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Chapter Title: SYMBIOGENESIS, SYMPOIESIS, AND ART SCIENCE ACTIVISMS FOR STAYING WITH THE TROUBLE

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Book Title: Arts of Living on a Damaged Planet

Book Subtitle: Ghosts and Monsters of the Anthropocene

Book Editor(s): Anna Tsing, Heather Swanson, Elaine Gan and Nils Bubandt

Published by: University of Minnesota Press

Stable URL: https://www.jstor.org/stable/10.5749/j.ctt1qft070.20

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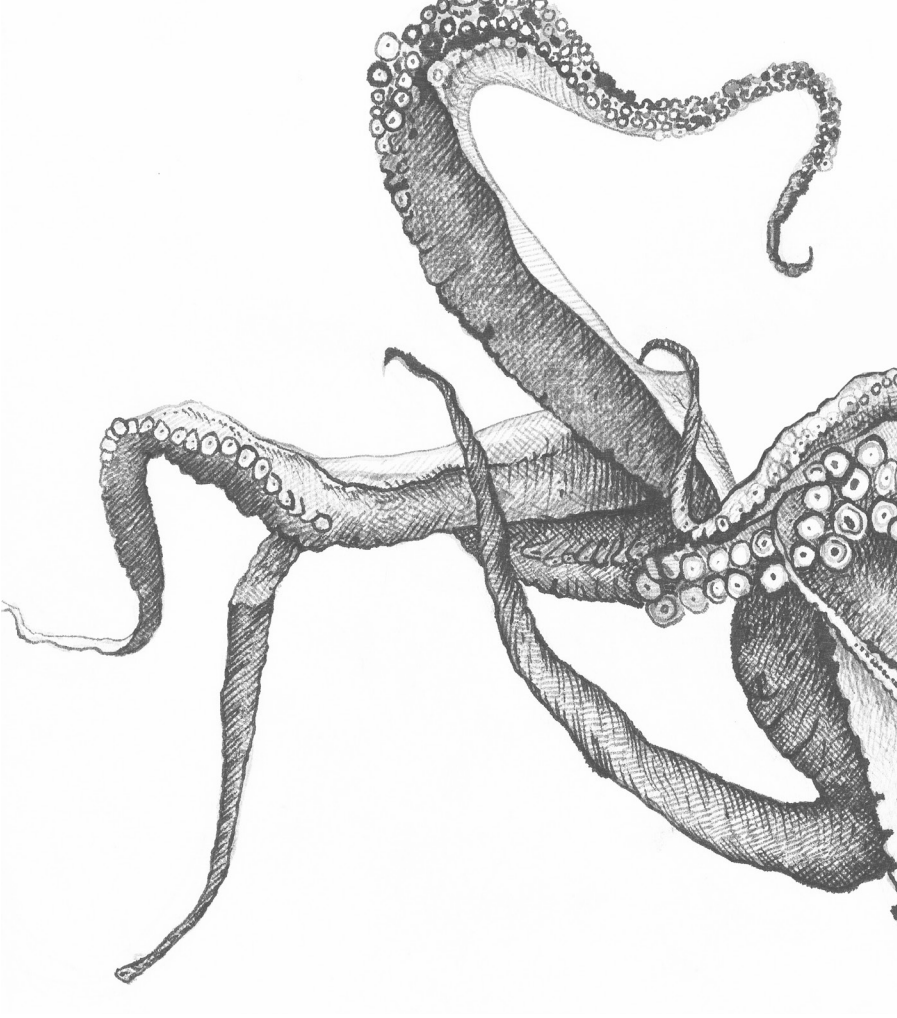

INHABITING MULTISPECIES BODIES

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THERE IS A BIG NEW STORY IN BIOLOGY TODAY. Zoologist Margaret McFall-Ngai calls it the "postmodern synthesis." This postmodern is not the same as the *postmodernism* of the humanities. It requires readers to know that the "modern synthesis" in biology was a marriage of Darwinian evolutionary theory and Mendelian inheritance mechanisms; evolution worked through the passing of desirable traits to offspring. Every species evolved on its own. In the big new story, cross-species interaction has been shown as essential to development, evolution, and ecology. This volume offers articles by a number of the most prominent pioneers in this field, including Margaret McFall-Ngai, Scott Gilbert (see "Beyond Individuals"), and Donna Haraway. This trio has worked together, across distance and disciplinary boundaries, to move us toward new practices of research, inquiry, and storytelling, where natures and cultures, microorganisms and worlds, bodies and environments, are driven not by individuals but by symbiotic relationships all the way down.

McFall-Ngai explains the "nested ecosystems" that form our bodies in cross-species interaction. Her experimental organism, the bobtailed squid, has become a model for the whole field: bobtailed squid can only evade predators through their relation with *Vibrio* bacteria, with which they develop a light organ. The more we learn about microbes, the more we realize how integral they are to the lives of multicellular organisms.

Donna Haraway is a leading figure in the formation of radical interdisciplinarities, the combination of arts, sciences, and humanities into modes of "worlding," where McFall-Ngai's nested ecosystems and Gilbert's holobionts become our primary characters. This move challenges us to inhabit new ecologies, invent new words, and work across many knowledge practices; these demand new stories. "Worlding" is theorizing and storytelling that is rooted in the historical materialities of meetings between humans and nonhumans. In her chapter, she uses art–science activisms to craft new genres, what she calls "speculative fabulations."

For decades, McFall-Ngai, Haraway, and Gilbert have read and cited each other's work, diffracting their practices across disciplinary silos. Long-term dialogues across the science–humanities line are arts we need for living on a damaged planet. ●

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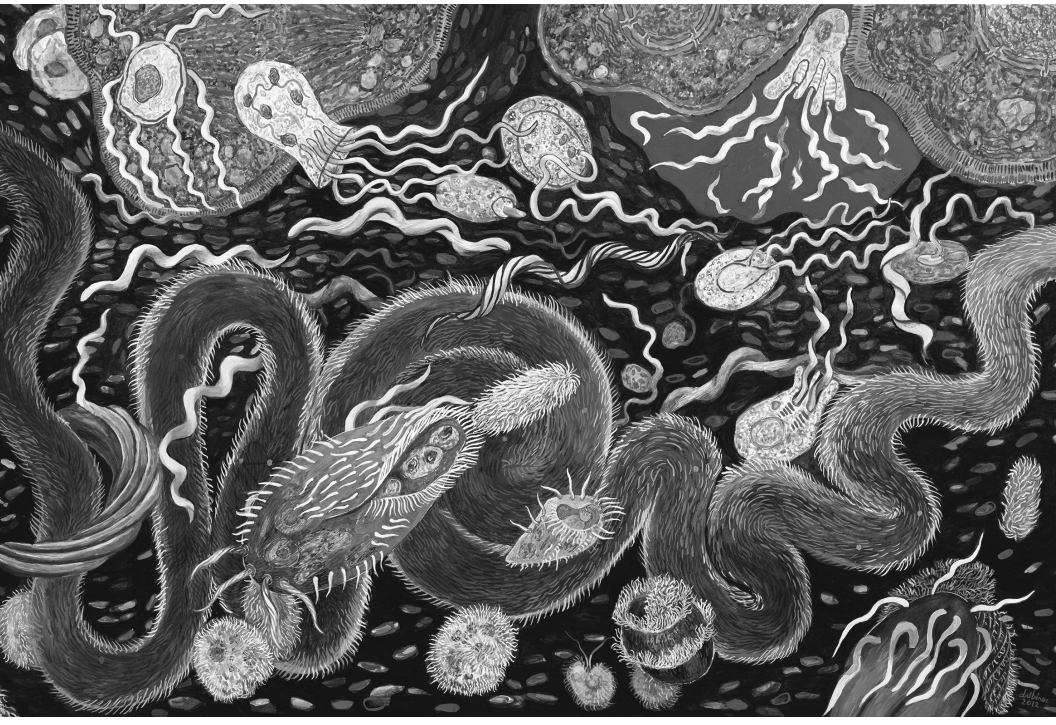

Figure M2.1. Shoshanah Dubiner, *Endosymbiosis: Homage to Lynn Margulis,* 2012. Gouache on watercolor paper, 23 × 35 inches. Reproduced for the Morrill Science Center, University of Massachusetts, Amherst, as a fine-art giclée on canvas, 48 × 72 inches. Courtesy of the artist. http://www.cybermuse.com/.

