nations living conditions, and settler/Native relationships informed by childhood experiences have become key elements in my creative practice, which has encompassed printmaking, painting, drawing, photography, and beadwork.

Ruth Cuthand

The 1876 Indian Act was passed into law as a means to protect, civilize and assimilate the Indian population. Today it remains a barrier to improvement in First Nations standards of living and a paternalistic system of governance devoid of transparency. My personal experiences with this system are reflected in work that throughout my career has included subjects such as “white liberal” attitudes towards Aboriginal women, the Canadian response to the 1990 Oka crisis, Mormon-Native relations in Cardston, Alberta (my childhood home), the diseases that ravished First Nations upon European contact, and the deplorable living conditions in Indigenous communities that exemplify the social issues that have affected Canadian First Nations people.

In my early work, I adopted a consistently anti-aesthetic stance, refusing to be stereotyped by forcefully rejecting the authority of both Western high art and traditional Aboriginal art and design. In true anarchic style, however, I borrow freely from both when it suits my purposes. This approach has allowed me to challenge mainstream perspectives on colonialism and the relationships between “settlers” and Natives, addressing the frictions between cultures, the failures of representation, and the political uses of anger in Canada, employing stylistic crudeness to counter the stereotype of Canada as the great polite nation. In my work, I challenge the status quo by exposing the inequities that have plagued for centuries Canada’s relationship with its First Peoples, while proudly claiming a complex and self-determined Aboriginal identity.

Adopting the traditional craft of beading in my recent work was a way to continue to centre the Aboriginal woman in my art while addressing other issues of concern. Maintaining the anti-aesthetic principles on which my practice was founded, I have traded crudeness of style for materials and techniques that have long been denied status as serious art. This shift has allowed for a more sophisticated end-product that capitalizes on my fascination with the attractive and repellant subject; the simultaneously beautiful and abhorrent. This dichotomous relationship between appearance and content, or between style and subject creates a cognitive schism; it is that gap that creates a space for contemplation about the work and what it means.

Though humour softens the blow of a critical message, I have found that making work which confronts the most difficult truths about Canadian society and the impacts of colonization on Aboriginal people are made remarkably palatable when delivered in a strikingly seductive package.

Could you tell us about this series?

The Trading...Series started in 2006. I had been doing some beading and was looking for new subject matter. One day I got a shipment of beads. As I was laying them out and admiring the colours, something clicked in my brain: What was the first reaction of Indigenous women when they saw beads for the first time? I then thought about trade items that changed lives, the iron pot, knives and diseases. I did research and found the first 11 diseases that came from the old world to the new world.

What kind of techniques do you use for your work?

I use glass beads, I look up microscopic images of diseases and use them in my work.

Portfolio

Ruth Cuthand

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

I tend to use media that will work the best for my projects. The response to my beaded works has been overwhelming.

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

Time and space are what feed my creativity. I currently am trying to figure out two future projects in the back of my mind. Every once in a while a project will push itself forward and I will find a way to think differently about it.

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

I am currently working on beading MRI images of different mental health issues. ×

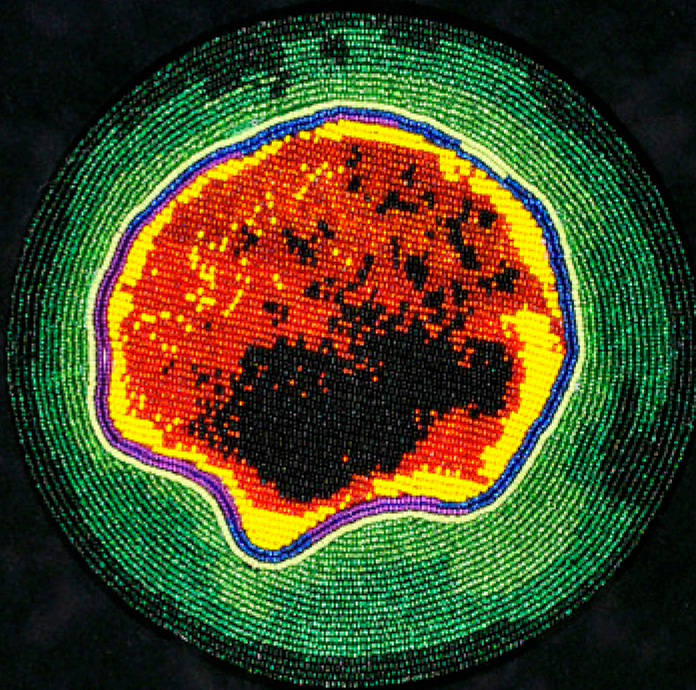
For more of Ruth's work please see https://www.ruthcuthand.ca

We would appreciate your feedback on this article:

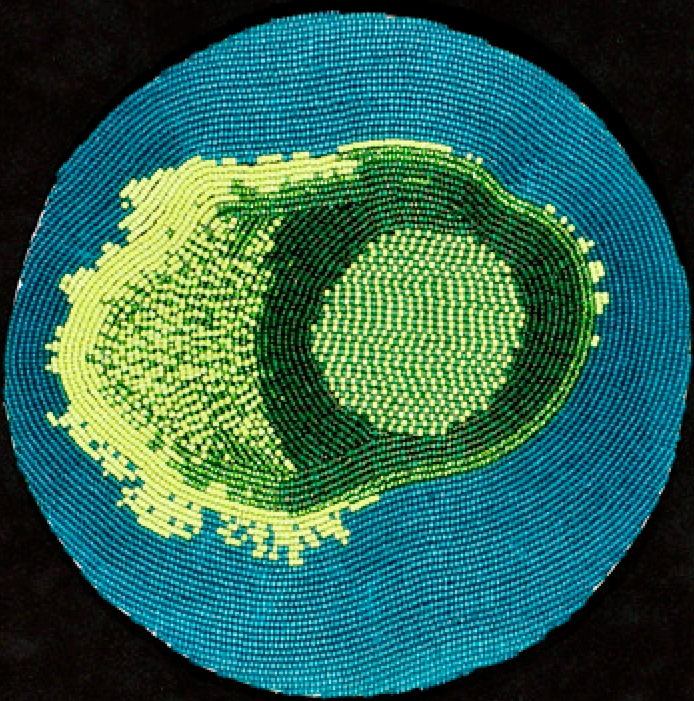
Work in order of appearance: p. 29 Bubonic Plague, p. 30 Chicken Pox, p. 31 Cholera, p. 32 Diphtheria, p. 33 Influenza, p. 34 Measels, p. 35 Scarlet Fever, p. 36 Small Pox, p. 37 Typhoid Fever, p. 38 Whooping Cough, p. 39 Yellow Fever (pp. 29-39 Beadwork and acrylic on suedeboard), p. 40 Syphilis (Dyed porcupine quills and thread).

Bubonic Plague, Chicken Pox, Measles, Smallpox, Typhoid Fever, Whooping Cough, Collection of the MacKenzie Art Gallery | Cholera, Diptheria, Yellow Fever, Collection of the Mendel Art Gallery | Influenza, Syphilis, Collection of the Saskatchewan Arts Board | Scarlet Fever, Collection of Wally Dion

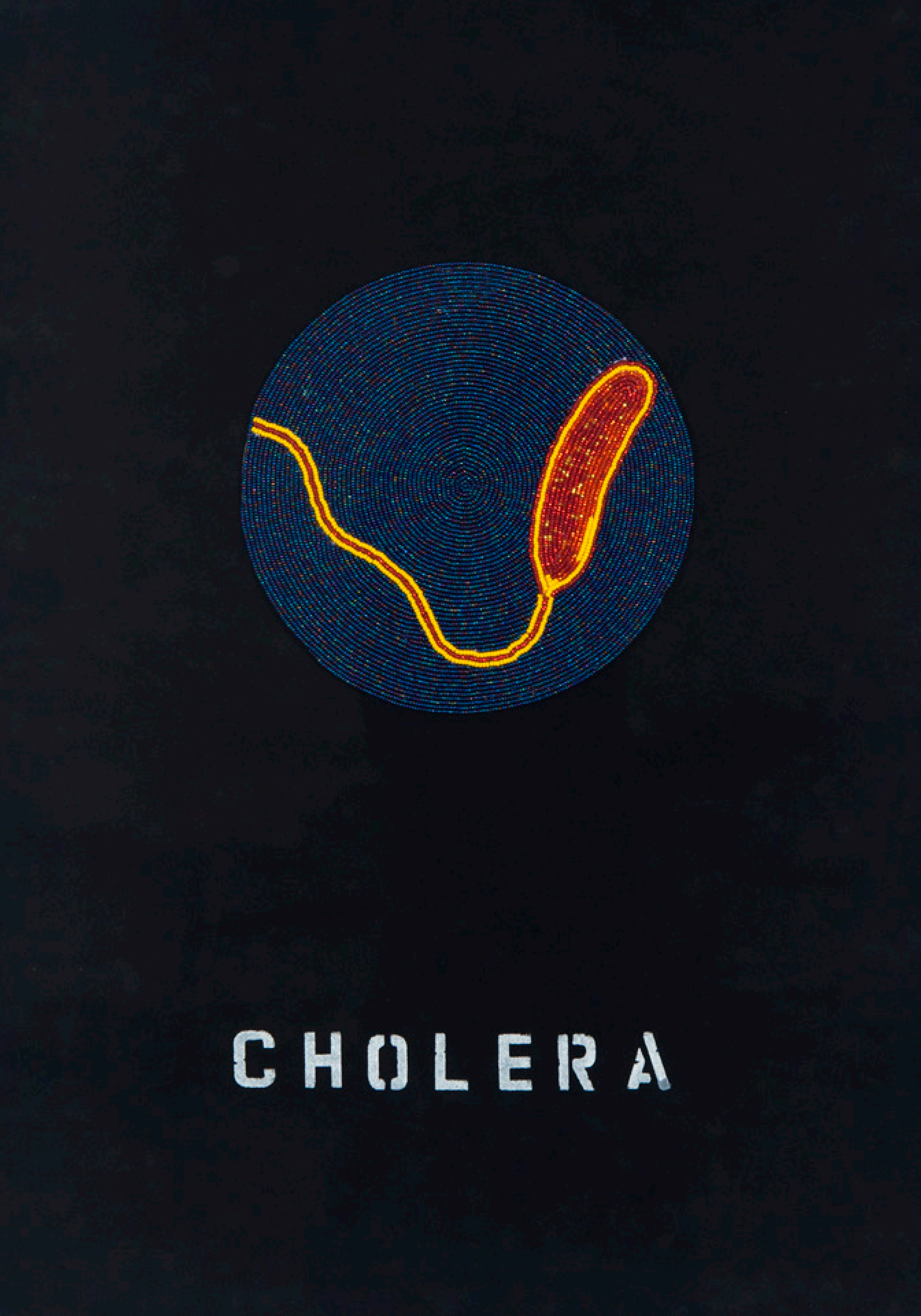
Images courtesy of The Mendel Art Gallery Collection at Remai Modern



BUBONIC PLAGUE



CHICKEN POX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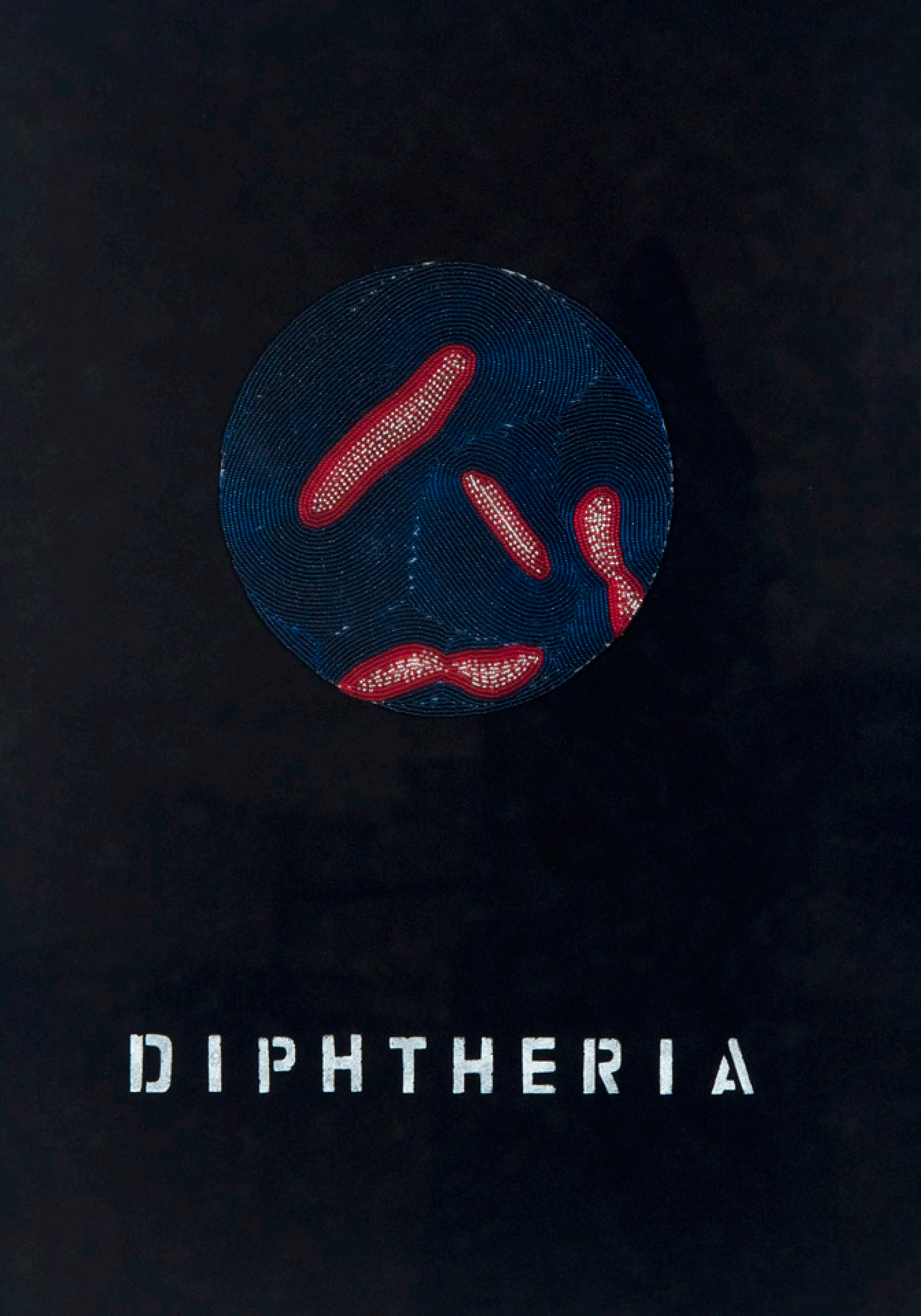
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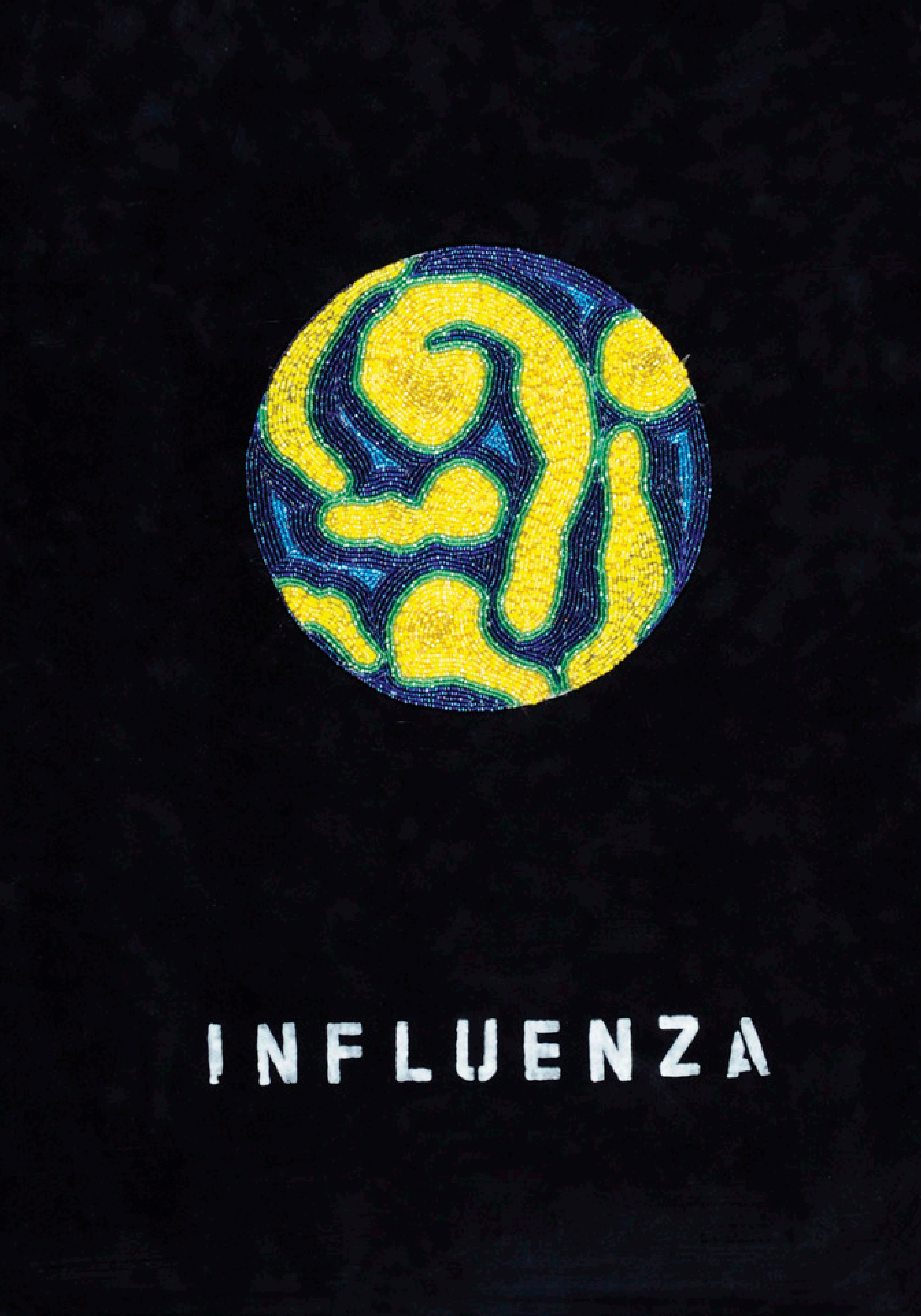
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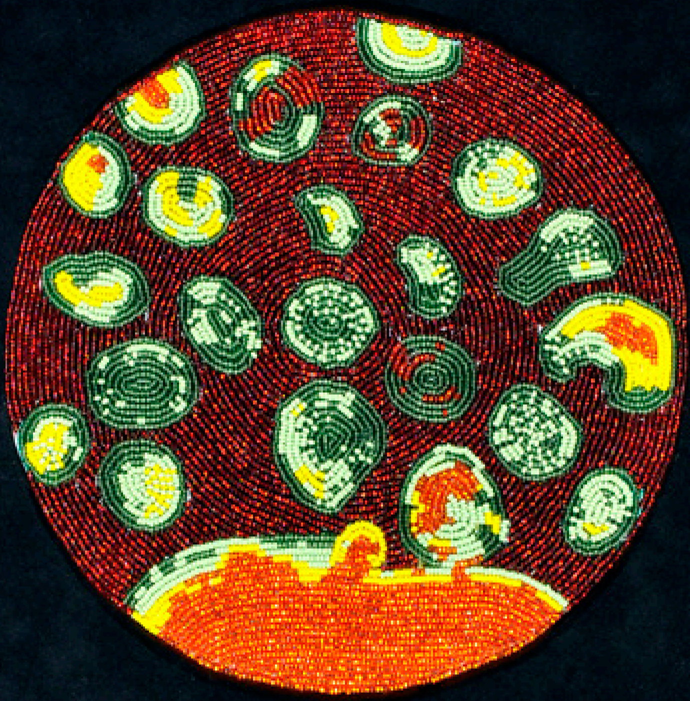