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SYMBIOGENESIS, SYMPOIESIS, AND ART SCIENCE ACTIVISMS FOR STAYING WITH THE TROUBLE

Donna Haraway

Symbiogenesis

Shoshanah Dubiner's vivid painting called *Endosymbiosis* (Figure M2.1) hangs in the hallway joining the Departments of Geosciences and Biology at UMass Amherst, near the Life and Earth Café, a spatial clue to how critters become with each other.[1] Irresistible attraction toward enfolding each other is the vital motor of living and dying on earth. Critters interpenetrate one another, loop around and through one another, eat each another, get indigestion, and partially digest and partially assimilate one another, and thereby establish sympoietic arrangements that are otherwise known as cells, organisms, and ecological assemblages.

Sym-poiesis is a simple word; it means "making-with." Nothing makes itself; nothing is really auto-poietic or self-organizing. In the words of the Iñupiat computer "world game," earthlings are Never Alone.[2] That is the radical implication of sympoiesis. Sympoiesis is a word proper to complex, dynamic, responsive, situated, historical systems. It is a word for worlding.

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Another word for these sympoietic entities is *holobionts,* or, etymologically, "entire beings" or "safe and sound beings."[3] That is decidedly not the same thing as One and Individual. Rather, in polytemporal, polyspatial knottings, holobionts hold together contingently and dynamically, engaging other holobionts in complex patternings. Critters do not precede their relatings; they make each other through semiotic material involution, out of the beings of previous such entanglements. Margulis (1938–2011) knew a great deal about "the co-opting of strangers," a phrase she proposed to describe the most fundamental practices of critters becoming with each other at every node of intra-action in earth history.[4]

Like Margulis, I use *holobiont* to mean symbiotic assemblages, at whatever scale of space or time, which are more like knots of diverse intra-active relatings in dynamic complex systems than like the entities of a biology made up of preexisting bounded units (genes, cells, organisms, etc.) in interactions that can be conceived only as competitive or cooperative. Like hers, my use of *holobiont* does not designate host + symbionts, because all the players are symbionts to each other, in diverse kinds of relationalities and with varying degrees of openness to attachments and assemblages with other holobionts. *Symbiosis* is not a synonym for "mutually beneficial." The array of names needed to designate the heterogeneous webbed patterns and processes of situated and dynamic dilemmas and advantages for the symbionts/holobionts is only beginning to surface as biologists let go of the dictates of methodological individualism and zero-sum games as the template for explanation.[5] I suggest we might also need a term like *holoent,* so as not to privilege only the living but to encompass the biotic and abiotic in dynamic sympoietic patterning.

An adept in microbiology, cell biology, chemistry, geology, and paleogeography, as well as a lover of languages, arts, stories, systems theories, and alarmingly generative critters, including human beings, Margulis was a radical evolutionary theorist. Her first and most intense loves were the bacteria and archaea of Terra and all their bumptious doings. The core of Margulis's view of life was that new *kinds* of cells, tissues, organs, and species evolve primarily through the long-lasting intimacy of strangers. The fusion of genomes in symbioses, followed by natural selection—with a very modest role for mutation as a motor of system-level change—leads to increasingly complex levels of good enough quasi-individuality to get through the day, or

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the eon. Margulis called this basic and mortal life-making process *symbiogenesis*.

Bacteria and archaea did it first. My sense is that in her heart of hearts, Margulis felt that bacteria and archaea did it all, and there wasn't much left for so-called higher-order biological entities to do or invent. Eventually, however, by fusing with each other in stabilized, ongoing ways, archaea and bacteria invented the modern complex cell, with its nucleus full of ropy chromosomes made of DNA and proteins and diverse other sorts of extranuclear organelles, from undulating whips and spinning blades for locomotion to specialized vesicles and tubules for functions that work better kept separate.[6] Because she was a founder of Gaia theory with James Lovelock and a student of interlocked and multileveled systemic processes of nonreductionist organization and maintenance that make earth itself and earth's living beings unique, Margulis called these processes *autopoietic*.[7] I think she would have often—not always—preferred the term *sympoietic,* but the word and concept had not yet surfaced.[8] Autopoiesis and sympoiesis are in generative friction rather than opposition.

In 1998, M. Beth Dempster suggested the term *sympoiesis* for "collectively-producing systems that do not have self-defined spatial or temporal boundaries. Information and control are distributed among components. The systems are evolutionary and have the potential for surprising change." By contrast, autopoietic systems are "self-producing" autonomous units "with self defined spatial or temporal boundaries that tend to be centrally controlled, homeostatic, and predictable."[9] Symbiosis makes trouble for autopoiesis, and symbiogenesis is an even bigger trouble maker for self-organizing individual units. The more ubiquitous symbiogenesis seems to be in living beings' dynamic organizing processes, the more looped, braided, outreaching, involuted, and sympoietic is terran worlding.

Mixotricha paradoxa is everyone's favorite critter for explaining complex "individuality," symbiogenesis, and symbiosis. Margulis described this critter that is/are made up of at least five different taxonomic *kinds* of cells with their genomes this way: "Under low magnification, *M. paradoxa* looks like a single-celled swimming ciliate. With the electron microscope, however, it is seen to consist of five distinct kinds of creatures. Externally, it is most obviously the kind of one-celled organism that is classified as a protist. But inside each nucleated cell, where one would expect to find mitochondria, are many spherical

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bacteria. On the surface, where cilia should be, are some 250,000 hair-like *Treponema spirochetes* (resembling the type that causes syphilis), as well as a contingent of large rod bacteria that is also 250,000 strong. In addition, we have redescribed 200 spirochetes of a larger type and named them *Canaleparolina darwiniensis.*"[10] Leaving out viruses, each *M. paradoxa* is not one, not five, not several hundred thousand, but a poster critter for holobionts. This holobiont lives in the gut of an Australian termite, *Mastotermes darwiniensis,* which has its own SF stories to tell about ones and manys.

Since Darwin's *On the Origin of Species* in 1859, biological evolutionary theory has become more and more essential to our ability to think, feel, and act well; and the interlinked Darwinian sciences that came together between the 1930s and 1950s into the "Modern Synthesis" or "New Synthesis" remain astonishing. How could one be a serious person without such works as Theodosius Dobzhansky's *Genetics and the Origin of Species* (1937), Ernst Mayr's *Systematics and the Origin of Species* (1942), George Gaylord Simpson's *Tempo and Mode in Evolution* (1944), and even Richard Dawkins's sociobiological formulations within the Modern Synthesis, *The Extended Phenotype* (1982)? However, bounded units (code fragments, genes, cells, organisms, populations, species) and relations described mathematically in competition equations are virtually the only actors and story formats of the Modern Synthesis. Evolutionary momentum, always verging on modernist notions of progress, is a constant theme, although teleology in the strict sense is not. Even as these sciences lay the groundwork for scientific conceptualization of the Anthropocene, they are undone in the very thinking of Anthropocenic systems that require both autopoietic and sympoietic analysis.

Rooted in units and relations, especially competitive relations, these sciences, for example population genetics, have a hard time with four key biological domains: embryology and development, symbiosis and collaborative entanglements of holobionts and holobiomes, the vast worldings of microbes, and exuberant critter biobehavioral inter- and intra-actions. Approaches tuned to "multispecies becoming-with" better sustain us in staying with the trouble on Terra. An emerging "new new synthesis" (or "extended synthesis") in transdisciplinary biologies and arts proposes string figures tying together human and nonhuman ecologies, evolution, development, history, affects, performances, technologies, and more.

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Indebted to Margulis, I am undone and redone by the "New New Synthesis" unfolding in the early twenty-first century.[11] Formulations of symbiogenesis predate Margulis in the early-twentieth-century work of the Russian Konstantin Mereschkowsky and others.[12] However, Margulis, her successors, and her colleagues bring together symbiogenetic imaginations and materialities with all of the powerful cyborg tools of the late-twentieth-century molecular and ultrastructural biological revolutions. The strength of the "New New Synthesis" is precisely in the intellectual, cultural, and technical convergence that makes it possible to develop new model systems, concrete experimental practices, research collaborations, and both narrative and mathematical explanatory instruments. Such a convergence was impossible before the 1970s and after.

A model is a work object; a model is not the same *kind* of thing as a metaphor or analogy. A model is worked, and it does work. A model is like a miniature cosmos, in which a biologically curious Alice in Wonderland can have tea with the Red Queen and ask how this world works, even as she is worked by the complex-enough, simple-enough world. Models in biological research are stabilized systems that can be shared among colleagues to investigate questions experimentally and theoretically. Traditionally, biology has had a small set of hard-working living models, each shaped in knots of practices to be apt for some kinds of questions and not others. Listing seven model systems of developmental biology, namely, fruit flies, a nematode, the house mouse, a frog, the zebra fish, the chicken, and a mustard, Scott Gilbert wrote, "The recognition that one's organism is a model system . . . assures one of a community of like-minded researchers who have identified problems that the community thinks are important."[13]

Excellent for studying how parts fit together into cooperating and/or competing units, all seven of these individuated systems fail the researcher studying symbiosis and sympoiesis, in heterogeneous temporalities and spatialities. Holobionts require models tuned to an expandable number of quasi-collective/quasi-individual partners in constitutive relatings; these relationalities *are* the objects of study. The partners do not precede the relatings. Such models are emerging for the transformative processes of EcologicalEvolutionaryDevelopmental biology.

Every living thing has emerged and persevered (or not) bathed and swaddled in bacteria and archaea. Truly nothing is sterile; and

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that reality is a terrific danger, basic fact of life, and critter-making opportunity. Margulis gave us dynamic multipartnered entities like *M. paradoxa* to study the symbiogenetic invention of eukaryotic cells from the entangling of bacteria and archaea. Nicole King's laboratory has proposed the clumping and subsequent tissuelike formations of choanoflagellates in the presence of specific bacteria as a new model system for studying the symbiogenetic origin of animal multicellularity.[14] Margaret McFall-Ngai and her colleagues have proposed the necessary infection of juvenile Hawaiian bobtail squid by specific vibrio bacteria as a symbiogenetic model system to study developmental patterning, in this case constructing the squid's ventral pouch to house light-emitting bacteria, so the moon cannot cast its shadow over the hunting squid, thus alerting the prey below.[15] Other emerging model systems tuned to symbiosis and EcoEvoDevo in mammals include both mouse brain and immune system development responding to signals from gut bacteria.[16] Coral reefs are an immense model for studying holobiome formation at the ecosystem level.

The collaborations of critters are matched by the string figures linking disciplines and methodologies, including genome sequencing, imaging technologies, functional genomics, and field biology, which make symbiogenesis such a powerful framework for twenty-first-century biology. Working on pea aphid symbiosis with *Buchnera,* Nancy Moran emphasizes this point: "The primary reason that symbiosis research is suddenly active, after decades at the margins of mainstream biology, is that DNA technology and genomics give us enormous new ability to discover symbiont diversity, and more significantly, to reveal how microbial metabolic capabilities contribute to the functioning of hosts and biological communities."[17] I add the necessity of asking how the multicellular partners in the symbioses affect the microbial symbionts. At whatever size, all the partners making up holobionts are symbionts to each other. They are holoents.

Two transformative papers embody for me the profound scientific changes afoot. Proclaiming "We Have Never Been Individuals," Gilbert, Sapp, and Tauber argue for holobionts and a symbiotic view of life by summarizing the evidence against bounded units from anatomy, physiology, genetics, evolution, immunology, and development.[18] In the second paper, signaling "A New Imperative for the Life Sciences," Margaret McFall-Ngai and Michael Hadfield, with twenty-four coauthors, present a vast range of animal–bacterial symbiotic

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interactions at both ecosystem and intimate scales. They argue that this evidence should profoundly alter approaches to five questions: "how have bacteria facilitated the origin and evolution of animals; how do animals and bacteria affect each other's genomes; how does normal animal development depend on bacterial partners; how is homeostasis maintained between animals and their symbionts; and how can ecological approaches deepen our understanding of the multiple levels of animal–bacterial interaction?"[19]

Stories about worried colleagues at conferences, uncomprehending reviewers unused to so much evidential and disciplinary boundary crossing in one paper, or initially enthusiastic editors getting cold feet surround these papers. Such stories normally surround risky and generative syntheses and propositions. The critics are crucial to the holobiome of making science, and I am not a disinterested observer. Nonetheless, I think it matters that both of these papers were published in prominent places at a critical inflection point in the curve of research on, and explanation of, complex biological systems in the urgent times called the Anthropocene, when the arts for living on a damaged planet demand sympoietic thinking and action.

Interlacing Sciences and Arts with Involutionary Momentum

I am committed to art science activisms as sympoietic practices for living on a damaged planet. Carla Hustak and Natasha Myers gave us a beautiful paper titled "Involutionary Momentum" that is a hinge between symbiogenesis and science art activisms. These authors reread Darwin's own sensuous writing about his attention to absurdly sexual orchids and their pollinating insects. Hustak and Myers attend to the enfoldings and communications among bees, wasps, orchids, and scientists. The authors suggest that "involution" powers the "evolution" of living and dying on earth. Rolling inward enables rolling outward; the shape of life's motion traces a hyperbolic space, swooping and fluting like the folds of a frilled lettuce, coral reef, or bit of crocheting. Like EcoEvoDevo biologists, Hustak and Myers argue that a zero-sum game based on competing methodological individualists is a caricature of the sensuous, juicy, chemical, biological, material–semiotic, and science-making world. Counting "articulate plants and other loquacious organisms" among their number, living critters

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practice the floridly repetitive mathematics of hyperbolic geometry.[20] "It is in encounters among orchids, insects, and scientists that we find openings for an ecology of interspecies intimacies and subtle propositions. What is at stake in this involutionary approach is a theory of ecological relationality that takes seriously organisms' practices, their inventions, and experiments crafting interspecies lives and worlds. This is an ecology inspired by a feminist ethic of 'response-ability' . . . in which questions of species difference are always conjugated with attentions to affect, entanglement, and rupture; an affective ecology in which creativity and curiosity characterize the experimental forms of life of all kinds of practitioners, not only the humans."[21]