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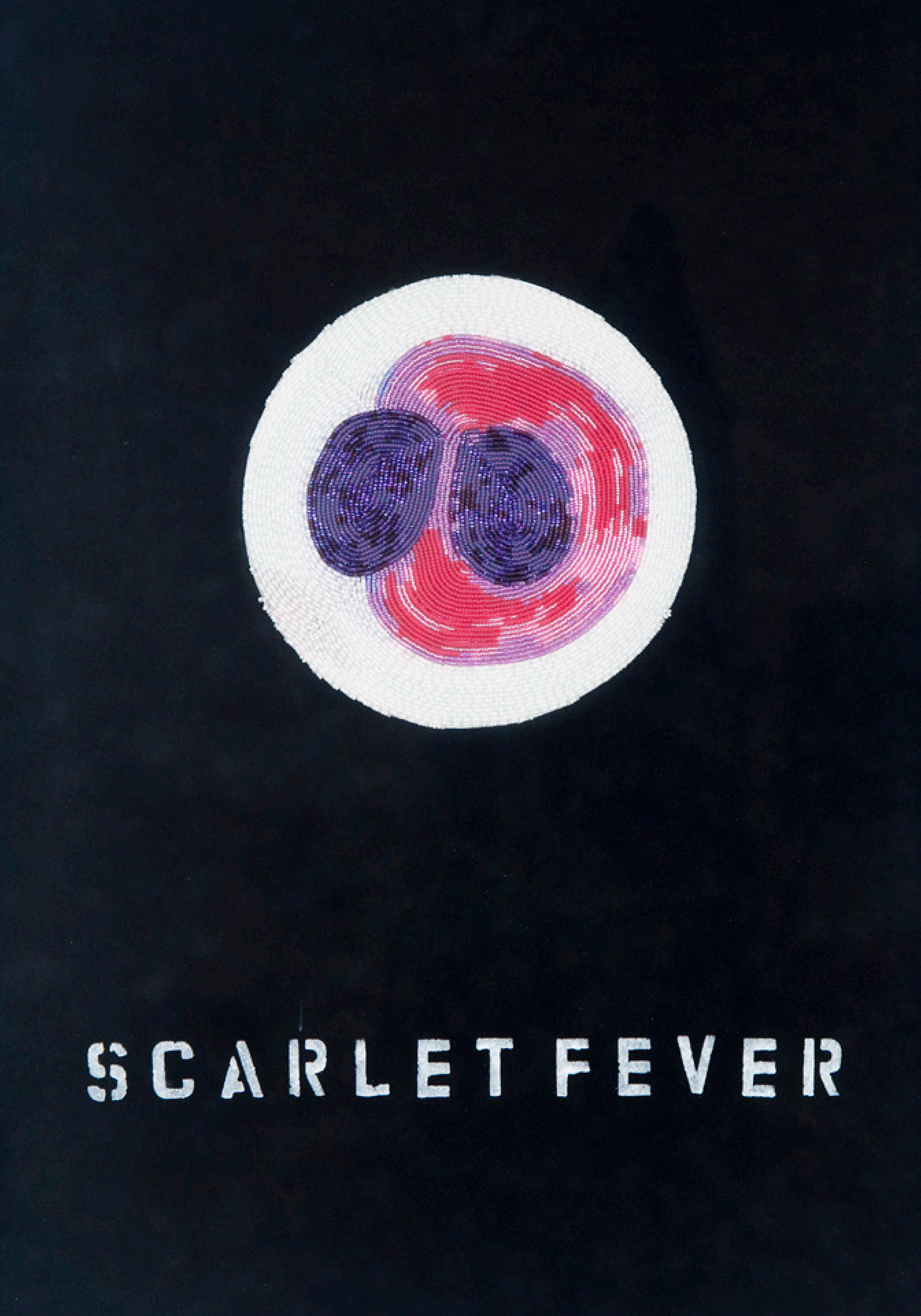
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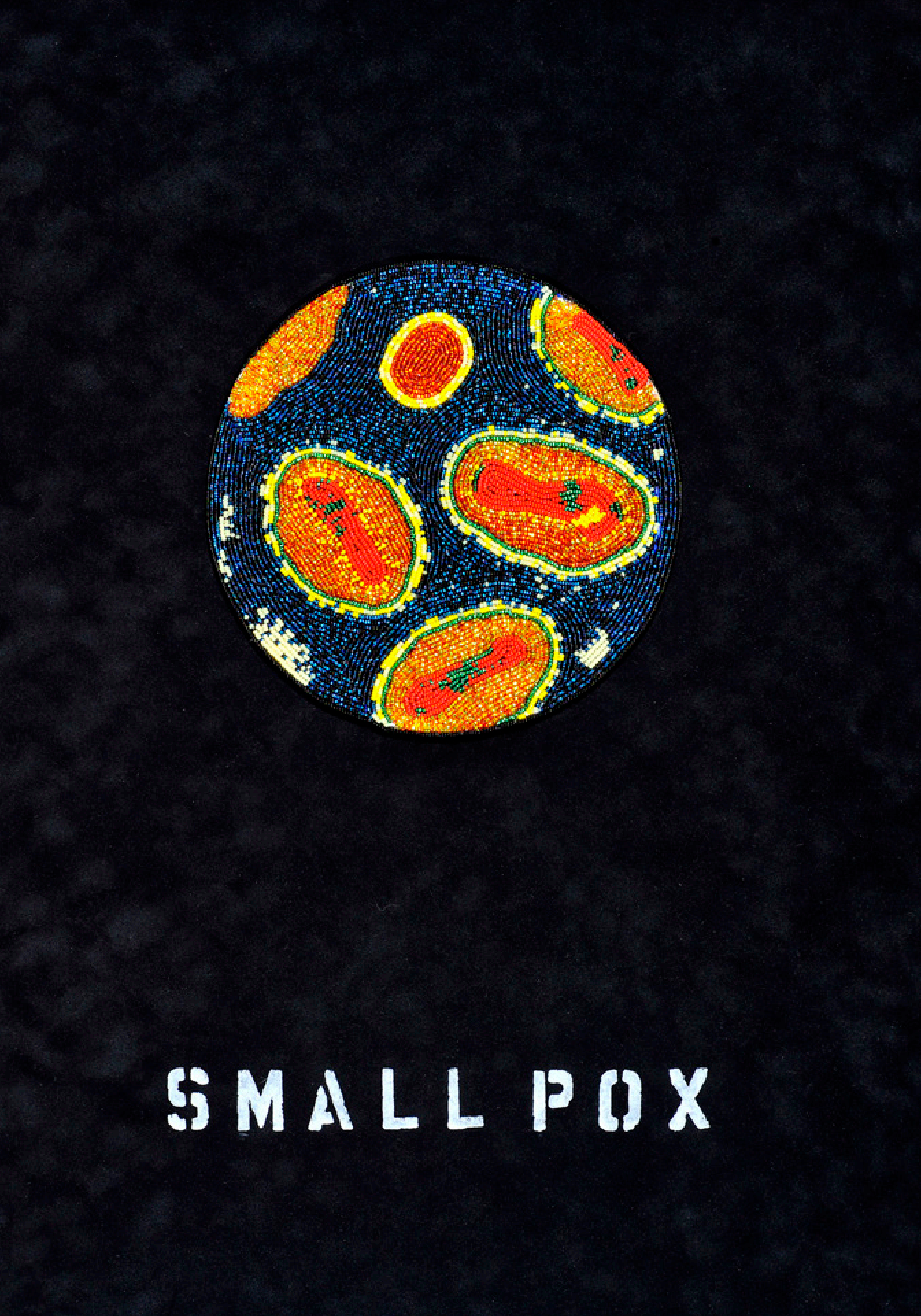
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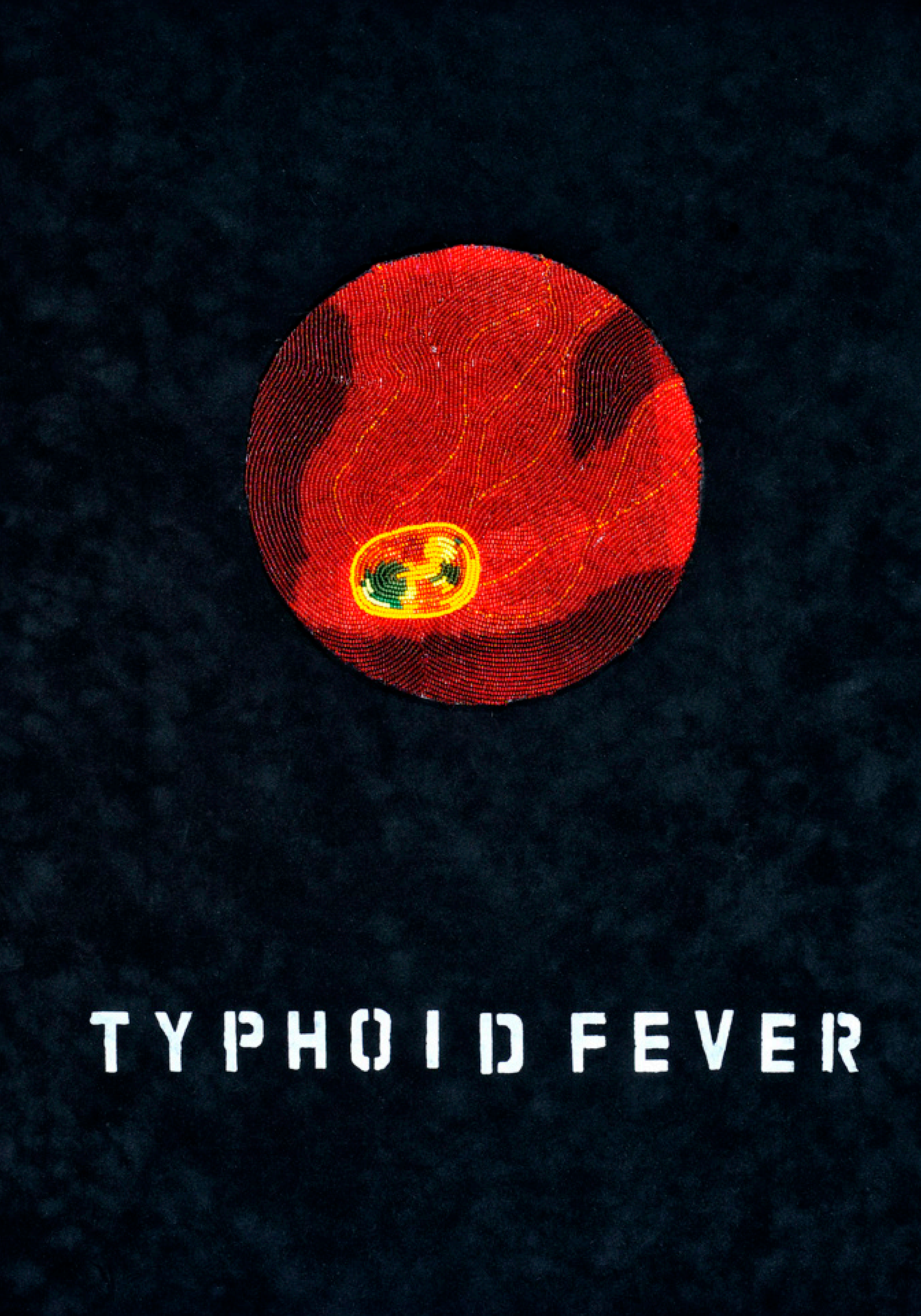
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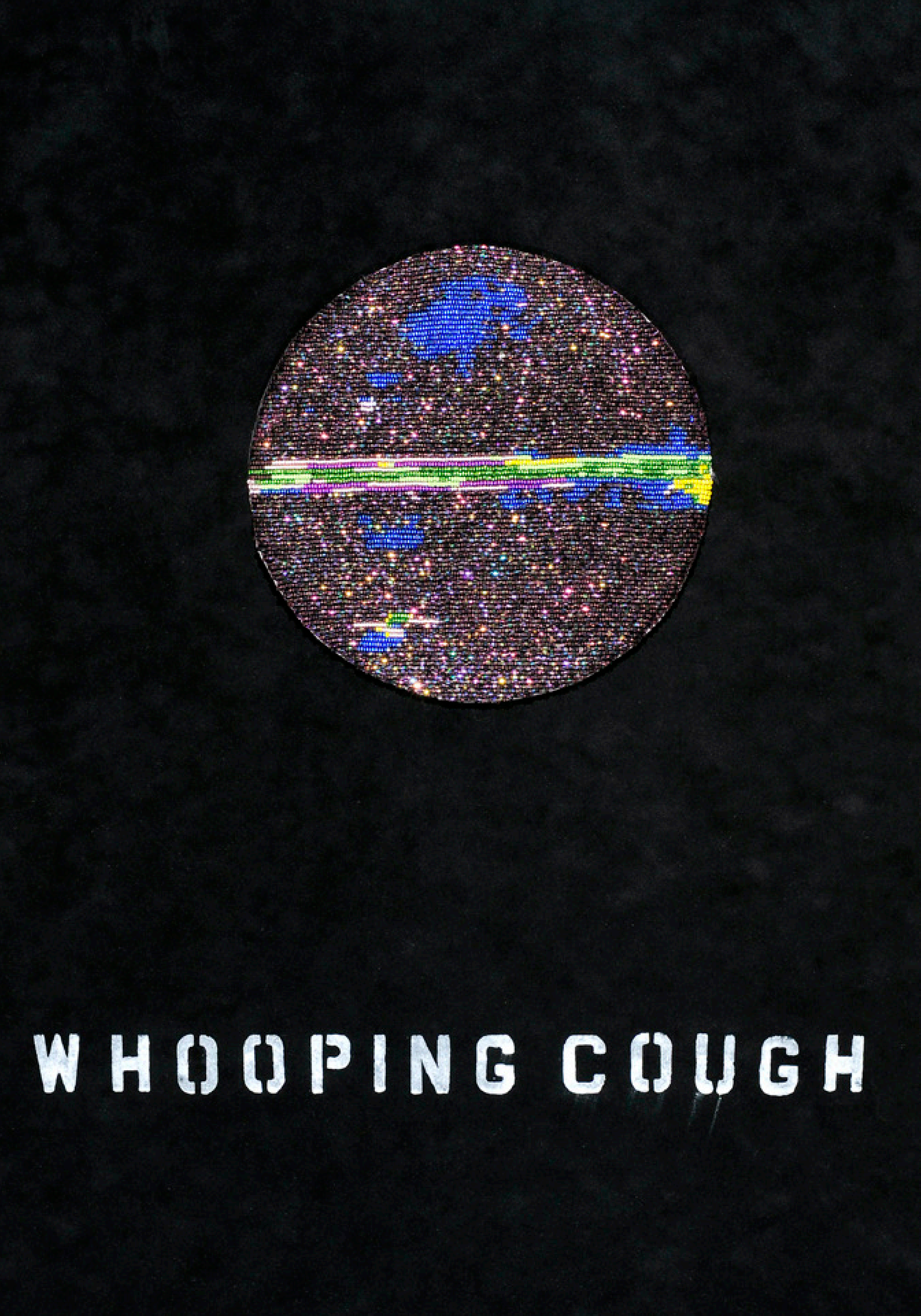

WHOOPING COUGH


YELLOW FEVER


SYPHILIS

Trading Series

Beads and viruses go hand-in-hand; new diseases and goods that traders brought to the Americas. Trading is a series of 12 images of viruses brought by the Europeans and a new disease that was brought back to Europe. The new diseases consisted of influenza, bubonic plague, measles, smallpox, typhus, cholera, scarlet fever, diphtheria, chicken pox, yellow fever and whooping cough. The disease that was taken back to Europe was syphilis; this image is in quillwork (Dyed porcupine quills and thread).

Beads are a visual reference to colonization; valuable furs were traded for inexpensive beads. On the plains beads were a valuable trade item, they replaced the method of using porcupine quills. Preparing the quills for decorating clothing was a long process that consisted of sorting the quills, preparing vegetal dyes and flattening the quill to sew down in patterns. Obviously beads were quicker to use, covered large areas and came in a wide variety of colours.

Trading examines both sides of European trade. Trade brought new items that revolutionized Native life. The iron pot made boiling food easier to digest, new trapping methods and the introduction of the horse are only a few. The downside was the decimation of many tribes through disease. Diseases quickly spread, arriving even before Europeans. ×

Fern code
Photo: Wayne Grazio, 2013 | Flickr cc

Article

What drives sustainability, innovation, and value in green design methods?

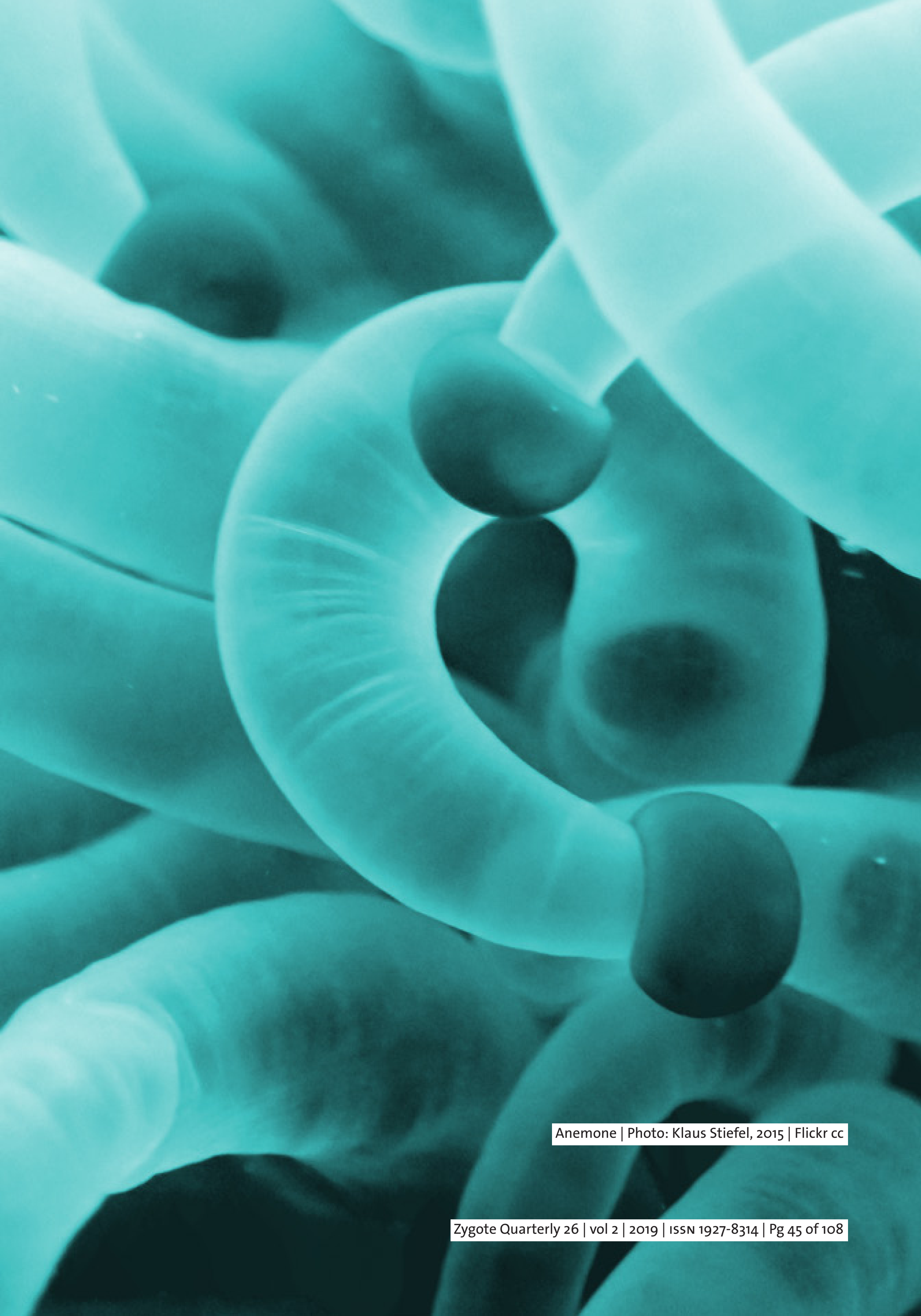
Jeremy Faludi

What drives sustainability, innovation, and value in green design methods?

There is growing interest in driving sustainability in business, and getting business to adopt green design methods like biomimicry, The Natural Step (https://thenaturalstep.org/), and Whole System Mapping (https://digitalcommons.dartmouth.edu/cgi/viewcontent.cgi?article=3810&context=facoa). But how do we do that if we don't know what value they provide? We need to know what works, what they are good for, to communicate their value to industry. I wanted to learn what people think are the general benefits of green design methods, as well as their sustainability, innovation, and other business benefits. I included innovation because sustainability is currently not enough by itself to motivate most companies or their engineering/design teams outside of specific industry sectors such as green buildings. Sustainability and innovation are linked, since sustainable solutions require novel approaches. Sustainability initiatives can also have ancillary benefits such as reducing manufacturing costs or regulatory risk.

Jeremy Faludi

As part of my PhD dissertation (http://faludidesign.com/work/publications/Faludi_2017_full_dissertation.pdf), I ran a series of workshops involving over 500 participants. Half were from industry – over 30 manufacturers and design consultancies, split between designers, engineers, and managers. Most industry participants brought real problems to work on. The other half were undergrad students from UC Berkeley taking a product design class – mostly engineers and some from business programs. Males comprised 48%, females 35%, and 17% did not indicate gender (Table 6.2 in dissertation). Attendance ranged from three people up to 25, split into teams of three to four. Each workshop covered either biomimicry, The Natural Step, or Whole System Mapping. More than half the companies had two different workshops on different days, and some participated in all three workshops. This article focuses primarily on how the participants perceived biomimicry.



Anemone | Photo: Klaus Stiefel, 2015 | Flickr cc

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For biomimicry, I provided a short lecture, then engaged them in activities to define the problem biologically, find strategies and models in nature using physical artifacts, identify the appropriate engineering and design principles, use AskNature.org for ideas relevant to their product, translate the strategies to buildable things, and use Life's Principles (https://biomimicry.net/the-buzz/resources/designlens-lifes-principles/). There was a two-hour and four-hour version of the workshop. In the two-hour version, they used Life's Principles to assess the sustainability of their design ideas. In the four hour workshop, they did this and then used Life's Principles to brainstorm new ideas.

Before the workshops, I surveyed the participants on what design methods they valued and why, what they valued in terms of innovation and sustainability, and whether they thought sustainability influenced factors such as legal risk and design process cost. I gave them the same survey after the workshop. In general, there were few statistically significant differences between the pre- and post-surveys, although there was a trend towards being more positive about green design as a result of the workshops. Prior to the workshop,

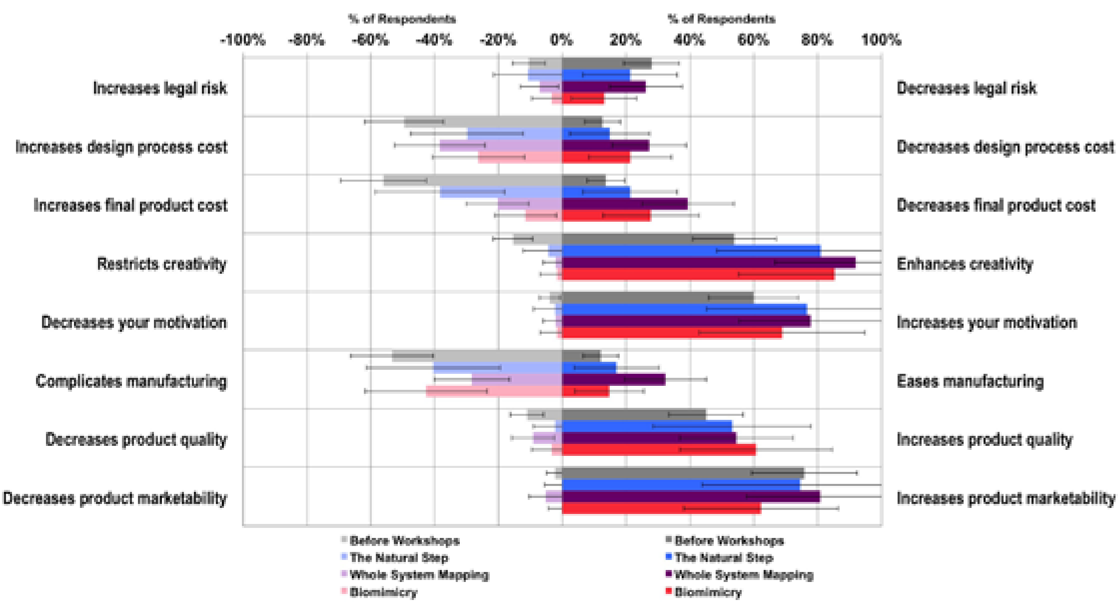

Figure 6.9 from Faludi 2017, reprinted with permission. Percent of respondents rating several positive (+) versus negative (-) effects of general sustainable design before workshops (in grey) and of the three sustainable design methods after workshops (in colors). For before workshops, n=127; for The Natural Step, n=48; for Whole System Mapping, n=96; for Biomimicry, n=57.

there were some who felt sustainability restricted creativity, but almost everyone after the workshop felt all of the design methods enhanced creativity. In the pre-survey, the majority felt sustainability would increase product cost, but in the post-survey, the majority felt that sustainability could decrease product cost, especially for biomimicry and Whole System Mapping (Figure 6.9).

I discovered from the post-workshop surveys that providing examples of successful biomimicry projects such as the Shinkansen train (https://zqjournal.org/editions/zq02.html p. 14) and the Eastgate Building (https://www.greenbiz.com/blog/2009/09/02/how-termites-inspired-mick-pearces-green-buildings) helped make the concepts of nature as mentor, model, and measure more meaningful and concrete. I was surprised that the examples were similarly valued to exploring artifacts from nature. Even exercises dedicated to translating ideas into to a buildable outcome (generally considered one of the hardest parts of doing biomimicry), were also not valued more highly than providing examples (Figure 6.6).

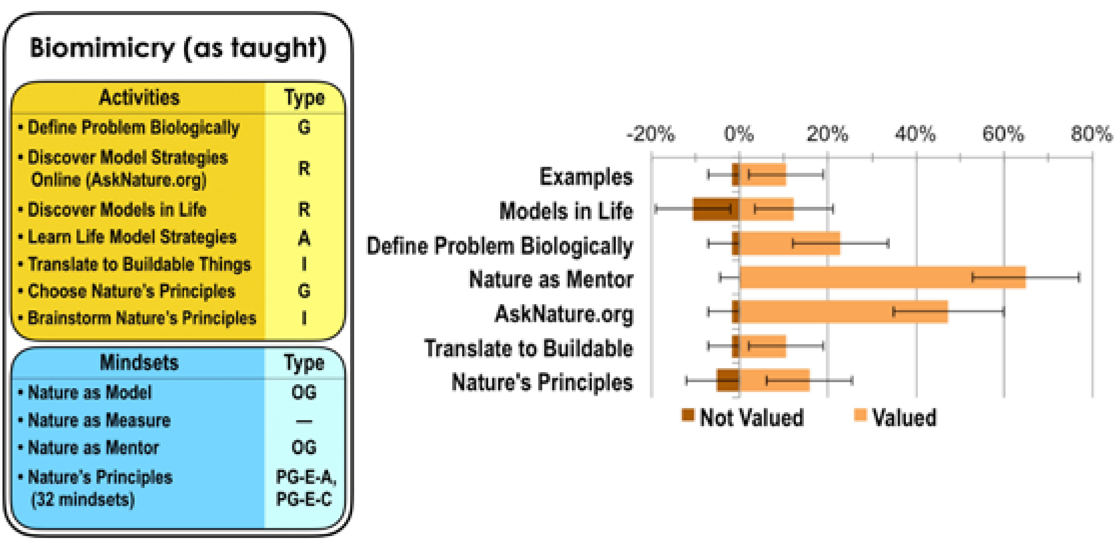

Figure 6.6 from Faludi 2017, reprinted with permission. Percent of respondents mentioning activities or mindsets they generally value or do not value in Biomimicry; n=57. “Models in Life” = Discover Models in Life. “Translate to Buildable” = Translate to Buildable Things..

crosse de fougère | Photo: christophe surman, 2017 | Flickr cc

What drives sustainability, innovation, and value in green design methods?

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Workshop participants strongly valued the general concept of looking to nature for inspiration. Out of three three design methods tested, they most often mentioned valuing AskNature.org for innovation – it is simple and generates ideas that are radically different from those generated by typical engineering or design teams, even if many of the ideas may not be implementable. Unfortunately, they did not strongly associate AskNature.org with sustainability. In general, participants did not score biomimicry highly on sustainability with the exception of Life's Principles, possibly because of its association with "nature as measure" (Figure 6.7). A number of participants argued that biomimicry should not be considered a 'green' design method because emulating nature often requires materials and processes that are unsustainable due to limitations in manufacturing capabilities.

I followed up with each company four to six months after the workshop to see if there were any long term changes. Figure 6.15 shows the percentage of survey responders who used the workshop design ideas and activities/mindsets in their jobs. The results were mixed, and not statistically significant due to the small sample size, but somewhat encouraging. Half of the

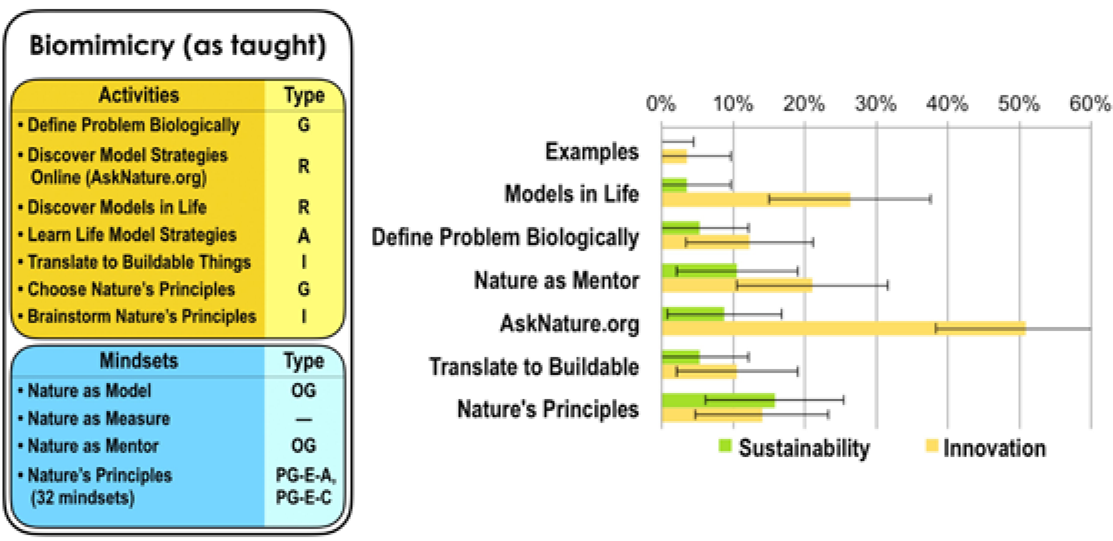

Figure 6.7 from Faludi 2017, reprinted with permission. Percent of respondents mentioning anything driving sustainability or innovation in Biomimicry; n=57. "Models in Life" = Discover Models in Life. "Translate to Buildable" =Translate to Buildable Things.

respondents for The Natural Step, three-quarters of the Whole System Mapping respondents, and one-eighth of the biomimicry respondents indicated that they had used or were influenced by the design ideas, activities, and mindsets.

I expected engineers to prefer Whole System Mapping, designers to prefer biomimicry, and managers to prefer The Natural Step. Surprisingly, though, the actual results did not support that – there were almost no demographic differences in who values what. The only statistically significant difference was that engineers in product development consultancies felt biomimicry enabled innovation but was less useful for sustainability, possibly because they were the most aware of the implications of getting things manufactured. The general lack of demographic differences is actually a good thing, though: it means we do not need to teach different design methods to different groups and roles, everyone can be on board with the same green design methods. Most of the important sustainability design decisions are made by businesspeople before designers and engineers get involved. Ultimately, we need designers and engineers to be part of the business and strategy sessions, and bringing

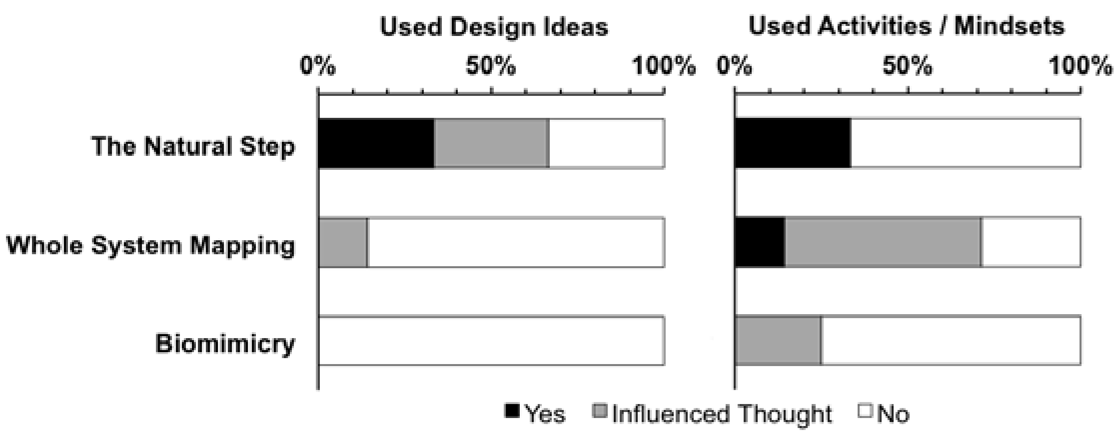

Figure 6.15 from Faludi 2017, reprinted with permission. Percent of follow-up interviewees reporting whether or not they used design ideas or activities/mindsets from the workshops. For The Natural Step, n=3; for Whole System Mapping, n=7; for Biomimicry, n=4..

them together doing the same green design method can help.

When working with industry clients as sustainability professionals promoting the benefits of biomimicry or other design practices, we need to remember that we are not our customers. They have different expertise, different constraints, and different mental models than we do. We can encourage them to be more sustainable, but it requires focus, effort, and an understanding of the constraints our clients face, particularly when developing biomimetic products that often need to fit within existing supply chain and manufacturing systems. There is a mismatch between what we want them to do and what they are capable of doing. The impact of a tool depends not only on the characteristics of the tool, but also the hands using the tool.

In my early interviews with designers, engineers, and managers, I found that no-one uses a specific green design method as an end-to-end process – they treat these methods as toolboxes that they mix and match as required for specific projects. We can make it easier for industry to adopt biomimicry by knowing what value they see in it, and knowing how to combine it advantageously with other design methods, like human centered design, Whole System Mapping, life cycle assessment, or other tools. This helps them get the most results for their time and effort, and can help integrate sustainable design practices into mainstream product design, even across many different contexts. Doing this requires an evidence-based approach to what professionals value and why, and experimentation with different ways of doing biomimicry and design. ×

About the author: Jeremy Faludi is an assistant professor of sustainable design at TU Delft, and until recently taught at Dartmouth College; he has also taught at Stanford and Minneapolis College of Art and Design. He designed the prototype of AskNature.org in 2004, and has contributed to six books on sustainability, including *Worldchanging: A User's Guide to the 21st Century*. A bicycle he helped design appeared in the Smithsonian Cooper Hewitt museum in 2007, and he wrote the OECD's recommendations for green 3D printing policy in 2017. He previously published "Biomimicry's Place in Green Design" (https://zqjournal.org/editions/zq03.html p. 120) in ZQ03 on the 'fit' of biomimicry with design processes and green design methods.

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Anemone and two polychaetes | Photo: NOAA Ocean Exploration & Research, 2015 | Flickr cc

Neo3
Photo: Nico Nelson, 2011 | Flickr cc

Article

Perspectives: Bringing Business Thinking to Biomimetic Innovation

Jacques E. Chirazi

Perspectives: Bringing Business Thinking to Biomimetic Innovation
Jacques E. Chirazi

This article is part of the “Perspectives on Stories from the Trenches” series in ZQ24 (https://zqjournal.org/editions/zq24.html p. 40) and ZQ25 (https://zqjournal.org/editions/zq25.html p. 38), which explored other viewpoints related to the “Stories from the Trenches” series in ZQ21, ZQ22, and ZQ23. Jacques Chirazi shares his experience as a consultant and helping entrepreneurs be successful.

Ryan Church, Rachel Hahs, and Norbert Hoeller

Bringing Business Thinking to Biomimetic Innovation

Launching a new enterprise—whether it’s a tech start-up, a small business, or an initiative within a large corporation—has always been a hit-or-miss proposition. According to the decades-old formula, you write a business plan, pitch it to investors, assemble a team, introduce a product, and start selling as hard as you can. And somewhere in this sequence of events, you’ll probably suffer a fatal setback. The odds are not with you: new research by Harvard Business School’s Shikhar Ghosh shows, 75% of all start-ups fail.[1]

Over the years, I’ve seen a lot of entrepreneurs succeed and a lot of them fail. The ones who succeed generally have five components in place before launching their venture: identify a genuine need, attract experienced team members, have access to resources, create customer interest, and develop a viable business model.

Jacques Chirazi

1. Identify A Genuine Need

If you can't pinpoint your customer’s problem, you won't be able to solve it. Worse, you will waste time and lose credibility. You must define the problem clearly, and do it from the customer's perspective. The problem should be one the customer sees value in solving. To identify these challenges/opportunities, you need to ask the right questions, test various hypotheses and actively listen.