Orchids are famous for their flowers looking like the genitals of the female insects of the particular species needed to pollinate them. The right sort of males seeking females of their own kind are drawn to the color, shape, and alluring insectlike pheromones of a particular orchid. These interactions have been explained (away) in neo-Darwinian orthodoxy as nothing but biological deception and exploitation of the insect by the flower, that is, an excellent example of the selfish gene in action. Even in this hard case of strong asymmetry of "costs and benefits," Hustak and Myers read aslant neo-Darwinism. The stories of mutation, adaptation, and natural selection are not silenced, but they do not deafen scientists, as if the evidence demanded it, when increasingly something more complex is audible in research across fields. "This requires reading with our senses attuned to stories told in otherwise muted registers. Working athwart the reductive, mechanistic, and adaptationist logics that ground the ecological sciences, we offer a reading that amplifies accounts of the creative, improvisational, and fleeting practices through which plants and insects *involve* themselves in one another's lives."[22]

But what happens when a partner involved critically in the life of another disappears from the earth? What happens when holobionts break apart? What happens when entire holobiomes crumble into the rubble of broken symbionts? This kind of question has to be asked in the urgencies of the Anthropocene if we are to nurture arts for living on a damaged planet. In his science fiction novel *The Speaker for the Dead,* Orson Scott Card explored how a boy, who had excelled in exterminationist technoscience in a cross-species war with an insectoid hive species, later in life took up responsibility for the dead, for collecting up the stories for those left behind when a being, or a way of

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being, dies.[23] The man had to do what the boy, immersed only in cyber-realities and deadly virtual war, was never allowed to do; the man had to visit, to live with, to face the dead and the living—including the unexpected survivors—in all of their semiotic materialities. The task of the Speaker for the Dead is to bring the dead into the present so as to make more response-able living and dying possible in times yet to come.

My hinge to science art activisms turns on the ongoing performance of memory by an orchid for its extinct bee.

In "Bee Orchid" (Figure M2.2), we know a vanished insect once existed because a living flower still looks like the erotic organs of the avid female bee hungry for copulation. But the cartoon does something special; it does *not* mistake lures for identities; it does *not* say the flower is exactly like the extinct insect's genitals. Instead, the flower collects up the presence of the bee aslant, in desire and mortality. The shape of the flower is "an idea of what the female bee looked like to the male bee . . . as interpreted by a plant. . . . The only memory of the bee is a painting by a dying flower."[24] No longer embraced by living buzzing bees, the flower is a speaker for the dead. A stick figure promises to remember the bee flower when it comes time. The arts of memory enfold terran critters. That must be part of any possibility for resurgence!

Science Art Activisms for Staying with the Trouble

Consider two science art activisms committed to partial healing, modest rehabilitation, and still possible resurgence in the hard times of the Anthropocene and Capitalocene. I think of these science art activisms as stinger-endowed, unfurling tentacles of the ink-spurting, disguise-artist, hunting critters of an ongoing past, present, and future that I call the Chthulucene.[25] The Chthulucene is the time-space of the sym-chthonic ones, the symbiogenetic and sympoietic earthly ones, those now submerged and squashed in the tunnels, caves, remnants, edges, and crevices of damaged waters, airs, and lands. To live and die well as mortal critters in the Chthulucene is to join forces to reconstitute refuges, to make possible partial and robust biological–cultural–political–technological recuperation and recomposition, which must include mourning irreversible losses.

Each science art project cultivates robust response-ability for

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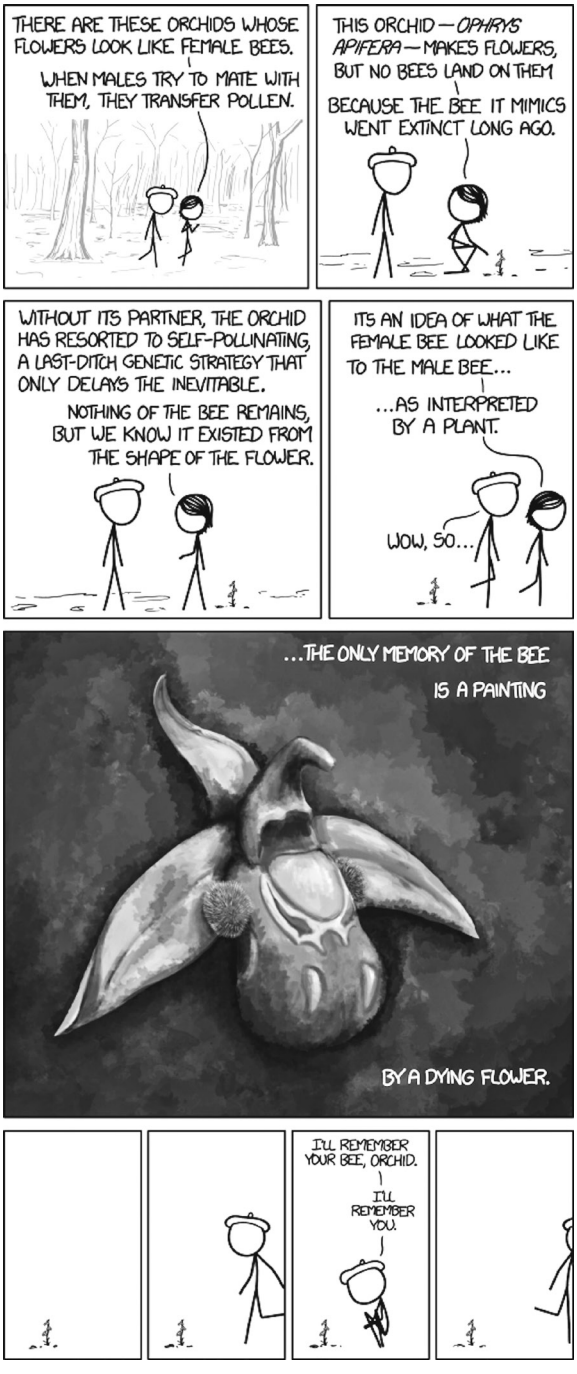

Figure M2.2. "Bee Orchid." Copyright Randall Munroe, http://xkcd.com/.

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powerful and threatened places and beings. Each is located in a particularly sensitive place: the Great Barrier Reef and sister reefs, for the Crochet Coral Reef project, coordinated from the Institute for Figuring in Los Angeles, and the island Republic of Madagascar, for the Malagasy–English children's natural history book series called the Ako Project.[26] Each project is a case of noninnocent, risky, committed "becoming involved in one another's lives."[27] Each is a case of multispecies becoming-with, a model system in which scientists, artists, ordinary members of communities, and nonhuman beings become enfolded in each other's projects, in each other's lives. Each is an animating project in deadly times.

Like Anna Tsing's refugia in forests of the land, coral reefs are the forests of the sea, critical to resurgence for humans and nonhumans. "Resurgence is the work of many organisms, negotiating across differences, to forge assemblages of multispecies livability in the midst of disturbance."[28] Bathed in increasingly hot and acid oceans, coral holobiomes everywhere are threatened. Coral reefs have the highest biodiversity of any marine ecosystem. The symbiosis of cnidarian polyps, photosynthesizing dinoflagellates called zooanthellae living in coral tissues, and a hoard of microbes and viruses make up the keystone assemblage of the coral holobiome, home also to multitudes of other critters. Tens of millions of human beings, many of them very poor, depend directly on healthy coral ecosystems for their livelihoods. Recognition of bleached corals was crucial to advancing the terms *holobiont* and *holobiome* in the 1990s, *Anthropocene* in 2000, and *hologenome* in the 2000s. Corals, along with lichens, are the earliest instances of symbiosis recognized by biologists in the nineteenth century; these critters taught biologists to understand the parochialism of their ideas of individuals and collectives. These critters instruct people like me that we are all lichens, all coral. Besides all of this, coral reef worlds are achingly beautiful. I cannot imagine it is only people who know this beauty in their flesh.