I can’t tell you how many aspiring entrepreneurs I’ve met who have fallen in love

Neo5 | Photo: Nico Nelson, 2011 | Flickr cc with an idea; it's an ingenuous and even amazing technological breakthrough. The only problem is, no one needs it, wants it, or is willing to pay for it. I tell them, "You have a great solution – now you need to find a problem it solves." It's far easier to do it the other way around.

True business opportunities meet needs or solve pain points people have in their lives. Most successful entrepreneurs starting a new business venture have worked in the industry, in a related industry, or are very familiar with the products, services, and problems through personal experience. They discover a need and verify it through direct observation.

2. Assemble a stellar experienced team

Knowing the products, services, and problems in an industry not only helps you avoid the pitfalls of trial-and-error learning, but it also gives all key stakeholders the confidence that you and your team have the knowledge and experience to build this business. Your team's experience and credibility are extremely important to potential investors, customers, suppliers, and strategic partners. If your team is lacking the skills and experience to build your business, you need to surround yourself with subject-matter experts, advisors, and partners who can fill in these knowledge and skills gaps.

3. No money, no business? Think again.

Many would-be entrepreneurs think they need money to start their new venture. However, successful entrepreneurs use a host of other resources to get started: find relevant mentors/subject-matter experts, participate in various business competitions, join incubator/accelerator programs, apply for grant funding, and engage/partner with early adopter (customers). The important thing is to determine what your new venture requires, then go out and find the resources you need to get started. You don't necessarily need funding, but you do need resources.

4. Create customer interest

Knowledgeable entrepreneurs strive to have customers committed to purchase their products or services as soon as they launch their ventures. In order to reach this step, you need to complete an extensive customer discovery and validation process. Customer discovery is all about figuring out who your customers are and how to reach them. Customer validation is about making sure that your research is correct and developing your business model to reflect that information. Essentially, if you can validate your customer-related assumptions then you have potentially found customers who will buy your product.

5. Define a viable business model

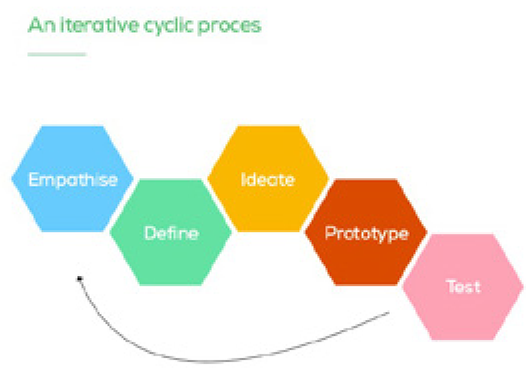
A company's strategy defines the company's market and customers, and determines the value proposition for the customer's business. The business model focuses on how a start-up captures some of the value for itself (that is, how the company makes money). It determines the viability of the company. According to Steve Blank, a well-known entrepreneur and Adjunct Professor at Stanford, "a startup is a temporary organization designed to search for a repeatable and scalable business model. ... A company is a permanent organization designed to execute a repeatable and scalable business model."[2]

So, how do you solve problems?

It's human nature to love answers; unfortunately, that very tendency can prevent us from coming up with truly delightful solutions. When faced with a problem, we tend to stop ideating as soon as we think we've found an answer. This Einstellung Effect (https://en.wikipedia.org/wiki/Einstellung_effect) keeps us from finding the right solutions since our first ideas are rarely our best ideas.

In the world of entrepreneurial incubation, design thinking, a user-centered way to conceive and create a successful product, is often compared and contrasted with the lean startup approach, which is more engineering-based and quantitative[3]. The two methods are far from mutually exclusive, however, as both seek to effectively serve customers' needs through a systematic, low-risk path to innovating in the face of uncertainty.

Design thinking is a human-centered way to envision and create a successful product. It incorporates analytical, synthetic, divergent, and convergent thinking to create



Source: Design Thinking Process | Stanford Design School

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Jacques E. Chirazi

a wide number of potential solutions and then narrow these down to a "best fit" solution. Designers must solve problems in order to add value through design – the design thinking process forces you to put yourself in the customer's shoes.

This is in contrast to the scientific method of problem solving which requires a highly-defined problem which focuses on delivering a single solution.

Biomimicry entrepreneurs/changemakers need to begin their entrepreneur journey by understanding the problem they are trying to solve. Is the identified problem worth solving? What problem (and/or pain points) are you trying to solve? Using a systems thinking approach will help entrepreneurs develop a broader understanding of the problem and unearth potential leverage points and critical connections in the industry/sector. What is the scope of the problem you are trying to solve? What are the non-negotiables, including social/economic/environmental factors, market forces, functionality, durability, cost, and accessibility?

Who are your targeted customers/users? Do you understand their specific pain points/needs and desires? This stage requires empathy toward the targeted customers/users. In its simplest and purest form, empathy enables us to not only experience and understand another person's circumstances, but it also puts us in our customers' shoes to experience what they are feeling.

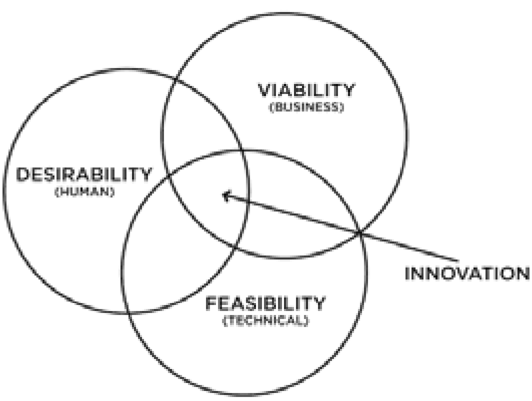
Source: California State University Channel Islands, Minder Chen

The trifecta of desirability, feasibility, and viability (IDEO)

Five years ago, I helped co-create a commercialization platform for biomimicry innovations at the Biomimicry Institute. The Launchpad provides entrepreneurs and changemakers with the resources they need to launch and grow successful biomimicry businesses, accelerates the development and commercialization of biomimicry innovations, and helps create the next generation of sustainability entrepreneurs.

We aim to turn the daunting task of starting a company into a set of core actions that will lead to innovative companies while training the next generation of sustainability entrepreneurs. Participants can be eligible to win cash awards, including the $100,000 Ray of Hope Prize®, sponsored by the Ray C. Anderson Foundation, a $25,000 second place prize, and additional cash prizes.

The Launchpad is structured in two stages, starting with a four-month market and technology validation phase where the teams focus on problem identification and scoping, customer discovery/validation, value proposition, market analysis, and technology validation. Then selected teams advance to a five-month customer development and proof of concept stage where the teams focus on customer development, market assessment, go-to-market readiness, proof of concept/prototyping, and field testing. In both stages, teams are assigned a domain-expert business advisor.



Source: IDEO.org

Nucleário (https://innovation.biomimicry.org/team/nucleario/), the 2018 Ray of Hope Prize winner, developed an all-in-one reforestation solution that mimics elements of natural forest progression to reduce maintenance costs and improve seedling survival rates. The multifunctional device was created to function like leaf litter, preventing soil leaching and increasing soil moisture levels, and protecting seedlings from leafcutter ants and invasive grasses. It also mimics how bromeliads collect water from rain and dew to provide a microclimate that attracts biodiversity[4].

Biomimicry as innovation

Within the biomimicry community, we need to remind ourselves that biomimicry is an innovation tool, but like any other innovation tool/methodology, there are limitations. We need to stop thinking that the biomimicry methodology can address everything without a deeper understanding of the problem and the customers/users. To develop and design meaningful solutions

Neo4 | Photo: Nico Nelson, 2011 | Flickr cc

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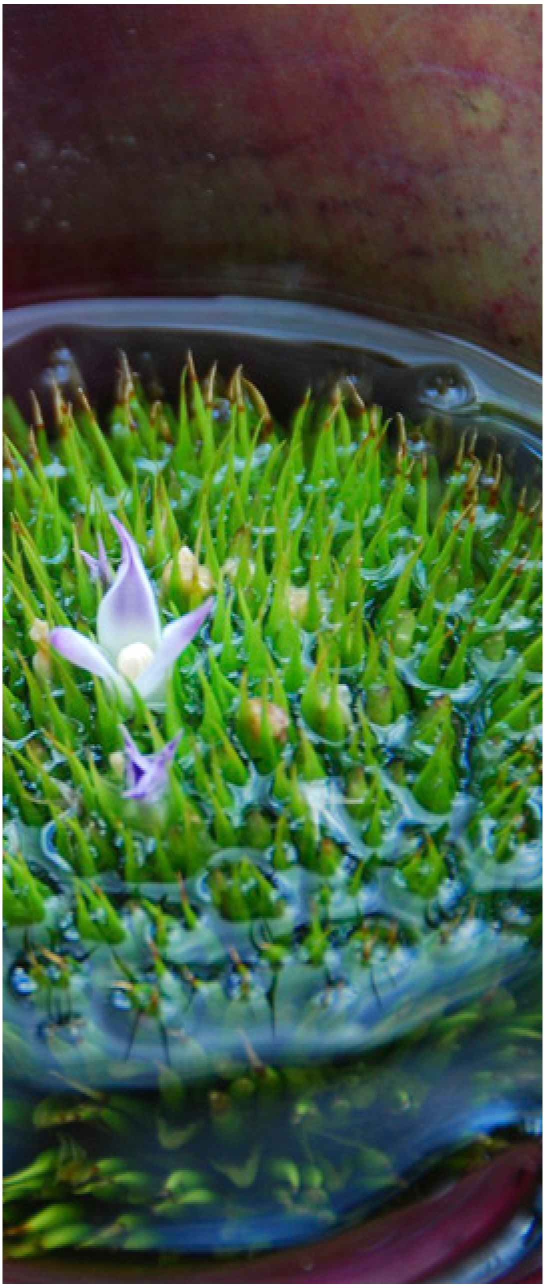

Bromeliad power
Photo: Jose Nicdao, 2008 | Flickr cc

that address real problem for businesses and end-users, we need to step back and listen to the user's needs, pains and desires. As biomimics, our task is to help identify these relevant business challenges and then take this opportunity to position biomimicry as a tool to potentially address and solve these problems.

To accomplish this task successfully, we need to be asking what are we trying to accomplish, which relevant problem should we solve, and is the problem worth solving? To address these questions, I found that the most successful companies marry two important ideologies: design thinking and lean startup methodology (http://thelean-startup.com/principles) – both seek to effectively service customers' needs through a systematic, low-risk path to innovating in the face of uncertainty.

However, these methodologies are missing a critical component, the 'environmental lens'. An 'environmental lens' can help businesses address environmental and social, as well as economic outcomes, and adopt more sustainable practices to radically transform their business processes and operations. There is an opportunity to infuse biomimicry/restorative business principles in the design thinking and lean startup methodologies to create a new type of business 'tool' that is designed to better tackle today's socioeconomic and environmental needs – leaving the world better off than before. ×

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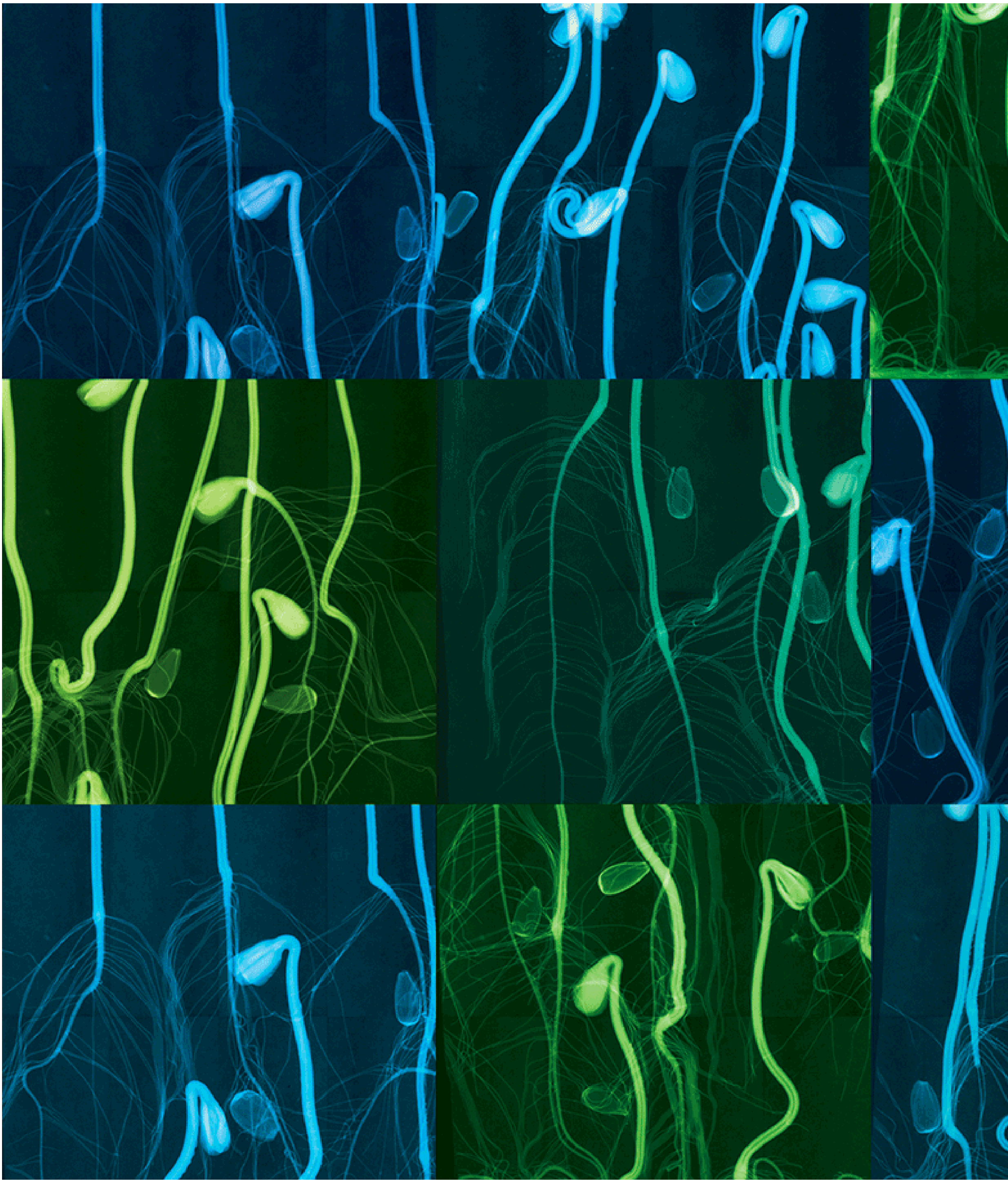
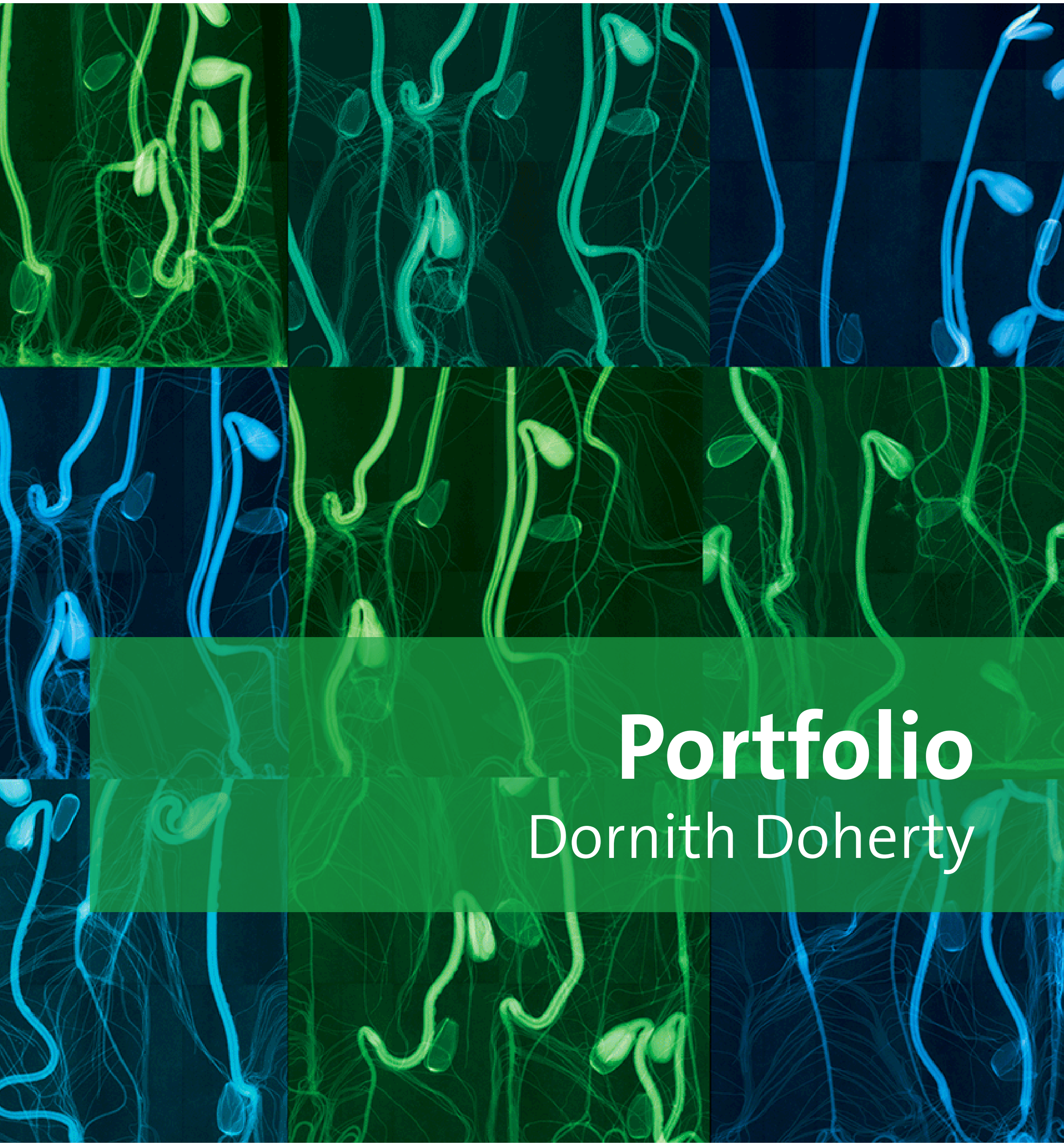
About the author: Jacques E. Chirazi earned his MS in Biomimicry from Arizona State University and is also a Certified Professional, Biomimicry Expert, Adjunct Instructor and, Business Adviser and Writer. As an independent consultant, Jacques has helped build biomimicry startups, published scientific research, and designed/launched the Biomimicry Launchpad, an accelerator program that helps early-stage entrepreneurs bring nature-inspired solutions to market, and inspire entrepreneurs to challenge the status quo. With a passion for learning about the natural world and understanding how nature could transform the corporate environment, his long-term vision is to create new business models and financial instruments to accelerate the commercialization of biomimetic solutions.

We would appreciate your feedback on this article:



Sunflowers | Archiving Eden
Dornith Doherty



Portfolio

Dornith Doherty

Portfolio
Dornith Doherty

A 2012 Guggenheim Foundation Fellow, Dornith Doherty was born in Houston, Texas and received a B.A. cum laude from Rice University and a MFA in Photography from Yale University. She currently resides in Southlake and is Distinguished Research Professor at the University of North Texas, where she has been on the faculty since 1996. In addition to the Guggenheim Fellowship, she has also received grants from the Fulbright Foundation, the Japan Foundation, the Indiana Arts Commission, and the United States Department of the Interior, the University of North Texas, and the Houston Center for Photography. She received the Honored Educator Award from the Society of Photographic Education South Central Conference in 2012 and, more recently, the Texas Legislature named her 2016 Texas State Artist 2D.

Dornith Doherty

Archiving Eden (2008- Present)

Since 2008 I've worked in an ongoing collaboration with renowned biologists at the most comprehensive international seed banks in the world: the United States Department of Agriculture, Agricultural Research Service's National Center for Genetic Resources Preservation in Colorado, the Millennium Seed Bank, Royal Botanic Gardens, Kew in England; and PlantBank, Threatened Flora Centre, and Kings Park Botanic Gardens in Australia. In this era of climate change and declining biodiversity, seed banks play a vital role in ensuring the survival of genetic diversity in wild and agricultural species by collecting, researching, and storing seeds in secure vaults.

Utilizing the archives' on-site x-ray equipment that is routinely used for viability assessments of accessioned seeds, I document and subsequently collage the seeds and tissue samples stored in these crucial collections. The amazing visual power of magnified x-ray images, which springs from the technology's ability to record what is invisible to the human eye, illuminates my considerations not only of the complex philosophical, anthropological, and ecological issues surrounding the role of science and human agency in relation to gene banking, but also of the poetic questions about life and time on a macro and micro scale. I am struck by the power of these tiny plantlets and seeds (many are the size of a grain of sand) to generate life and to endure the time span central to the process of seed banking, which seeks to make these sparks last for two hundred years or more.

Use of the color delft/indigo blue evokes references not only to the process of cryogenic preservation, central to the methodology of saving seeds, but also to the intersection of east and west, trade, cultural exchange, and migration. Lenticular animations created from the collages present still-life images of an archive that appears to change color or move when viewed from different angles. This tension between stillness and change reflects my focus on the elusive goal of stopping time in relation to living materials, which at some moment, we may all like to do.

Could you tell us about this series?

In 2008, I read about the pending completion of the Svalbard Global Seed Vault located on an island only 600 miles from the North Pole. This remote and secure seed bank is buried deep inside a mountain so tall that if both polar ice caps melt, the collection of seeds will remain safe. When I read that a modern day Noah's ark for plants had been built near the North Pole, I immediately wanted to photograph it. I was inspired by the simultaneously optimistic and pessimistic nature of the effort to create a global seed bank. On one hand, volunteers, scientists, and governments from around the world are collaborating to create the first truly global botanical back-up system. But, on the other hand, the bleak gravity of climate change and political instability has created the need for an inaccessible and fortified vault. In the time between my first impulse to record the Svalbard Vault and now, Archiving Eden expanded into a wide-ranging expeditionary project that explored almost 20 national seed banks on five continents, from Australia to Brazil.

As I photographed the constant, agonizing quest to sustain the spark of life in tiny, vulnerable seeds, many only the size of a grain of sand, I became fascinated not only by the complex issues surrounding the role of human agency in relation to genebanking but also questions about extending life and considering time at radically different scales. This led me to collaborations with research biologists at the seed banks who allowed me to use on site x-ray machines to make images of the seeds. So Archiving Eden has two parts: the photographs of the spaces and technological interventions required

Portfolio
Dornith Doherty

to store the seeds in a state of suspended animation and digital collages made from x-rays of materials safeguarded in the banks.

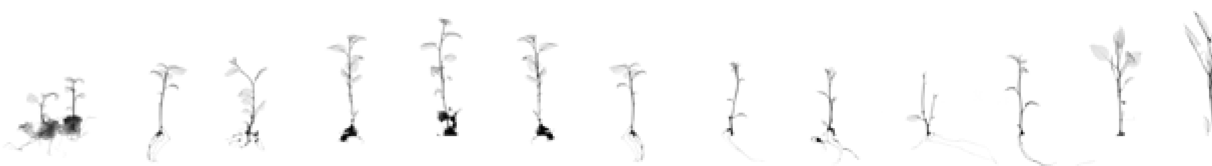
What kind of techniques do you use for your work?

I have been working on Archiving Eden for more than a decade. Originally, I started the documentary aspect of the project with a view camera and 4x5 inch sheet film. As the project progressed, I switched to a DSLR used with a custom stitching head that allowed me to photograph the sites and subsequently assemble the final images at very high resolution. (About 2.5 meters tall at 300ppi resolution)

The x-rays used in the digital collages were captured at a few of the seed banks that had labs with the necessary research machines. Working nonstop for a few days at a time, I would amass a large archive of digital x-rays of seeds and plantlets made from research specimens stored in the seed bank, and upon return to my studio in Texas, I would create digital collages like Columbian Exchange I, Banksias or Pycnantha that you see in this publication. The extraordinary visual power of x-rays, springing from this technology's ability to record what is invisible to human vision, allows a different way for me to address some of my poetic concerns. I am interested in creating work that is open-ended, escapes categorization, and can draw out subtle details that will allow for multiple interpretations and resonate with many of the questions I have about the race between reproductive power and extinction.

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

The stewardship of natural resources and the challenging complexity of human interaction with our world are of utmost



importance to me, so my work is linked thematically through a concern for the environment. My practice is to simultaneously pursue a series of long-term projects, and with each, I tend to shift technical or other aspects of the picture making, which results in a distinct visual identity and style for the individual projects.

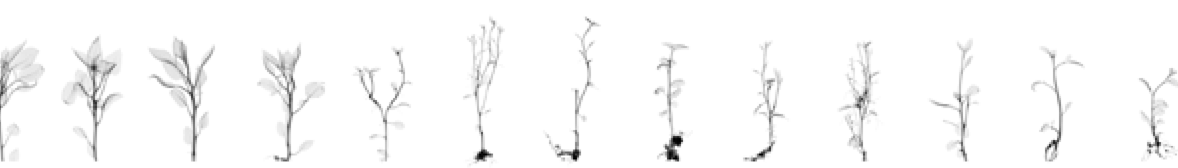
Once I start a project, my next step is to research all I can about a subject. Even though the resulting images I make may be fictional or open-ended, they have a foundation in research.

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

I have always loved 19th century expeditionary photography that brought images of remote locations to light. I love to think about how photography works: that when I am in the field, I am collecting light rays directly from the scene onto a mechanical recording device. That connection to the original scene, whether it's an x-ray or a traditional photograph, is very special to me. It is a privilege to make inaccessible places visible for others to see and think about. It's my hope that the experience is like reading a novel: you have an intimate, one-on-one experience with a work of art, and maybe the work makes you think about things in a way you hadn't considered before.

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

My sources of inspiration are so varied! I am a voracious reader of both fiction and nonfiction, and literary sources conjure images and weave themes, while allowing time for reflection. I am also a huge fan of seeing artwork in person, the physicality of the pieces are so different from the experience of seeing something online.



Then and Now Potato Diversity and the Irish Diaspora | Archiving Eden
Dornith Doherty

Portfolio

Dornith Doherty

Can you tell us what you have learned from the scientists you interact with?

In my case, scientists have been invaluable collaborators, not only for sharing their research with me and providing access to these high security spaces and rare specimens, but also, through longer-term collaborations, which sometimes included their growing seeds for me to x-ray.

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

In addition to continuing work on Archiving Eden, I am working on a project called Atlas of the Invisible. This project is a visual rumination about air and the effect air pollution has on birds as they move through the sky.

What is the last book you enjoyed?

This has been a great year for non-fiction. I've enjoyed *The Invention of Nature* by Andrea Wulf, *The Evolution of Beauty* by Richard Prum, and *The Genius of Birds* by Jennifer Ackerman.

What are your favorite 3 websites, and why?

Hyperallergic: https://hyperallergic.com – wonderful, wide ranging, inclusive coverage of art

Women photographers: https://www.fire-cracker.org

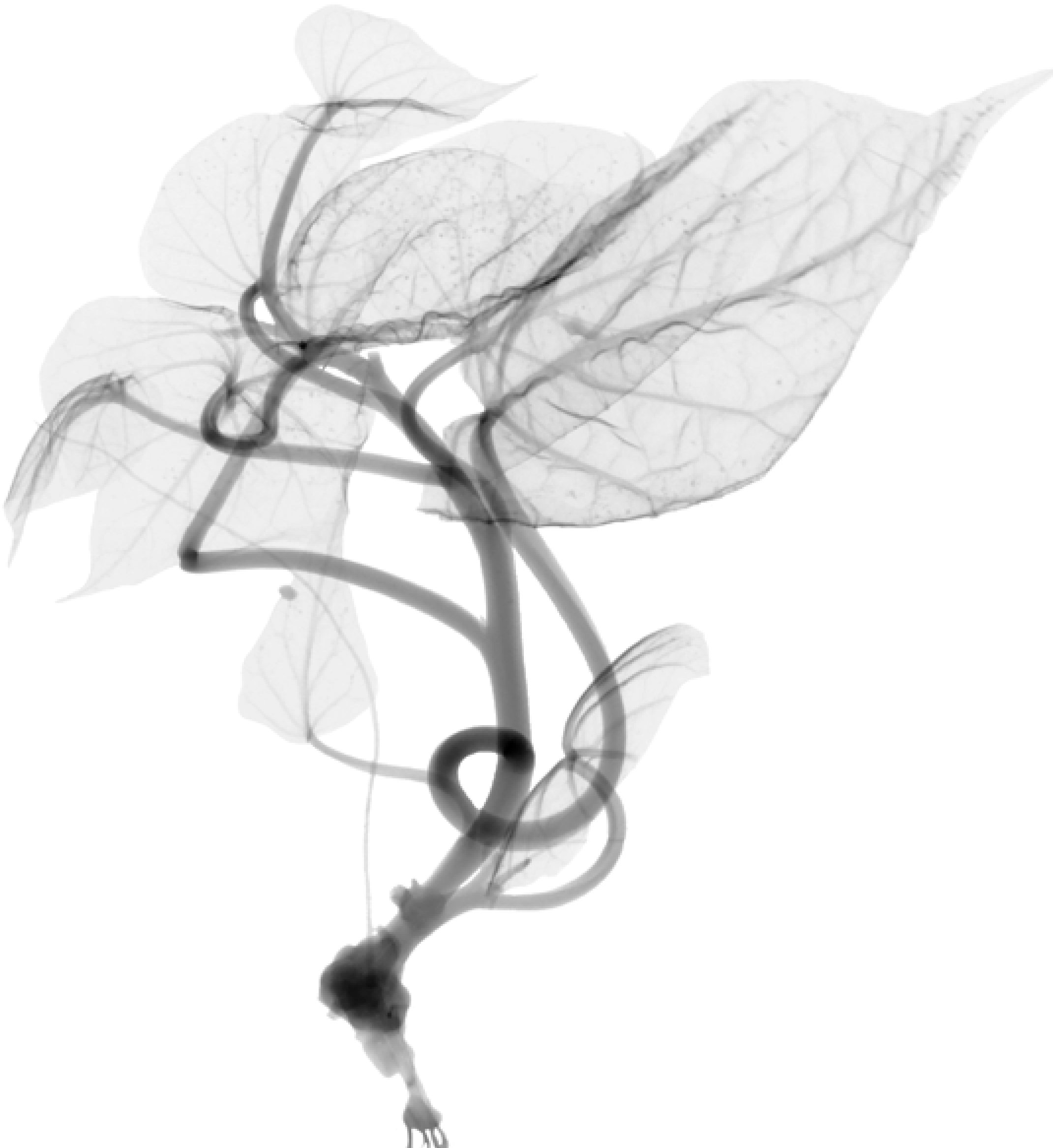
Elizabeth Avedon's blog: https://elizabethavedon.blogspot.com – wonderful interviews and essays

What's your favorite motto or quotation?

This one is a current favorite:

"Great is the power of steady misrepresentation; but the history of science shows that fortunately this power does not long endure." - Charles Darwin, *Origin of the Species*, Chapter XV

We would appreciate your feedback on this article:



Sweet Potato Clone | Archiving Eden
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Eucalyptus I | Archiving Eden
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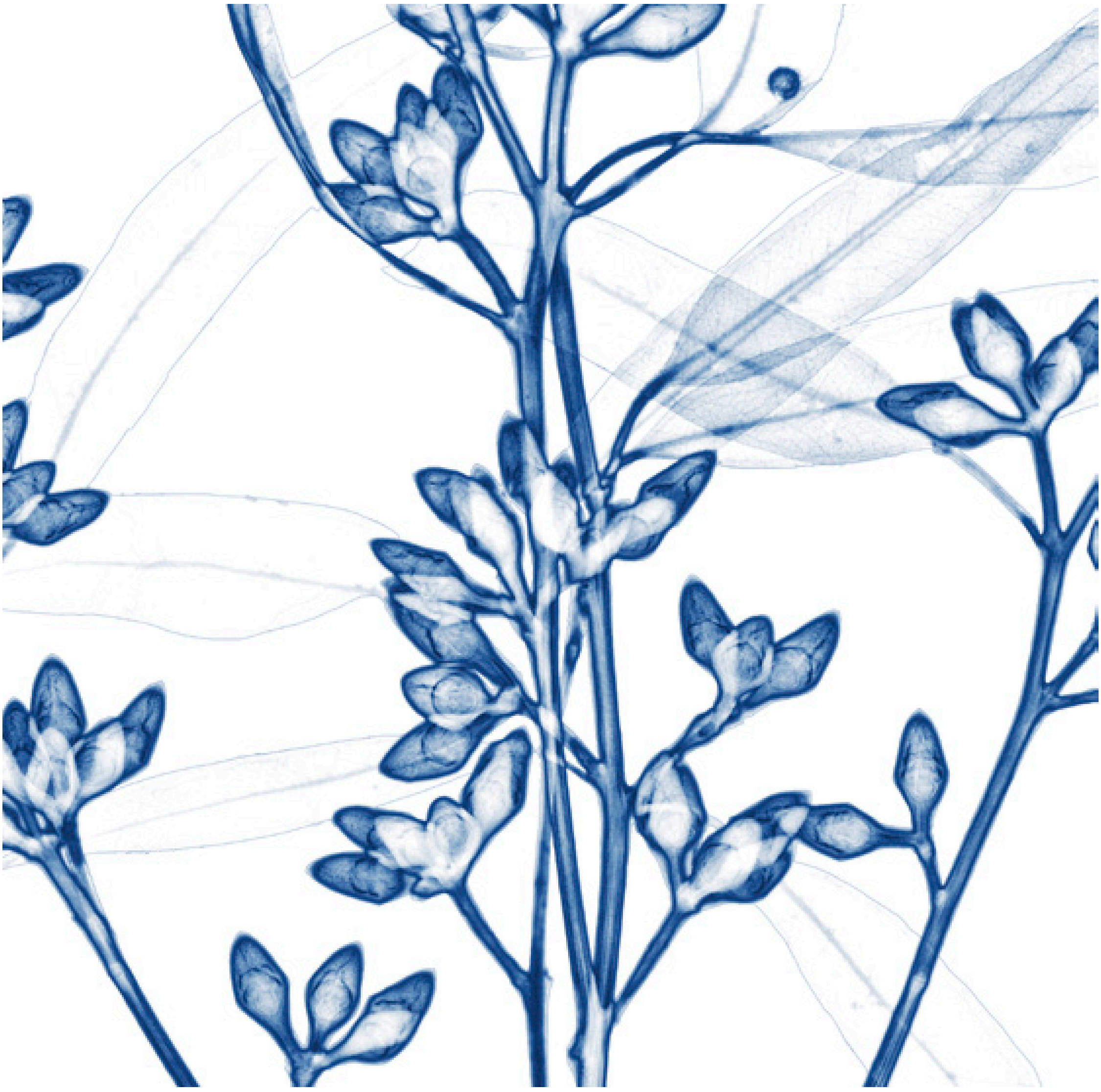
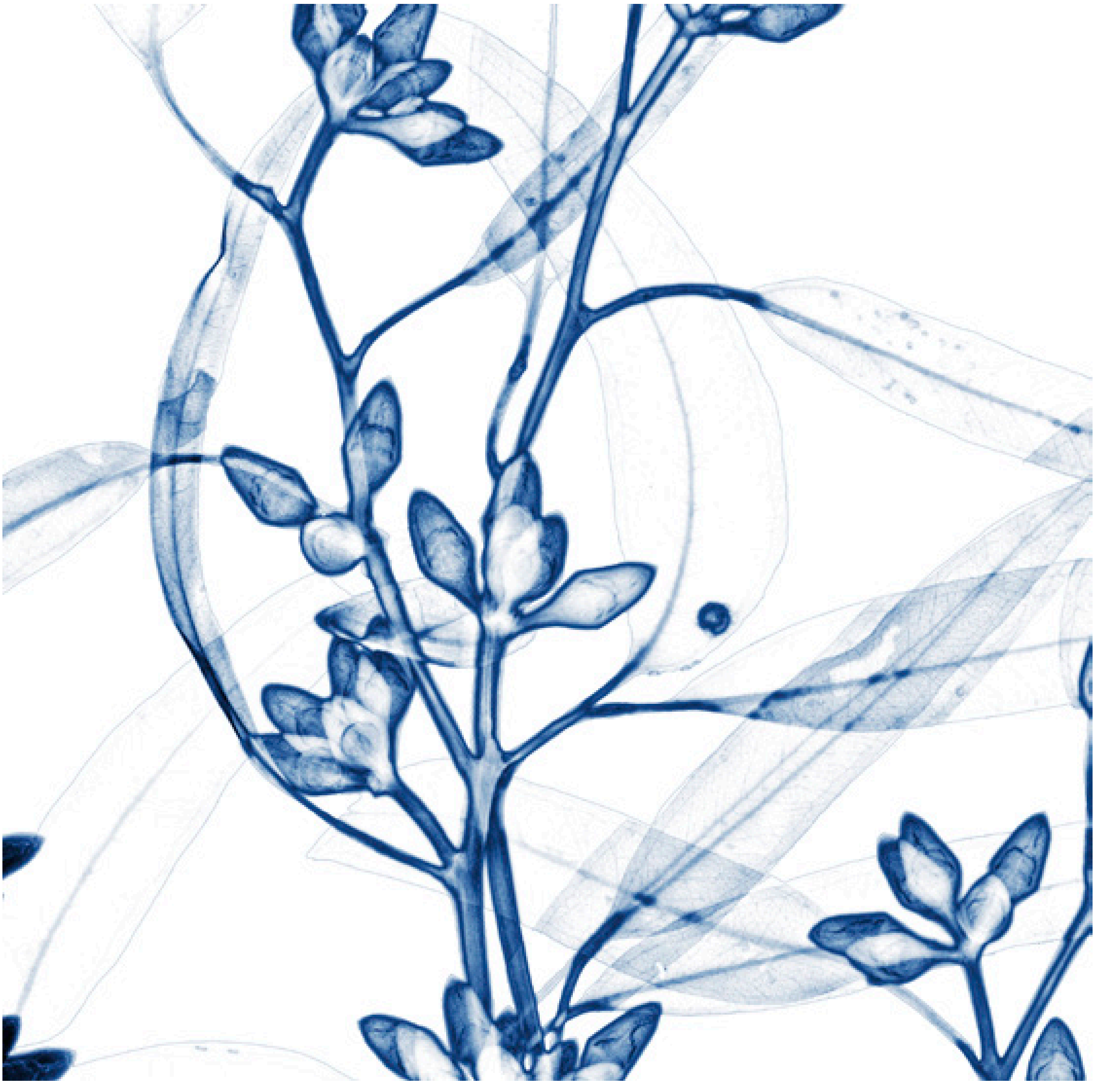