A large island nation off the east coast of Africa, the Republic of Madagascar is home to complex, layered tapestries of historically situated peoples and other critters, including lemurs, close relatives of monkeys and apes. Nine out of ten kinds of Madagascar's nonhuman critters, including all species of lemurs, live nowhere else on earth. The rate of extinction and destruction of the many kinds of Madagascar's forests and watersheds vital for rural people (the large

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majority of Madagascar's citizens), urban and town residents, and myriad nonhumans is almost beyond imagination, except that it is well advanced—but not uncontested locally and translocally. By 2015, only about 10 percent remained of the forests of Madagascar that were still thriving in the early twentieth century, despite a far from undisturbed history at that time. Forest well-being is one of the most urgent priorities for flourishing—indeed, survival—all over the earth. The contestations must matter; it's not a choice, it's a necessity.

The Crochet Coral Reef

In 1997, Daina Taimina, a Latvian mathematician at Cornell University, "finally worked out how to make a physical model of hyperbolic space that allows us to feel, and to tactilely explore the properties of this unique geometry. The method she used was crochet."[29] In 2005, after reading an article on coral bleaching, Christine Wertheim suggested to her twin sister Margaret, "We should crochet a coral reef" (Figure M2.3).[30] We can fight for the coral reefs that way, she intimated. The sisters were watching an episode of *Xena: Warrior Princess*; Xena's and her sidekick Gabrielle's fabulous fighting action inspired them.[31] The consequences have been utterly out of proportion to what the twin sisters imagined that night. So far, about eight thousand people, mostly women, in twenty-seven countries have come together to crochet in wool, cotton, plastic bags, discarded reel-to-reel tape, vinyl jelly yarn, plastic wrap, and anything else that can be induced to loop and whirl in the codes of crocheting.

The code is simple: crocheted models of hyperbolic planes achieve their ruffled forms by progressively increasing the number of stitches in each row. The emergent vitalities of this experimental life-form take diverse corporeal shape as crafters increase the numbers from row to row irregularly, strictly, or whimsically to see what forms they could make—not just any forms, but crenulated beings that take life as marine critters of vulnerable reefs.[32] "Every woolen form has its fibrous DNA."[33] But wool is hardly the only material. Plastic bottle anemone trees with trash tendrils and anemones made from *New York Times* blue plastic wrappers inhabit these reefs. Making fabulated, rarely mimetic, evocative models of coral reef ecosystems, the Crochet Coral Reef has morphed into what is probably the world's largest collaborative art project.

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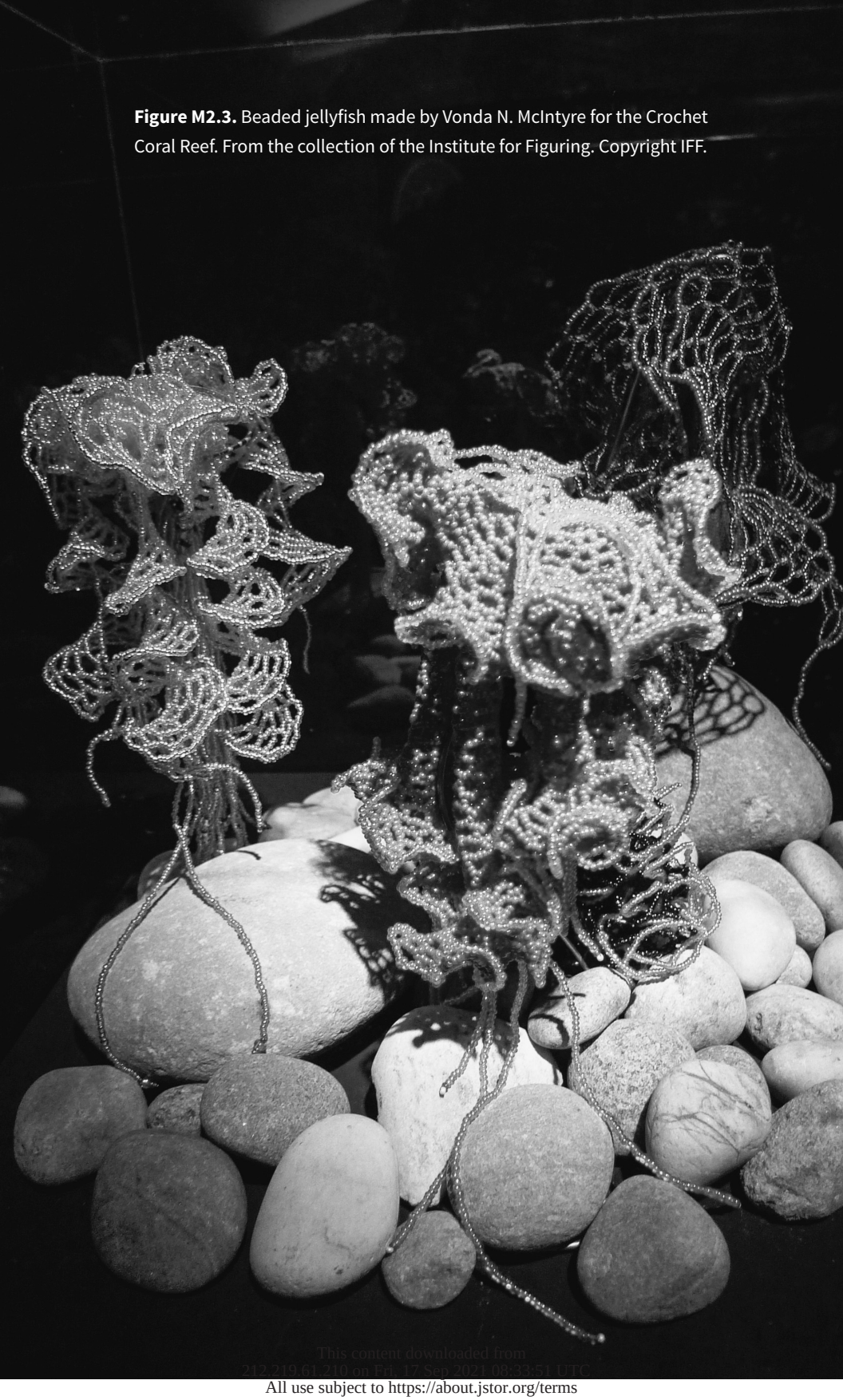

Figure M2.3. Beaded jellyfish made by Vonda N. McIntyre for the Crochet Coral Reef. From the collection of the Institute for Figuring. Copyright IFF.

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The involutionary momentum of the Crochet Coral Reef powers the sympoietic knotting of mathematics, marine biology, environmental activism, ecological consciousness raising, women's handicrafts, fiber arts, museum display, and community art practices. A kind of hyperbolic embodied knowledge, the crochet reef stitches the materialities of global warming and toxic pollution. The makers of the reef practice multispecies becoming-with to cultivate the capacity to respond, response-ability. The crochet reef is the fruit of "algorithmic code, improvisational creativity, and community engagement."[34] The reef works not by representation but by open-ended, exploratory process. "Iterate, deviate, elaborate" are the principles of the process.[35]

The Crochet Coral Reef has core sets made for exhibitions, like the first ones at the Warhol Museum in Pittsburgh and the Chicago Cultural Center, both in 2007, to the Coral Forest exhibited in Abu Dhabi in 2014 and beyond. Morphing assemblages live at the Institute for Figuring and in the Wertheims' home. The IFF is the Wertheims' nonprofit organization, founded in 2003 and dedicated to "the aesthetic dimensions of mathematics, science, and engineering."[36] The core concept is material play, and the IFF proposes and enacts not think tanks or work tanks but play tanks, which I understand as arts for living on a damaged planet. The IFF and the Crochet Coral Reef are art science activisms, bringing people together to do string figures with math, sciences, and arts to make active attachments that might matter to resurgence in the Anthropocene and Capitalocene—that is, to make string figures in the Chthulucene. There are incarnations of a "biodiverse reef," "toxic reef," "bleached reef," "coral forest," "plastic midden," "bleached bone reef," "beaded coral garden," "coral forest medusa," and more, along with the satellite reefs made by collectives of crafters all over the world. Crafters make fabulated healthy reefs, but my sense is that most of the reefs bear the stigmata of plastic trash, bleaching, and toxic pollution. Crocheting with this trash feels to me like the looping of love and rage.