Eucalyptus II | Archiving Eden
Dornith Doherty



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Eucalyptus IV | Archiving Eden
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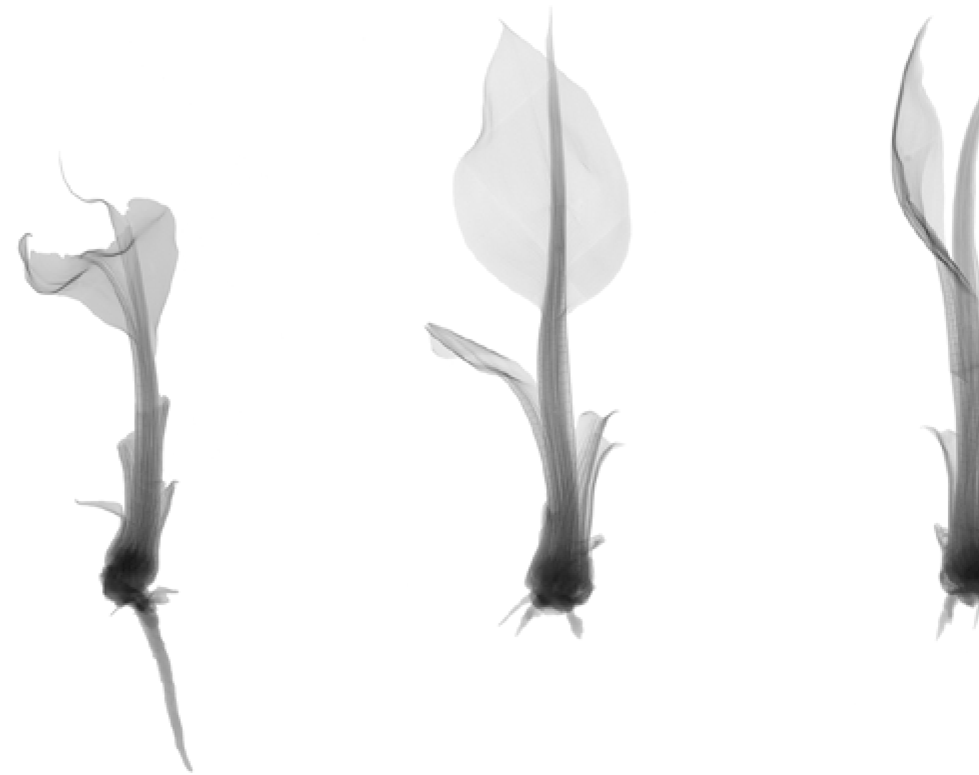

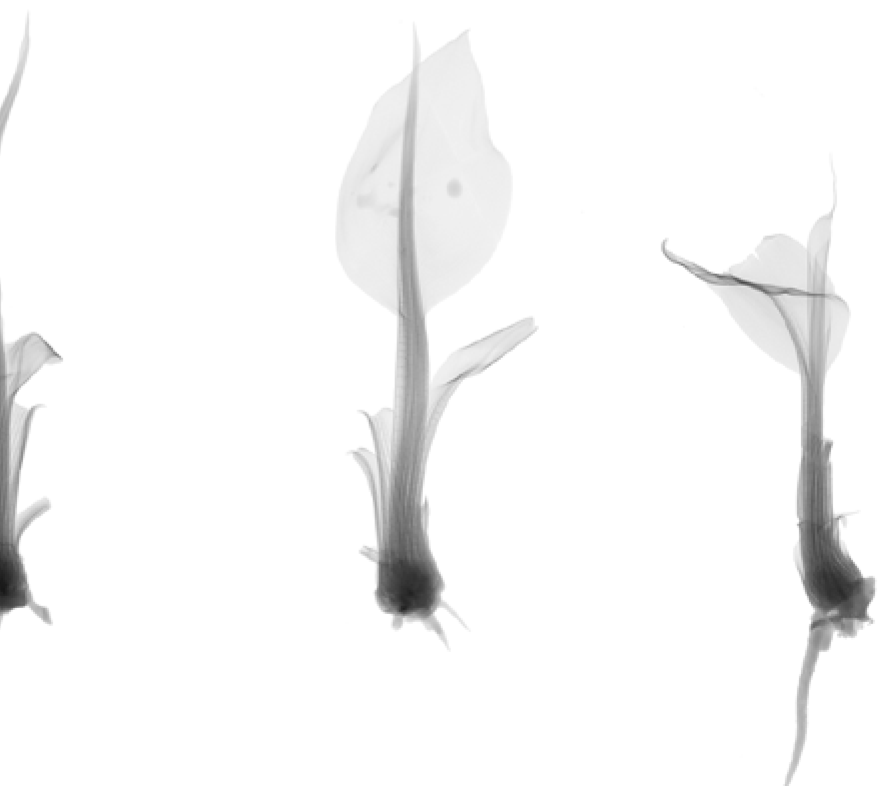

Banana Clones | Archiving Eden
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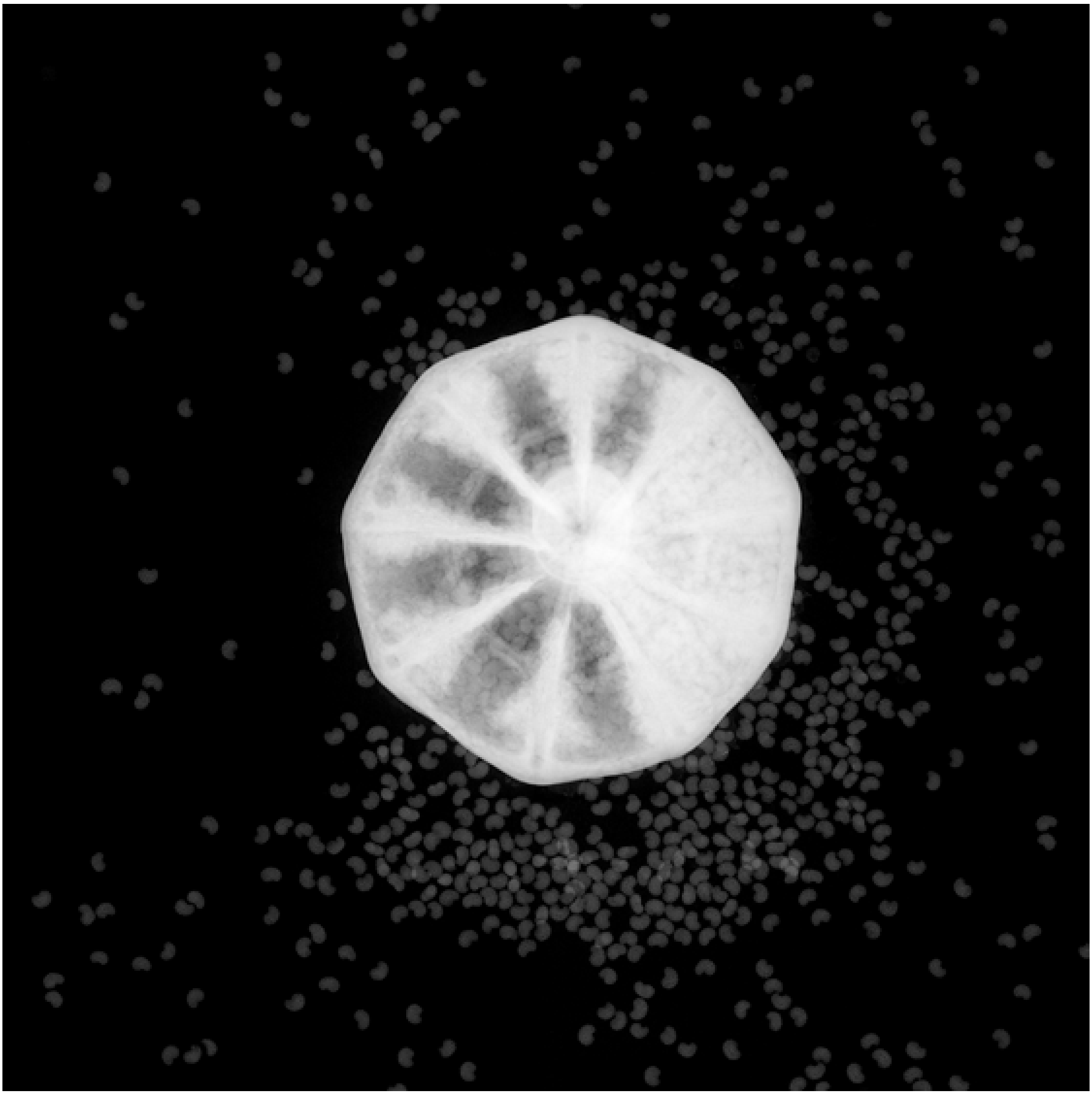

Poppy | Archiving Eden
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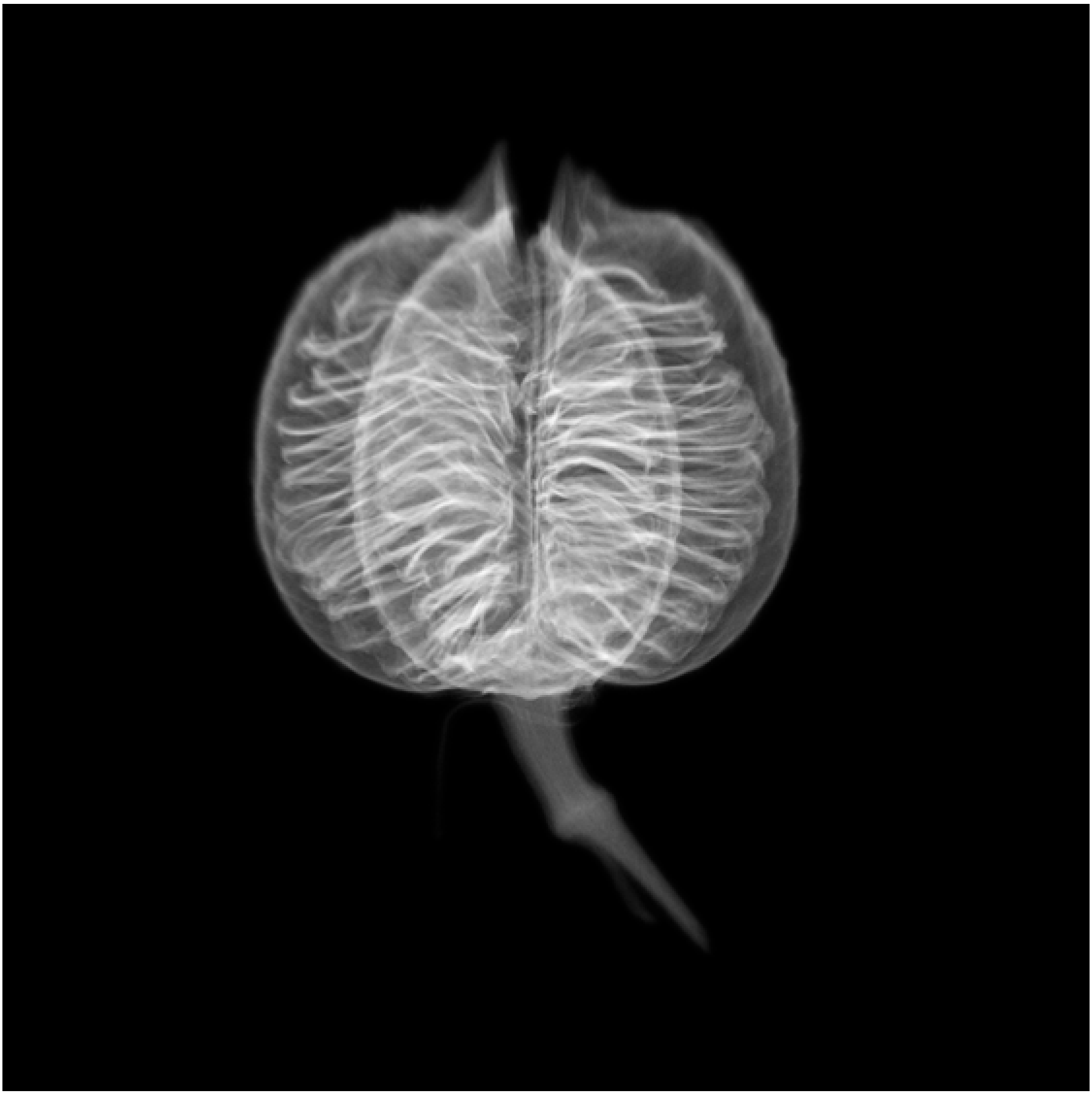

Red Yucca | Archiving Eden
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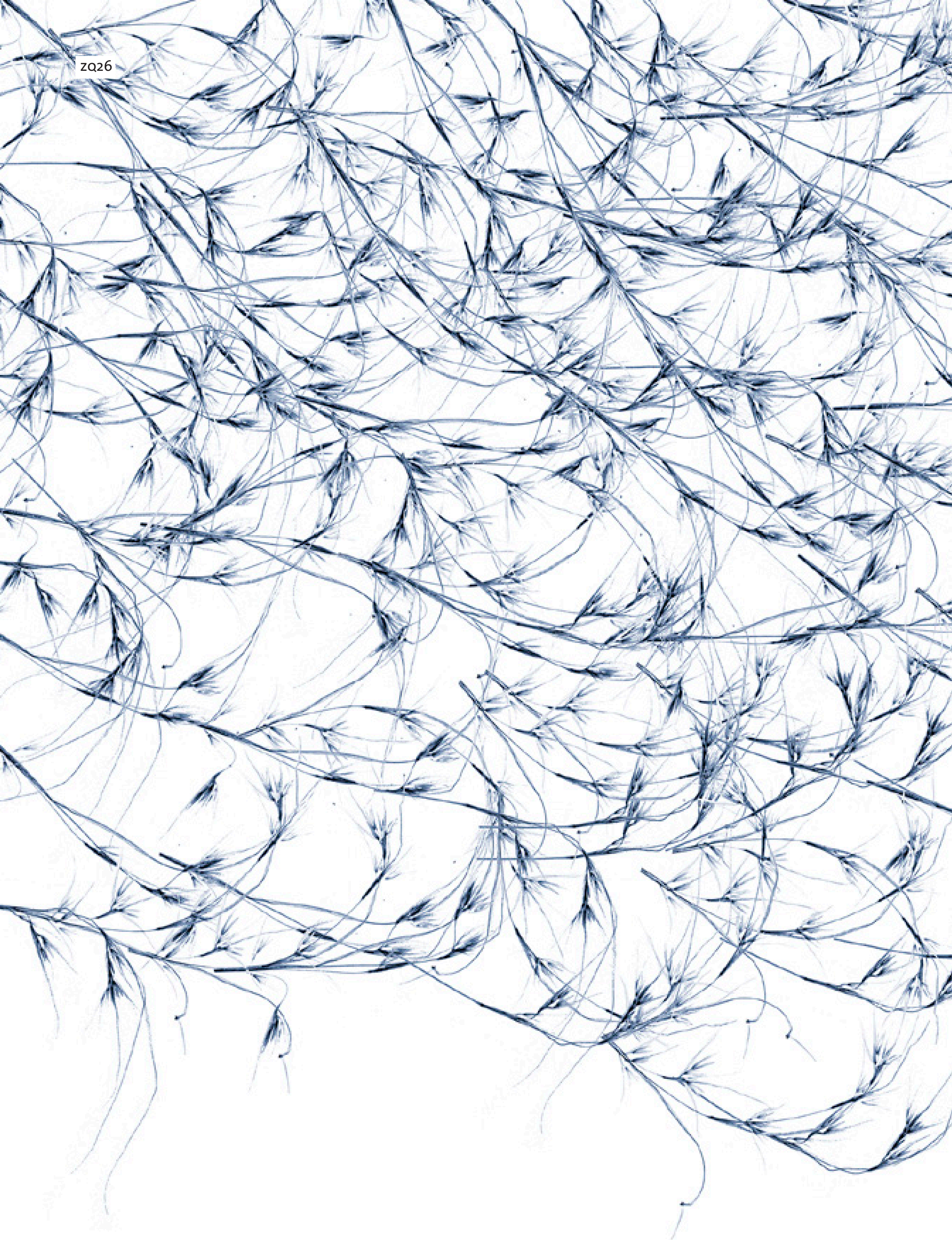

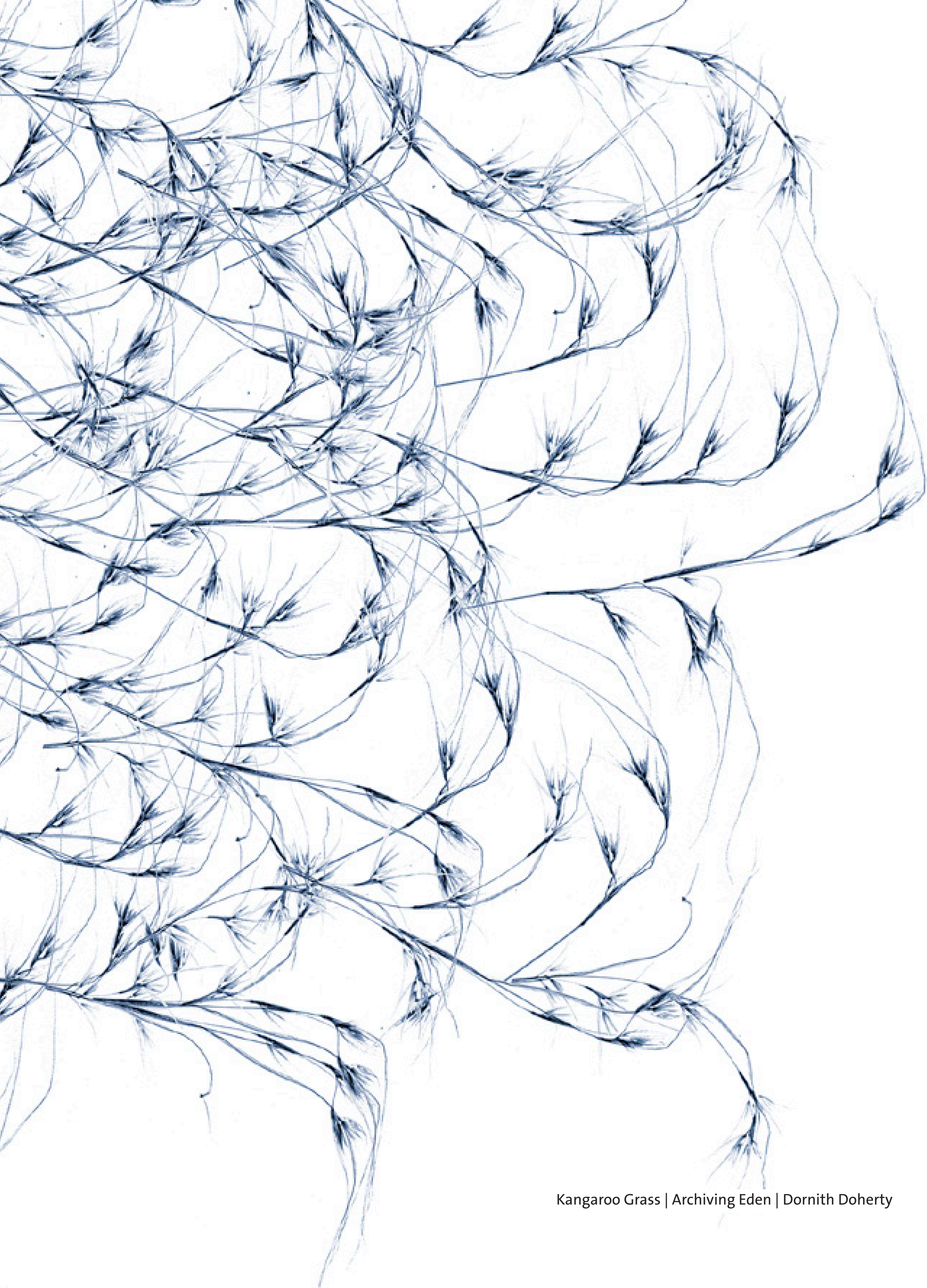

Kangaroo Grass | Archiving Eden | Dornith Doherty

Columbian Exchange I & III | Archiving Eden
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Pear Tree Clone | Archiving Eden
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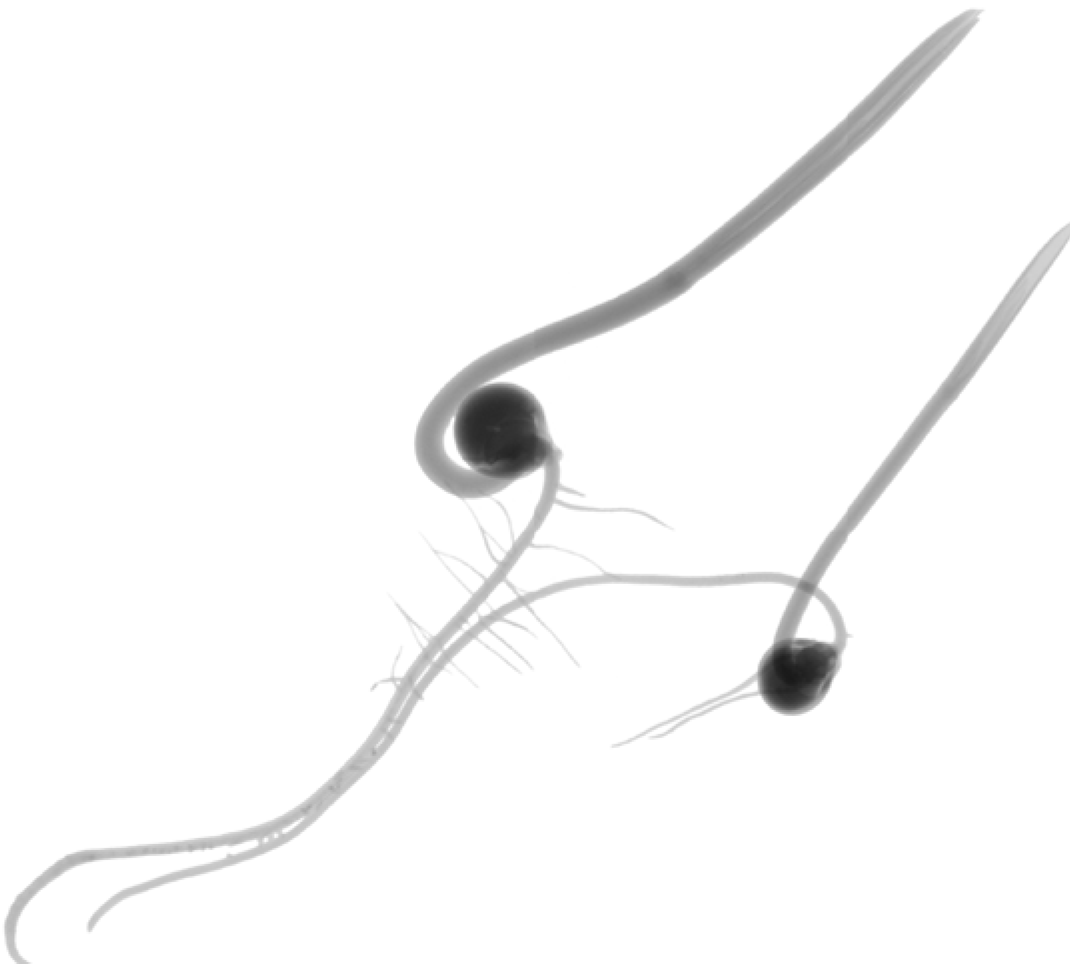

Corn | Archiving Eden
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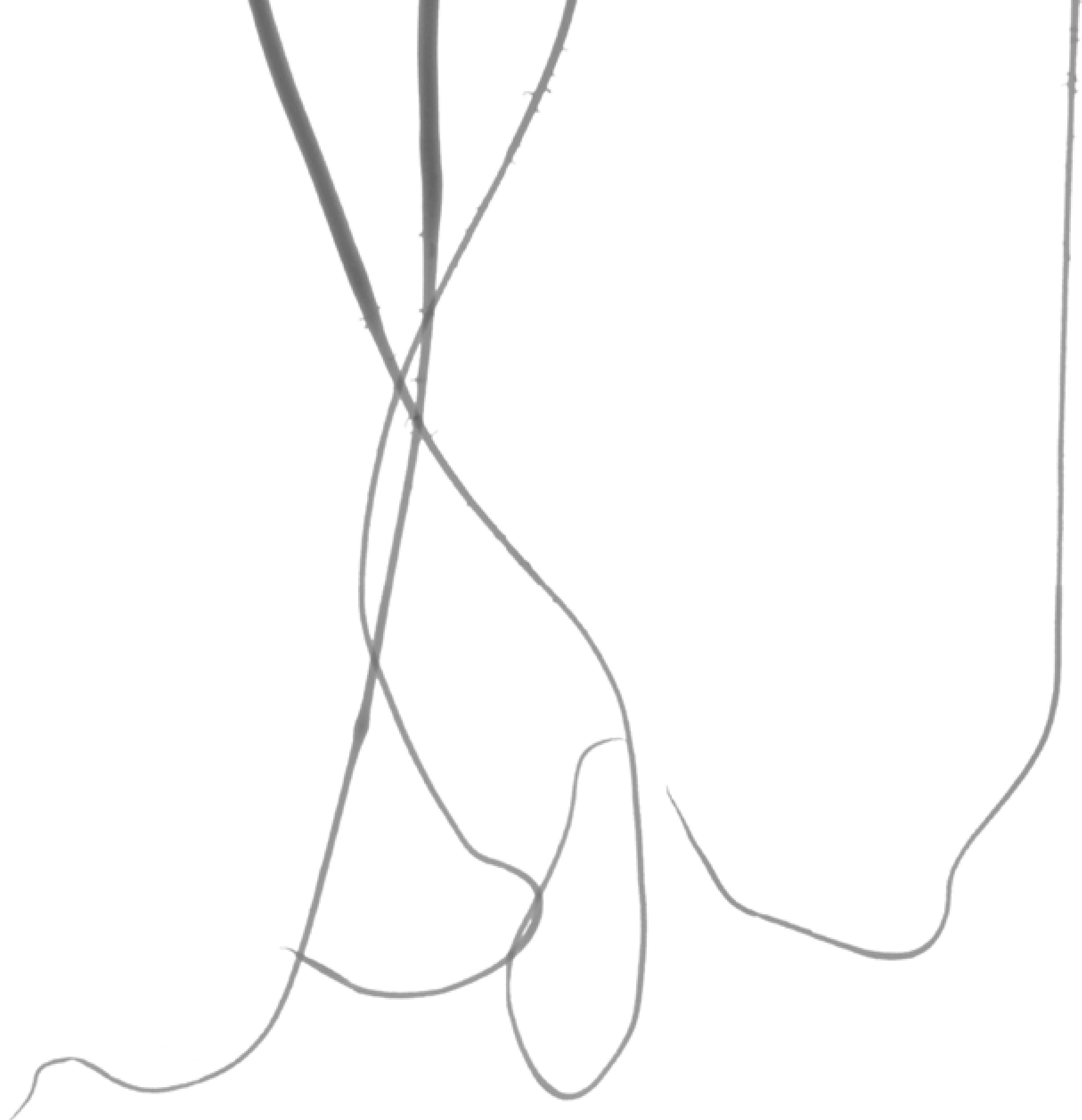

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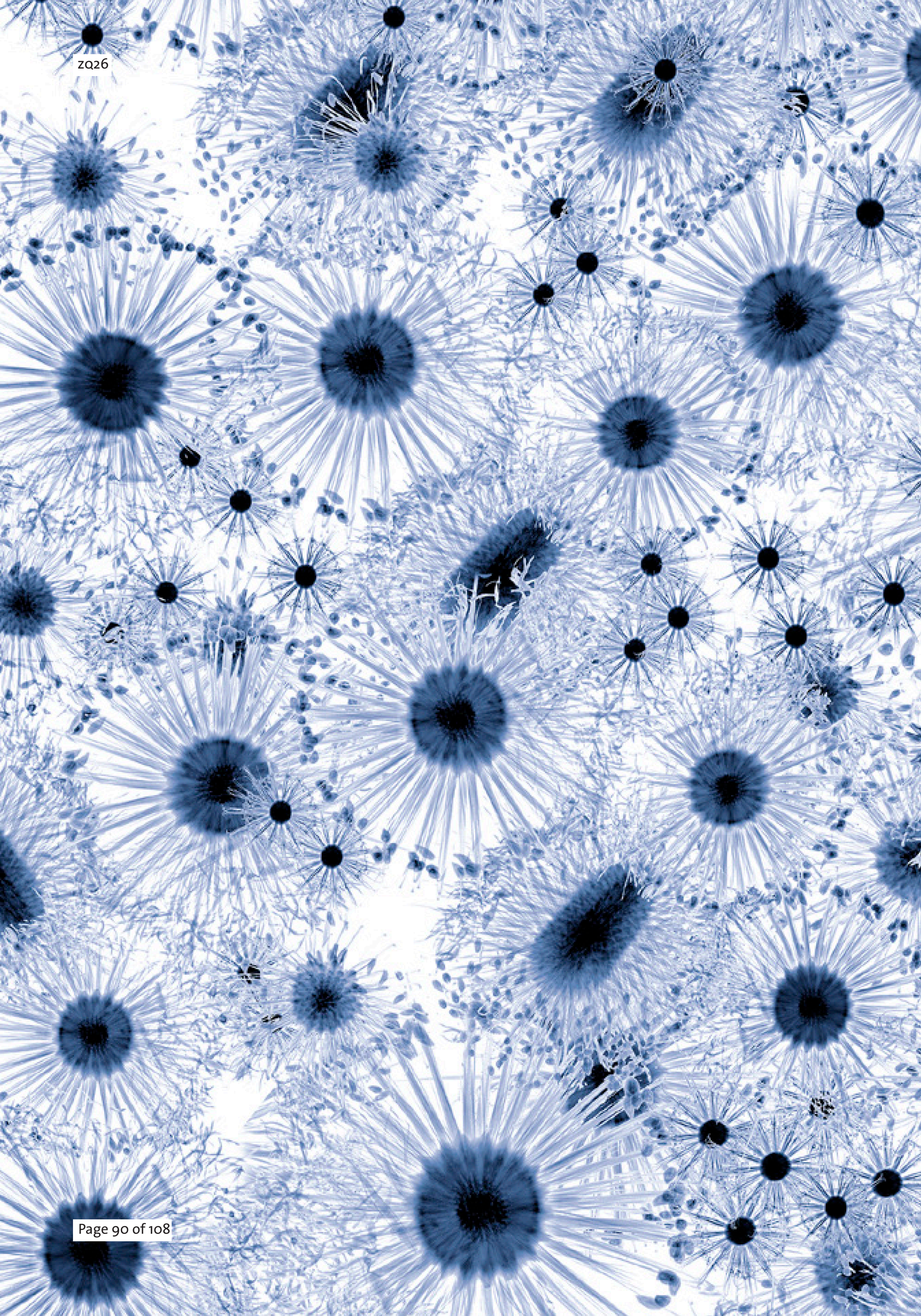

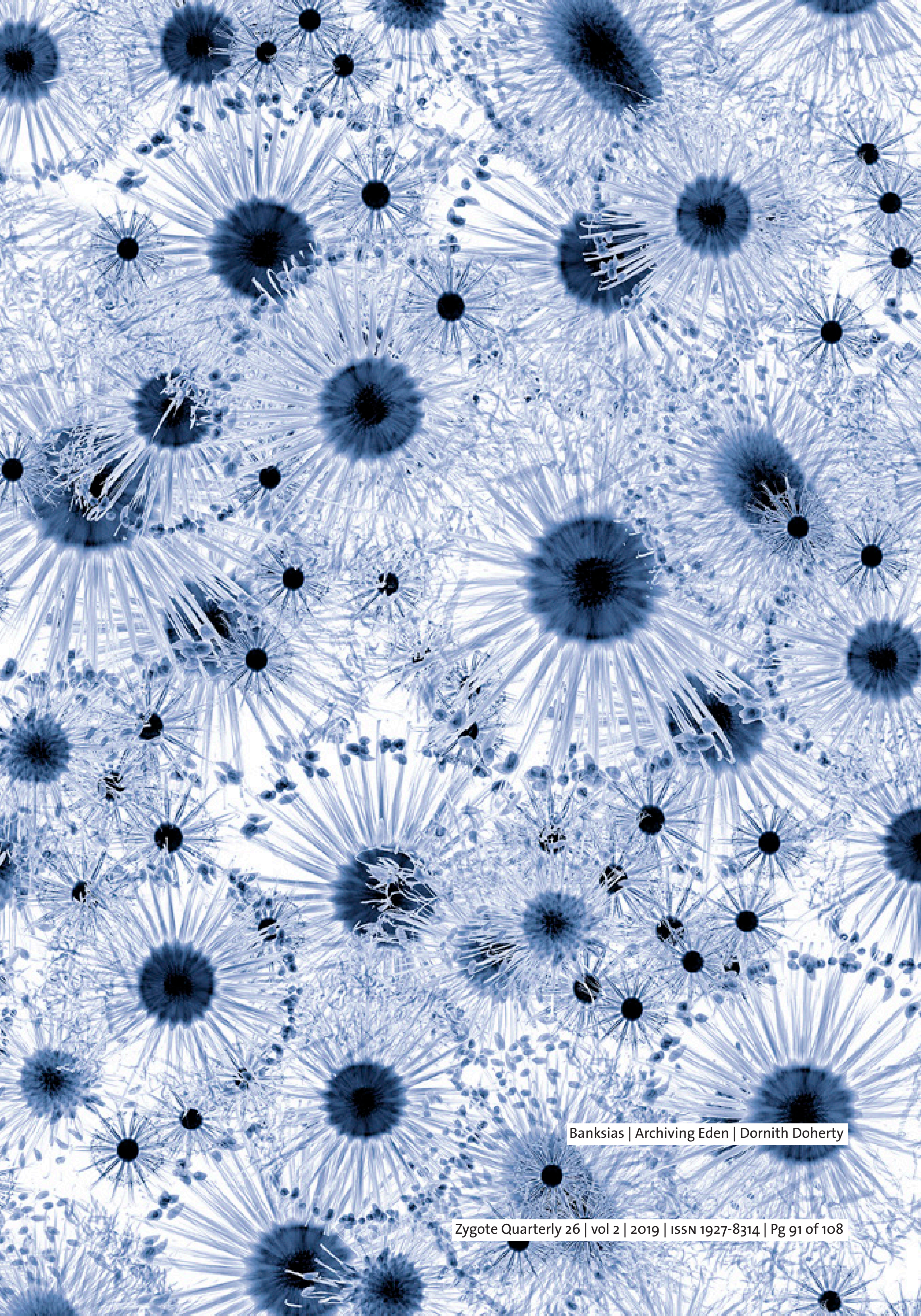

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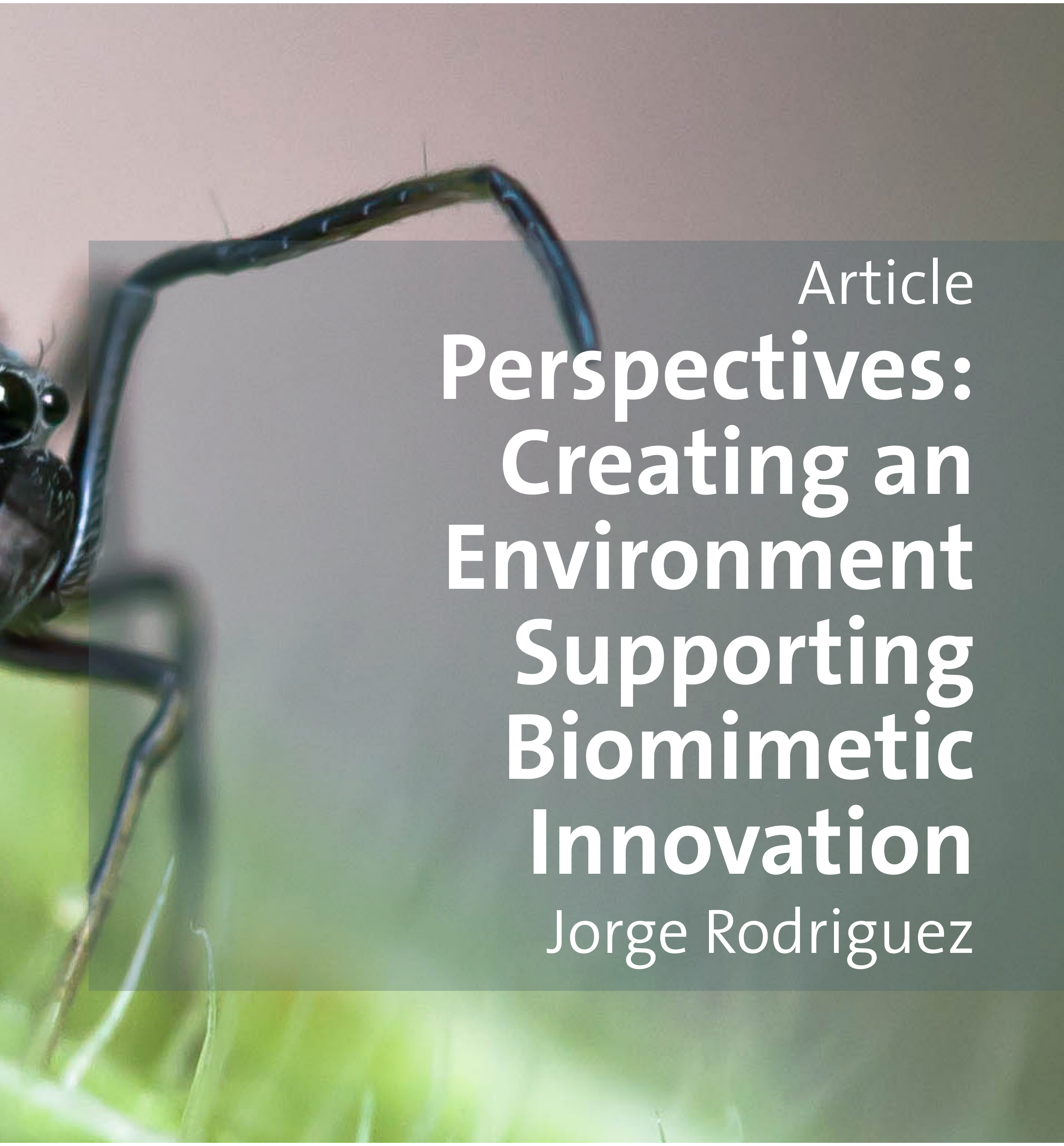
Myrmarachne sp - Ant Mimic Jumping Spider (male)
Photo: Rushen, Thai National Parks, 2015 | Flickr cc



Article

Perspectives: Creating an Environment Supporting Biomimetic Innovation

Jorge Rodriguez

Perspectives: Creating an Environment Supporting Biomimetic Innovation
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This article is part of the “Perspectives on Stories from the Trenches” series in ZQ24 (https://zqjournal.org/editions/zq24.html p. 40) and ZQ25 (https://zqjournal.org/editions/zq25.html 38), which explored other viewpoints related to the “Stories from the Trenches” series in ZQ21, ZQ22, and ZQ23. Jorge Rodriquez describes working in a highly competitive environment, but the challenges he faces and his suggested solutions are relevant in some degree to other businesses creating biomimetic products.