The skills and sensibilities of Margaret and Christine Wertheim, born in Brisbane near the Great Barrier Reef, are fundamental. With degrees in mathematics and physics, Margaret Wertheim is a science writer, curator, and artist. She has written extensively on the cultural history of theoretical physics. Over a million people have watched her 2009 TED talk on "The Beautiful Math of Coral."[37] With two books written in feminine feminist materialist poetics, Christine Wertheim

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is a poet, performer, artist, critic, curator, crafter, and teacher. She aptly describes her work as "infesting fertile zones between cunning linguistics, psychoanalysis, poetry and gender studies."[38] These twin sisters were primed for sympoietic mergers.

Infecting each other and anyone who comes into contact with their fibrous critters, the thousands of crafters crochet psychological, material, and social attachments to biological reefs in the oceans, but not by practicing marine field biology, or by diving among the reefs, or by making some other direct contact. Rather, the crafters stitch "intimacy without proximity," a presence without disturbing the critters that animate the project, but with the power to confront the exterminationist, trashy, greedy practices of global industrial economies and cultures.[39] Intimacy without proximity is not "virtual" presence; it is "real" presence, in loopy materialities. The abstractions of the mathematics of crocheting are a lure to an affective cognitive ecology stitched in fiber arts. The crochet reef is a practice of caring without the neediness of touching by camera or hand in yet another travelogue of discovery. Material play builds caring publics. The result is a strong thread in the holobiome of the reef: we are all corals now.

The Madagascar Ako Project

As a Yale graduate student studying lemur behavior in 1962 in what is now the Berenty Primate Reserve, Alison Jolly fell into noninnocent love and knowledge in her first encounter with female-led, swaggering, opportunistic ringtail lemurs in the southern spiny forest. Transformed, this young six-foot-tall American white woman became a seeker of knowledge and well-being with and for the beings of Madagascar, especially the astonishing species of lemurs, the radically different forest ecosystems the length and breadth of the island, and the land's complex people and peoples. Author of many books and scientific papers and participant in numerous study and conservation teams, Jolly died in 2014. Her contributions to primatology, biodiversity conservation, and historically informed, passionate analyses of conservation conflicts and necessities were legion. But Jolly herself seemed especially to prize the sympoietic gift she helped craft, the Ako Project, which is tuned to practices for resurgence in vulnerable Malagasy worlds (Figure M2.4).[40] This is the part of her work I most love.[41]

Jolly understood well the terrible contradictions and frictions in

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a Ohy. Niomana
a. Tsy hiaraka
ndry vavy kely ry zareo.
R tamin'ilay zaza i
R PRRRRR koa razandry
zana ary te- hitarika

xt day he set off again, alone.
sister. Maky Mazana said PURRRRRRR
zana wanted to stay home and become

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Figure M2.4. Page from *Tik-Tik the Ringtailed Lemur/Tikitiki Ilay Maky.* UNICEF Madagascar and the Lemur Conservation Foundation. Text by Alison Jolly and Hanta Rasamimanana. Art by Deborah Ross. Courtesy Margaretta Jolly.

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her embrace of *both* the rural people, who cut and burn the forests to make small agricultural plots called *tavy,* and her beloved prosimians with all their forest partners. Of course, she knew she was not Malagasy but at best a guest who might reciprocate appropriately and at worst another in a long line of colonizers, always taking land and giving advice for the best reasons. She knew better than almost any other Westerner and better than many Malagasy what made ongoing *tavy* burnings and other destructive practices so lethal to the future of the forests and all their critters, including the people who need them not just for their products (including lemurs for food) but to sustain fertility in phosphorous-poor, tropical, laterite soils. She also knew that *tavy* had once been part of the cycle of forest succession and biodiversity maintenance, with evidence in old stands in Ranamafuna Park.[42]

But not anymore. Nothing has time to regenerate anymore. Jolly knew in detail what the press of rapidly increasing human numbers means to the forests in the situated history of multiple land dispossessions, relocations, violent suppressions, a succession of failed national governments, huge solicited and imposed national debt, and broken development promises. She wrote vividly about local people's accurate assessment of the effects of generations of visiting experts, while the experts and visiting research scientists often knew little or nothing about the terrible history of land seizures, colonial and postcolonial search-and-destroy operations, rapacious extraction schemes, and the impact on villagers of the failed projects of usually well-intentioned but often ignorant foreign scientists and both local and foreign NGOs. She also knew what sustained committed work of real colleagues and friends could accomplish in Madagascar against the odds and across differences of all sorts. There are many possible examples and many important people, but I want to tell about one little project that might be considered a model system for sympoiesis.

Written in both English and Malagasy, each book in the Ako Project vividly narrates the adventures of a young Malagasy lemur from one of six species, from the tiny mouse lemur or *ny tsididy* to the queer-fingered aye-aye or *ny aiay,* to singing indri or *ilay babakoto*. The stories are rich natural histories, full of the empirical sensuous curiosity of that genre; and they are bumptious adventures of young lemurs living the joys and dangers of their habitats and their groups' social arrangements. Surrounding each lemur species with diverse plant and animal critters, the project provides teachers' guides in Malagasy and

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beautifully crafted posters showing the unique regions of Madagascar where the stories take place. The books are *not* textbooks; they are stories, feasts for mind, heart, and body for children (and adults) who have no access to storybooks or to the critters of their own nation or even region. Most Malagasy never see a lemur in the wild, on television, or in a book. For generations, those privileged enough to go to a school with books saw pictures of French rabbits, a fact Alison Jolly told me with disgust in the 1980s when I interviewed her for *Primate Visions*.[43] Many villages are still without schools; and the formal curriculum remains conservative, modeled on French systems, with no place for local critters or ecologies in teacher training. In exciting, beautiful, funny, and scary stories distributed outside the school bureaucracies, the Ako Project nurtures empathy and knowledge about the extraordinary biodiversity of Madagascar *for the Malagasy*.

The Ako Project is the generative fruit of a colleagueship and friendship over decades.[44] In 1983, Alison Jolly met Hanta Rasamimanana, a scientist seventeen years her junior; they bonded as mothers doing fieldwork in challenging conditions, primatologists riveted by ringtail lemurs, lovers of Malagasy people and nature, and participants in global and local politics, with differently situated vulnerabilities and authority. Born in the capital and part of the generation sponsored by the Soviet Union under Didier Ratsiraka's socialism, Rasamimanana trained in animal husbandry at the Veterinary Academy in Moscow. She earned a PhD at the Museum d'Histoire Naturelle in Paris, and she has a master's in primate conservation. She is professor of zoology and scientific education at l'École Normale Supérieure of Antananarivo. Rasamimanana has published on ringtail feeding behavior, energy expenditure, and lemur female precedence and authority. Initiating a master's in primate conservation run in Mahajanga and the Comoros, her responsibilities in Madagascar's scientific academy have been multiple. An adviser on the Madagascar National Curriculum, she heads the Ako Project teacher support program, and she wrote the Malagasy teacher's guides based on workshops she ran in rural areas.

In all their attachments, together Jolly and Rasamimanana brought the Ako Project into the world. In their work and play across many crises in Madagascar and its conservation history, they have nurtured new generations of Malagasy naturalists and scientists, including small children, field station guides, and school and university

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students. They have practiced the arts of living on a damaged planet; it matters.

Conclusion

Like coral reefs and forests, the arctic is profoundly vulnerable in the Anthropocene. Global warming is advancing at twice the rate in the arctic compared to anywhere else on earth. In the computer game *Never Alone* (Kisima Ingitchuna), a northern Alaskan Iñupiat girl and an arctic fox set out to find the source of a world-destroying blizzard (Figure M2.5). The idea that disaster will come is not new to indigenous peoples; genocidal disaster has already come, decades and centuries ago, and has not stopped, and the people have not ceased ongoing worlding either. No one acts alone; connections and corridors are practical and material, including in the spirit world. Stories for the Anthropocene must learn with these complex histories.

Figure M2.5. Cover image for *Never Alone* (Kisima Ingitchuna). Courtesy of E-line Media, in collaboration with Upper One Games and the Cook Inlet Tribal Council.

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Taking place inside indigenous stories, world games invite contemporary sympoietic collaborations among designers of computer game platforms, indigenous storytellers, visual artists, carvers and puppet makers, digital-savvy youngsters, and community activists.[45] But the sympoiesis of *Never Alone* has another thread, too, namely, the spirit helpers crucial to the stories. *Never Alone* ties sym-anima-genic fibers into the string figure of this essay.

Working with Brazilian Amerindian hunters, with whom he learned to theorize the radical conceptual realignment he called multinaturalism and perspectivism, Eduardo Viveiros de Castro wrote, "Animism is the only *sensible* version of materialism."[46] Animism is not about "belief," a foreign Christian concept. Believing is not "sensible." I am talking about practices of worlding, about sympoiesis that is not only symbiogenetic but always a *sensible* materialism. The sensible materialisms of involutionary momentum are much more innovative than secular modernisms will allow. Stories for living in the Anthropocene demand a certain suspension of ontologies and epistemologies, holding them lightly, in favor of a more venturesome, experimental natural history. Without inhabiting symanimagenic sensible materialism, with all its pushes, pulls, affects, and attachments, one cannot play *Never Alone*; and the resurgence of this world might depend on learning to play.

We relate, know, think, world, and tell stories through and with other stories, worlds, knowledges, thinkings, yearnings. So do all the critters of Terra, in all our bumptious diversity and category-breaking compositions and decompositions. Words for this might be *materialism, evolution, ecology, sympoiesis, history, situated knowledges, animism,* and *science art activisms,* complete with the contaminations and infections conjured by each of these terms. Critters are at stake in each other in every mixing and turning of the terran compost pile. We are compost, not posthuman; we inhabit the humusities, not the humanities. Philosophically and materially, I am a compostist, not a posthumanist. Beings—human and not—become with each other, compose and decompose each other, in every scale and register of time and stuff in sympoietic tangling, in earthly worlding and unworlding. All of us must become more ontologically inventive and sensible within the bumptious holobiome that earth turns out to be, whether called Gaia or a Thousand Other Names.[47]

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An original and pathbreaking scholar, **DONNA HARAWAY** has contributed to bringing many new fields into existence, including feminist science studies and multispecies storytelling. Distinguished Professor Emerita in the History of Consciousness program at the University of California, Santa Cruz, she is the author of many books that extend the scientific imagination, including *When Species Meet* (Minnesota, 2007), *Manifestly Haraway* (Minnesota, 2016), and *Staying with the Trouble.*

Notes

For an extended development of this chapter, see Donna J. Haraway, *Staying with the Trouble: Making Kin in the Chthulucene* (Durham, N.C.: Duke University Press, 2016).

1. Shoshanah Dubiner, "New Painting in Honor of Lynn Margulis," *Science in Service to Society,* no. 3 (October 2012), https://www.cns.umass.edu/about/newsletter/october-2012/memorial-painting-in-honor-of-lynn-margulis.
2. http://neveralonegame.com/game/.
3. In 1991, "Margulis proposed any physical association between individuals of different species for significant portions of their lifetime constitutes a 'symbiosis' and that all participants are bionts, such that the resulting association is a holobiont." Sarah Walters, "Holobionts and the Hologenome Theory," *Investigate: A Research and Science Blog,* September 4, 2013, http://www.intellectualventureslab.com/investigate/holobionts-and-the-hologenome-theory; Lynn Margulis, "Symbiogenesis and Symbionticism," in *Symbiosis as a Source of Evolutionary Innovation: Speciation and Morphogenesis,* ed. L. Margulis and R. Fester, 1–14 (Boston: MIT Press, 1991).
4. Lynn Margulis and Dorion Sagan, *Acquiring Genomes: A Theory of the Origin of Species* (New York: Basic Books, 2002), 205.
5. It would be hard to summarize the symbiotic/holobionic view better than this statement does: "Life is sustained by symbioses between nitrogen-fixing rhizobial bacteria and legumes, sulphide-oxidizing bacteria and clams in tidal seagrass communities, algae and reef-building corals, and protective mycorrhizal or endophytic fungi and plants. In addition to these grand symbioses are the nodes of symbiosis called organisms." Scott F. Gilbert, Thomas C. G. Bosch, and Cristina Lédon-Rettig, "Eco-Evo-Devo: Developmental Symbiosis and Developmental Plasticity as Evolutionary Agents," *Nature Reviews Genetics* 16 (October 2015): 612.

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6. Like many paradigm-setting papers, Margulis's theory of the origin of the nucleated cell was rejected several times before being published. Lynn Sagan, "On the Origin of Mitosing Cells," *Journal of Theoretical Biology* 14, no. 3 (1967): 225–74.
7. James E. Lovelock, "Gaia as Seen through the Atmosphere," *Atmospheric Environment* 6, no. 8 (1967): 579–80; James E. Lovelock and Lynn Margulis, "Atmospheric Homeostasis by and for the Biosphere: The Gaia Hypothesis," *Tellus, Series A* 26, no. 1–2 (1974): 2–10.
8. Autopoietic systems theory was crucial to formulating the concept of the Anthropocene. Lovelock and Margulis's Gaia describes complex nonlinear couplings between processes that compose and sustain entwined but nonadditive subsystems as a partially cohering systemic whole. As Stengers stresses, Gaia is not a nurturing mother but an intrusive event that undoes thinking as usual. Gaia can flip out, in system collapse after system collapse. Complexity can unravel; earth can die. Isabelle Stengers, in conversation with Heather Davis and Etienne Turpin, "Matters of Cosmopolitics: On the Provocations of Gaïa," in *Architecture in the Anthropocene: Encounters among Design, Deep Time, Science, and Philosophy,* ed. Etienne Turpin, 171–82 (London: Open Humanities Press, 2013).
9. M. Beth Dempster, "A Self-Organizing Systems Perspective on Planning for Sustainability" (MA thesis, University of Waterloo, 1998), http://www.bethd.ca/pubs/mesthe.pdf.
10. Lynn Margulis and Dorion Sagan, "The Beast with Five Genomes," *Natural History,* June 2001, http://www.naturalhistorymag.com/htmlsite/master.html?http://www.naturalhistorymag.com/htmlsite/0601/0601_feature.html.
11. Margaret McFall-Ngai suggested "Postmodern Synthesis" for the revolutionary changes to the "Modern Synthesis" coming from EcoEvoDevo. McFall-Ngai, "Divining the Essence of Symbiosis: Insights from the Squid-Vibrio Model," *PLOS Biology* 12, no. 2 (February 2014): e1001783, doi:10.1371/journal.pbio.10017833. Allergic to "post-" prefixes, I suggest the ungainly "New New Synthesis." Scott Gilbert prefers "extended synthesis." Scott F. Gilbert and David Epel, *Ecological Developmental Biology,* 2nd ed. (Sunderland, Mass.: Sinauer Associates, 2015).
12. Konstantin Mereschkowsky, "Theorie der zwei Plasmaarten als Grundlage der Symbiogenesis, einer neuen Lehre von der Entstehung der Organismen," *Biologisches Zentralblatt* 30 (1910): 353–67.
13. Scott F. Gilbert, "The Adequacy of Model Systems for Evo-Devo," in *Mapping the Future of Biology,* ed. A. Barberousse, T. Pradeu, and M. Morange (New York: Springer, 2009), 57.
14. Nicole King, "King Lab: Choanoflagellates and the Origin of Animals," https://kinglab.berkeley.edu/.