Ryan Church, Rachel Hahs, and Norbert Hoeller

Creating an Environment Supporting Biomimetic Innovation

For those of us working towards the development and promotion of biom*, an umbrella term that comprises bio-inspired design, biomimicry, and biomimetics, there is one question that summarizes all our hopes and challenges simultaneously.

What is biom*?
This simple question stands unanswered, as some sort of Rosetta stone holding the secrets of the future of biom*. If we cannot define our own field, it will be very difficult to sell it to engineering practitioners and business owners. Most answers to questions like “What is biom* useful for?”, “How is it better than my current engineering design approach?”, or “What commercial advantages does it provide?”, seem to be broad, without any specifics. Arguments in favour of more sustainable design, a better usage of energy and resources, high-efficient systems, and closed-cycle processes (such as Circular Economy) are common. Yet none of these arguments possess enough strength and lack sufficient practical details to displace traditional engineering approaches in industry. One could argue that for biom* to flourish, a change of mentality might be required, a change of focus from profit-driven industry or even a different economic policy altogether. Those are reasonable requests, but well outside the remit of engineers and designers. What biom* promoters seem to be overlooking is that the latest design methods that became mainstream, such as rapid prototyping, carried the necessary punch to carve a niche for themselves without the need for changes in the political or economical landscape.

Until biom* is mature enough to sustain itself among pragmatists more interested in what it can yield rather than how fascinating it is, we should strive towards making businesses more biom*-friendly.

The forces preventing biom* from penetrating industry

In my experience as a designer who has had exposure to biom* across two commercially successful companies, there is a certain degree of dissonance between biom*-led design engineering and orthodox R&D engineering design. Biom*, except for the simplest cases, requires a painful ad-hoc process of translation, from the biological insight, whether mimicked from or inspired by nature, to engineering language.

Nature's self-assembled materials are a good example of this. Their science is understood, yet their production needs a set of very specific conditions difficult to replicate using available industrial processes and equipment. The gap between designing solutions for practical problems and developing the technologies required to make them happen is a well-known budget and time guzzler. Biom* can be a way of introducing a wealth of concept designs but they often require the use of technologies not yet available. This is most likely because translating between biology and engineering can be like trying to translate an extraterrestrial language to Old Aramaic. That is why our translation efforts are very iterative and

Jumping Spider (*Tutelina similis*) - male
Photo: sankax,2010 | Flickr cc

Polyrhachis dives | Photo: Rushen, Thai National Parks 2013 | Flickr cc

normally carried out in the grey area that demarcates the space between science and engineering.

In other words, to push biom* projects up the Technology Readiness Level ladder (https://en.wikipedia.org/wiki/Technology_readiness_level) is a painfully slow and resource-hungry process, as parallel technology creation efforts become essential to implementing the design itself. To take biom* beyond the prototype level is even more challenging, as the exercise of "productionising" prototypes turns into a series of nested trade-offs that often force the designer to compromise between keeping innovation intact or making concessions to the use of existing technologies.

These trade-offs are unavoidable in most cases, as businesses want products that are often quite the opposite to biom*-derived prototypes. Businesses do not necessarily value innovation over safety, reliability, ease of manufacturing, or even consumer appeal. Therefore, the challenge is to imbue the biom* mindset with a sense of practicality; we must achieve function and also direct our efforts towards products that are easily reproducible with the methods and technologies readily available in industry. This is a big ask, but a genius idea that cannot be materialised is worth very little. Conceptualizing ideas in biom* must happen in the current technological context, otherwise almost certainly there will be not enough resources to create the tools needed for the idea to happen as well as the materialisation of the idea itself. We have to manage our imagination to operate within the limits of what is possible.

Not only practitioners have to make the effort, businesses need to do their part too; we must help them understand that biom* is a long-term pursuit, and the perceived-as-acceptable R&D timeframes might not be valid when it comes to assessing biom* projects. The message must be accompanied by certain positivity – long-term innovation is more costly and risky, but it yields radically innovative products that have the potential to disrupt or even create their own markets.

Biom* is the mind but, where is the body?

Until now, biom* is a collection of ideas and approaches and cannot call itself a systematised method. As far as I am aware, no one can claim to have a well-defined approach to designing biom* products following a series of steps that reliably yield viable products. Using an analogy, biom* is the mind, but to carry out any work, we also need some muscles. Luckily, engineering design has existed for a while now and it enjoys a diversity of techniques that can be learned and practiced quite consistently.

One engineering design approach that seems to not only enhance biom* benefits but also mitigates some of its downsides is rapid prototyping (RP). To practice RP successfully requires the mindset to "fail small, fail fast, fail early". These three statements can help manage the complexity and risk often found in biom* projects.

Biom* Proofs-of-Principle (POPs) are often based on physical principles for which there is little reference literature available or that are too complex to simulate and require time-consuming background research. Instead of trying to analyse POPs in order to make a conscientious choice after an initial generation of ideas, multiple very crude POPs based on different ideas can be developed in parallel and tested very early in the project. This approach might seem expensive (hardware is always judged as more expensive than simulation), but this only holds true in the short term. In the long term, creating and testing multiple POPs provides a clearer development path that produces results earlier.

RP not only cuts costs, it also mitigates risk very effectively, because by failing early in the project we avoid committing resources to a solution that has a high level of uncertainty and might not yield results. The inevitable circulation between the problem and solution spaces, as described by Cross in his book *Engineering Design Methods: Strategies for Product Design* (4th Edition), happens fast when RP is used. Feedback collection speeds up – if well managed, it normally allows designers to make better and more controlled decisions. RP seems an ideal partner by mitigating some of the current shortcomings of biom*.

Upsetting the gods of concurrent design

For those of us that have been working in design for a while, the struggle to convert sequential engineering design practitioners into concurrent engineering design devotees (https://en.wikipedia.org/wiki/Concurrent_design_and_manufacturing) has been one of the most important events in our careers. Suddenly, engineers were no longer confined to their Fortress of Solitude and were required to constantly communicate with other departments in simple understandable terms. Not only that, a culture of accepting feedback on technical matters, regardless of the level of technical expertise, became the new norm, although this remains controversial in some engineering design circles as the 'noise vs meta-information' debate.

However, like many other revolutions of the past, the rebels were too quick to

Erianthus versicolor - Spot monkey grasshopper | Photo: Rushen, Thai National Parks 2013 | Flickr cc

Perspectives: Creating an Environment Supporting Biomimetic Innovation
Jorge Rodriguez

ostracise the old system; the design community considered obsolete all sequential design without pondering that some of its characteristics are still applicable in certain occasions. Biom* in its current immaturity could benefit from a certain degree of isolation from business structures. Although this evokes the old ways of sequential design, with highly compartmentalized departments that are black boxes to the rest of the business, companies willing to accept separate R&D operations that talk very little to product design and business development might be more successful at biom*-based innovation. The intent is not to contravene modern operations management or revert to the “good old days” of sequential design – it is well-proven that concurrent design is leaner and quicker, from a business perspective. The idea is to retain some sequential engineering, to encourage companies to have small unconventional R&D operations that enjoy some extra isolation in parallel with traditional R&D.

While maintaining two separate operations with similar functions might seem redundant, it is not. Biom* is a long-term pursuit and requires its own timelines due to its current level of maturity. Let’s create business structures than shield biom*, and

Jumping Spider (*Tutelina similis*) - female
Photo: sankax,2010 | Flickr cc

by extension any immature and innovative future design processes, from the short-term pressures and let more orthodox R&D approaches bear that burden. With some cleverness, this two-speed R&D department structure can be implemented without significant increases in staff or equipment, by changing Project Management and the expected level of communication within the business structure.

How to decouple biom* from marketing (just a bit)

This is another rather bold request, not especially appealing to business. We should try to encourage biom* R&D to happen before Business Development – we should grant biom* some freedom to explore products and solutions that might not have a defined market now and then direct Business Development to find market niches. Currently, marketing departments drive products that are demanded by the public to mitigate development risks, but this is a limiting approach. If we allow biom* to research within areas of interest without trying to meet the requirements of a market niche, then innovation can transcend the markets' collective imagination and open a door to disruptive ideas that are discouraged by current marketing practices.

Healthy mix increases your chances of survival

The previous paragraphs have a pretty provocative tone, especially from a business management perspective, which is why we should make a conscious effort to avoid selling biom* as a silver bullet to solve all innovation and design problems. Biom* is still too immature to be the mainstay of any engineering business, let alone to design a full marketable product, except for the simplest, such as VELCRO®. We must keep a healthy mix between biom* and orthodox engineering approaches when it comes to innovation and design. This is particularly important when we talk to entrepreneurs – we do not want to ruin the reputation of biom* by overpromising delivery of results.

What actions do we need to take?

1. Biom* cannot be presented as a replacement of traditional design and engineering – it will not stand a chance against orthodox engineering unless its application brings tangible results. To frame biom* as a replacement instead of a complement to current engineering practices is to set it against an almost impossible task, a sure-fire way to fail. Let's be humble; human design has allowed us to reach the Moon and beyond and has created the foundation

on which human existence depends. Traditional design and engineering have proven they can provide efficient and effective solutions, given the right requirements.

2. Functions in nature are often expressed in novel ways that make use of technologies we have not yet mastered. For example, insect motion relies heavily on compliant resonant mechanisms involving periodic motion to amplify force, in contrast to our use of rotary motion (dragonflies vs. helicopters). Unfortunately, we are currently not able to replicate these compliant resonant mechanisms at the required levels of control, efficiency, reliability, and durability to be used as an alternative to rotary machinery. Although compliant resonant mechanisms can be designed, they are not as widely applicable as rotary motion due to their complexity and limited performance.

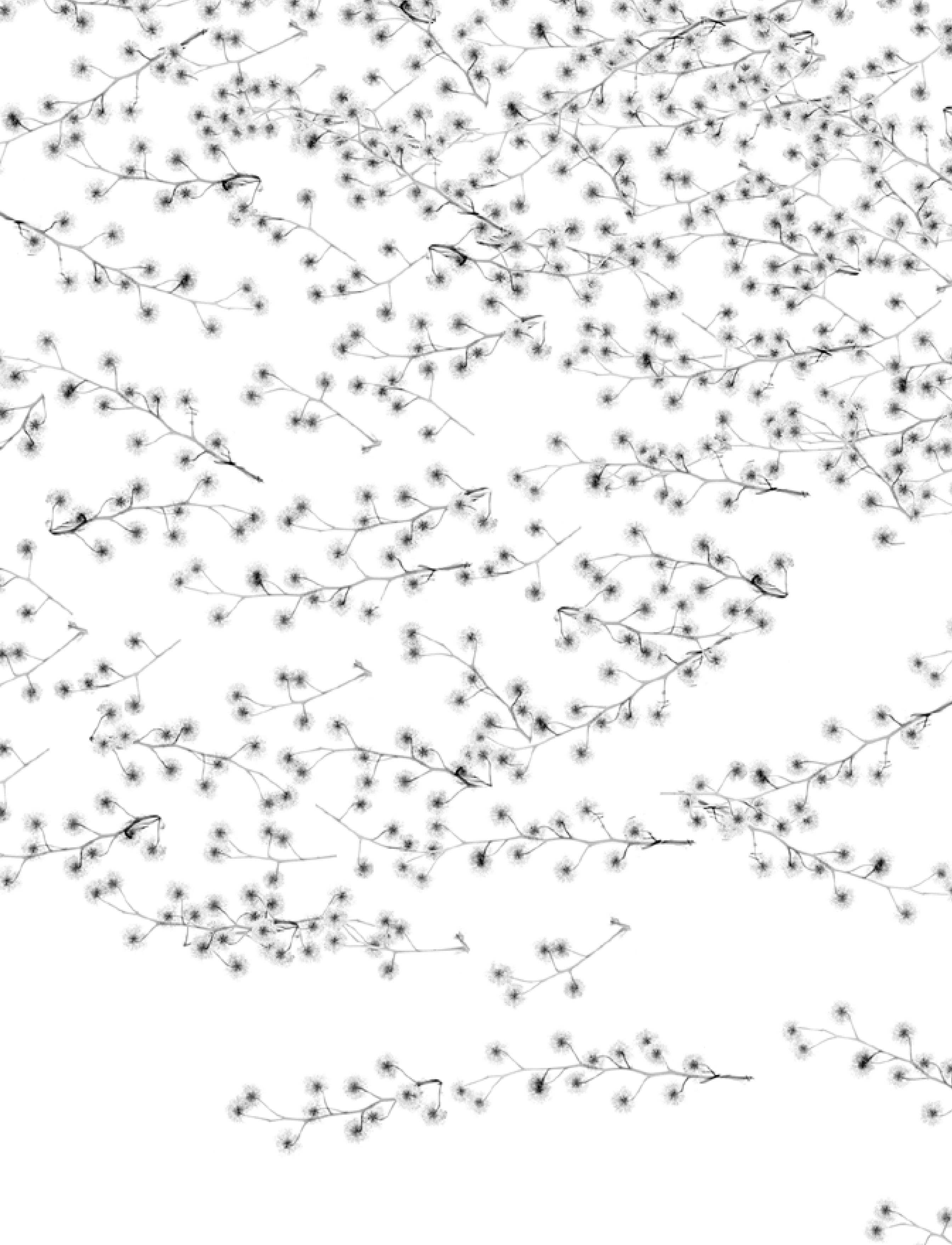
3. Human technologies are quite scalable, while biological technologies tend to be confined to a certain scale which can reduce their versatility. For instance, ball bearings come in a vast range of sizes whereas resonant flight is largely found at insect scales.

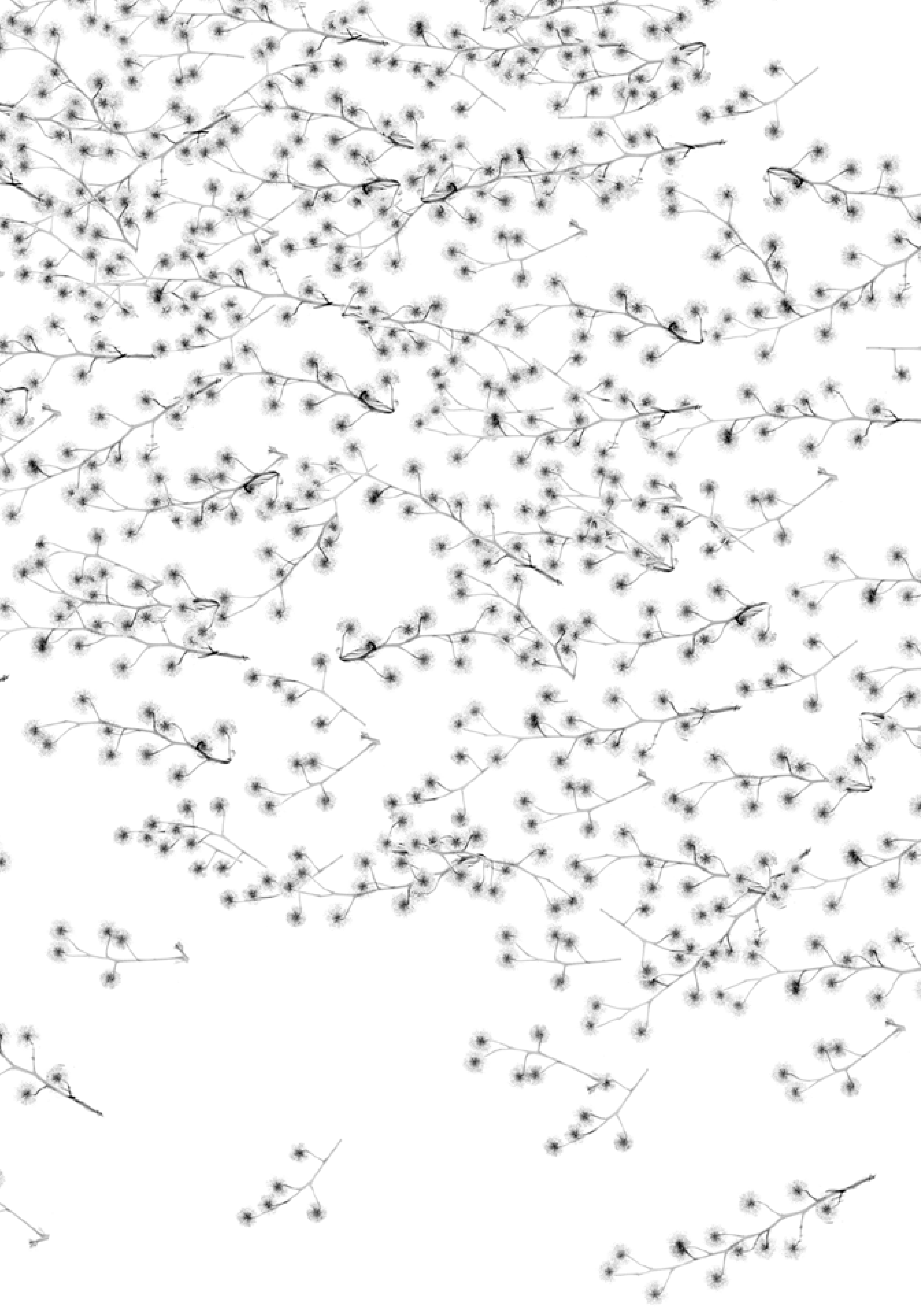
4. Theodore Von Karman said, “Scientists discover the world that exists; engineers create the world that never was”. We need to understand the fundamental design principles of nature even if we do not yet understand all the inner workings of those design principles. For much of human history, technology could deliver viable solutions even if the underlying science was not fully understood. Before we understood the crystalline structure of iron, all blacksmiths worth their salt knew the fundamental rules to forge objects from durable plowshares to cutting edge swords. Building a library of nature’s design principles that have been tested through repeated practice can help spark and guide the creation of valuable and ideally environmentally compatible innovations. ×

About the author: Jorge Rodriguez has been a professional engineer for 13 years and has worked as a mechanical engineer for nine years at Rolls-Royce Nuclear Services (robotics design for remote handling), RSL Steeper (now Ottobock), UKAEA, and Animal Dynamics.

We would appreciate your feedback on this article:


Metallic stag beetle | Photo: Zleng, 2016 | Flickr cc





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