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15. Margaret McFall-Ngai, "Pacific Biosciences Research Center at the University of Hawai'i at Manoa," http://www.pbrc.hawaii.edu/index.php/margaret-mcfall-ngai.
16. Jeffrey Gordon, "Gordon Lab," https://gordonlab.wustl.edu/; Sarkis Mazmanian, "Sarkis Mazmanian Lab Site," https://www.sarkis.caltech.edu/.
17. Statement from Nancy Moran, "Nancy Moran's Lab," http://web.biosci.utexas.edu/moran/.
18. Scott F. Gilbert, Jan Sapp, and Alfred Tauber, "A Symbiotic View of Life: We Have Never Been Individuals," *Quarterly Review of Biology* 87, no. 4 (2012): 325–41. Gilbert cowrote a separate paper because of unresolved disagreements at the National Evolutionary Synthesis Center workshop concerning whether the holobiont can be considered a level of selection. Gilbert maintains that it must be so considered and that the immune system has evolved to manage a dialogue with (and not merely exterminate or exclude) potential symbionts and to block cooperation-destroying cheaters.
19. Margaret McFall-Ngai, Michael G. Hadfield, T. C. Bosch, H. V. Carey, T. Domazet-Lošo, A. E. Douglas, N. Dubilier, et al., "Animals in a Bacterial World: A New Imperative for the Life Sciences," *Proceedings of the National Academy of Sciences of the United States of America* 110, no. 9 (2013): 3229. This paper is the result of a workshop supported by the National Evolutionary Synthesis Center.
20. Margaret Wertheim, *A Field Guide to Hyperbolic Space* (Los Angeles, Calif.: Institute for Figuring, 2007).
21. Carla Hustak and Natasha Myers, "Involutionary Momentum," *differences* 23, no. 3 (2012): 79, 97, 106.
22. Ibid., 77.
23. Orson Scott Card, *The Speaker for the Dead* (New York: Tor Books, 1986).
24. http://www.explainxkcd.com/wiki/index.php/1259:_Bee_Orchid. This orchid, *Ophrys apifera,* mimics the not-quite-extinct solitary bee *Eucera.*
25. Donna Haraway, "Anthropocene, Capitalocene, Plantationocene, Chthulucene: Making Kin," *Environmental Humanities* 6 (2015): 159–65.
26. Crochet Coral Reef, http://crochetcoralreef.org/; Ako Project, http://www.lemurreserve.org/akoproject2012.html.
27. Hustak and Myers, "Involutionary Momentum," 77.
28. Anna Tsing, "A Threat to Holocene Resurgence Is a Threat to Livability" (unpublished manuscript, 2015). Tsing argues that the Holocene was/is the long period when refugia, places of refuge, still existed. Veronique Greenwood, "Hope from the Deep," *Nova Next,* March 4, 2015, http://www.pbs.org/wgbh/nova/next/earth/deep-coral-refugia/.
29. Wertheim, *Field Guide to Hyperbolic Space,* 35.

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30. Margaret Wertheim and Christine Wertheim, *Crochet Coral Reef: A Project by the Institute for Figuring* (Los Angeles, Calif.: IFF, 2015), 17.
31. Rob Tapert and John Schulian, "Dreamworker," *Xena: Warrior Princess,* season 1, episode 3, dir. Bruce Seth Green, aired September 18, 1995 (United States: Renaissance Pictures, 1995).
32. On the crochet coral reefs as experimental life-forms, see Sophia Roosth, "Evolutionary Yarns in Seahorse Valley," *differences* 25, no. 5 (2012): 9–41.
33. Wertheim and Wertheim, *Crochet Coral Reef,* 21.
34. Ibid., 23.
35. Ibid., 17.
36. Ibid., 202.
37. Margaret Wertheim, "The Beautiful Math of Coral," February 2009, http://www.ted.com/talks/margaret_wertheim_crochets_the_coral_reef?language=en.
38. Christine Wertheim, "CalArts Faculty Staff Directory," https://directory.calarts.edu/directory/christine-wertheim.
39. Jacob Metcalf, "Intimacy without Proximity," *Environmental Philosophy* 5, no. 2 (2008): 99–128.
40. "Ako Project: The Books," http://www.lemurreserve.org/akobooks.html. Written by Alison Jolly, illustrated by Deborah Ross, Malagasy text by Hantanirina Rasamimanana. Published by the Lemur Conservation Foundation in the United States and Canada and by UNICEF in Madagascar. Unilingual books are available in English and Chinese, with more translations planned. Book artist Deborah Ross has works in major magazines, zoos, and botanical gardens, plus watercolor workshops for Walt Disney Studios, DreamWorks, Pixar, and Cal Arts and rural art workshops for Malagasy villagers. Poster artist Janet Mary Robinson has degrees in scientific illustration and ecology and environment.
41. See Alison Jolly, *Thank You, Madagascar* (London: Zed Books, 2015), for an astute, quirky, gorgeously written, often tragic account of tangles in the history of Malagasy–Western conservation encounters and projects over the late twentieth and early twenty-first centuries, all of which Jolly participated in. Thanks to Margaretta Jolly for documents on the Ako Project.
42. Ranomafana National Park could not have existed without the multi-stranded commitment of primatologist and conservationist Patricia Wright, whose work Jolly praised in *Thank You, Madagascar.* See Patricia C. Wright and B. A. Andriamihaja, "Making a Rain Forest National Park Work in Madagascar: Ranomafana National Park and Its Long-Term Commitment," in *Making Parks Work: Strategies for Preserving Tropical Nature,* ed. J. Terborgh et al., 112–36 (Washington, D.C.: Island Press, 2002).

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43. Donna J. Haraway, *Primate Visions: Gender, Race, and Nature in the World of Modern Science* (New York: Routledge, 1989).
44. Margaretta Jolly, "Alison Jolly and Hantanirina Rasamimanana: The Story of a Friendship," *Madagascar Conservation and Development* 5, no. 2 (2010): 45.
45. Dean Takahashi, "After *Never Alone,* E-Line Media and Alaska Native Group See Big Opportunity in 'World Games,'" *GamesBeat,* February 5, 2015, http://venturebeat.com/2015/02/05/after-never-alone-e-line-media-and-alaska-native-group-see-big-opportunity-in-world-games/. Thanks to Marco Harding for the reference and for teaching me to play.
46. Eduardo Viveiros de Castro, pers. comm., October 2, 2014. In conversations and in "Secular Trouble," an unpublished paper for the conference on Religion and Politics in Anxious States, University of Kentucky, April 4, 2014, Susan Harding teaches me about the cultural and historical roots of "belief" in colonial and Christian practices. See Déborah Danowski and Eduardo Viveiros de Castro, "L'Arret du monde," in *De l'univers clos au monde infini,* ed. Émilie Hache, Bruno Latour, Christophe Bonneuil, and Pierre de Jouvancourt, 221–339 (Bellevaux, France: Dehors, 2014).
47. "The Thousand Names of Gaia/Os Mil Nomes de Gaia: From the Anthropocene to the Age of the Earth," conference in Rio de Janeiro, September 15–19, 2014, https://thethousandnamesofgaia.wordpress.com/.

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