



Of Astronauts and Algae

NASA and the Dream of Multispecies Spaceflight

LEAH V. ARONOWSKY

Department of the History of Science, Harvard University, USA

Abstract This article uses the history of an unrealized technology to rethink conventional accounts of American spaceflight that cast the space cabin as the ultimate expression of human's capacity to technologically master their environments. Drawing on archival and published sources, I detail the history of the bioregenerative life-support system, a system in which simple organisms—most commonly algae—would inhabit the spacecraft and, through a series of interspecies symbioses, maintain cabin conditions and sustain astronaut life. By homing in on the maintenance practices of the system and taking seriously the kinds of interspecies possibilities they would have engendered, this account does the work of recovering how the history of American spaceflight as we know it today was not at all inevitable, and in fact it could well have been a thoroughly multispecies affair. At the same time, by offering an exaggerated example of the ways astronauts during space travel were (and are) in reality wholly reliant upon a host of technical systems for survival, the bioregenerative system points to the ways that this history not only *could* have been otherwise but *was* otherwise: the human in outer space is always already a problem of safely delivering a threatened body through an altogether inimical environment and back again. The maintenance practices of spacecraft life-support systems, real or imagined, thus afford occasion to recover a new layer of historical relations that, in turn, provide a frame through which to resignify the meaning of the space cabin in the history of American spaceflight: from an emblem of technoscientific supremacy to a place of interdependency.

Keywords space science, history of technology, multispecies, maintenance, Spaceship Earth, algae

Perfect smoothness is only possible in idealizations, while the rough and the real converge.

—Peter Sloterdijk, *Globes*

The American astronaut in the 1960s was the stuff of national-racial-gender fictions. “Clean cut,” “all-American,” “family man”—the astronaut was a paragon of virtue, the perennial darling of Norman Rockwell paintings and *Life* magazine covers. Culled

Environmental Humanities 9:2 (November 2017)

DOI 10.1215/22011919-4215343 © 2017 Leah V. Aronowsky

This is an open access article distributed under the terms of a Creative Commons license (CC BY-NC-ND 3.0).

from the “hypermasculine” world of military test-pilot culture, the first cohorts of American astronauts—sembled by the National Aeronautics and Space Administration (NASA) in 1959—repeated the pioneering semiotics of cowboys on the Western frontier.¹ These were distinctly American heroes who would gallantly surmount the frontier of the unknown in the name of securing America’s rightful place in the heavens and on Earth as an international, interplanetary superpower. At the same time, these men in many ways came to figure as beings that *exceeded* their humanness. Indeed, as Vivian Sobchack points out, astronauts often appeared “remarkably asexual,” with most made out to seem as “libidinally interesting as a Ken doll.”² As generic archetypes of heroism, astronauts were made to “reject their biology and sexuality—push it from their minds and bodies to concentrate on the technology required to penetrate and impregnate not a woman but the universe.”³

As a more-than-human being able to survive in environments that were by definition hostile to his life, the astronaut effortlessly defied the corporeal ties that bound him to Earth and his species. Indispensable to this preternatural mythology was the space cabin, the vessel that transported astronauts through these forbidding environments and back again. Indeed, in forming a self-sustaining world in the face of a lethal extra-spacecraft environment, the space cabin was propelled by its own mythos of sorts: the ark, the biblical structure, sealed and closed to the outside diluvial world, that maintained planetary life when no other place could. In the self-harboring environment of the ark, it was humans who controlled the composition of their lifeworld; the only nature that could survive was that which was invited into the safety of the floating refuge. In this the ark signaled a fundamental break between nature and humans. As Peter Sloterdijk puts it: “[In the ark,] it is not nature which makes provision for humans in all things; rather humans are condemned to care for themselves. . . . *In the floating house, nature no longer harbors humans—not even seemingly.*”⁴

Ascending from this iconography of valiant frontiersmen and self-sufficient closed worlds, the space cabin became the paradigmatic exemplar of an unyielding faith in the capacity of humans to technologically master their environments. Now that humans had successfully defied the strictures of planetary life by techno-scientific engineering ways to live beyond its bounds, the possibilities for subjecting the natural world to total human control seemed boundless. It is a confidence that has proven enduring—traces of its influence can be located in ideas spanning Spaceship Earth, the late 1960s model of technocratic governance advanced by Buckminster Fuller, to proposed

1. Hersch, “Return of the Lost Spaceman.” See also Cunningham, *All-American Boys*; McCurdy, *Space and the American Imagination*; Neufeld, *Spacefarers*; Hersch, *Inventing the American Astronaut*.

2. Sobchack, “Virginity of Astronauts,” 107.

3. *Ibid.*, 108. See also Casper and Moore, “Inscribing Bodies, Inscribing the Future.” Sexuality was not the only excretion-related bit of human biology from which these men were representationally untethered. Indeed, as Munns and Nickelsen note, the daily management of human waste products rarely—if ever—figured even in astronauts’ own popular accounts of their journeys. See Munns and Nickelsen, “Alcatraz versus the Fecal Bag.”

4. Sloterdijk, *Globes*, 240; emphasis added. See also Höhler, “Environment as a Life Support System.”

geoengineering fixes to climate change today.⁵ This article, though, tells a different story, one that considers the space cabin not as the ultimate expression of humans' supremacy over their environment but instead as a space that foregrounds their vital reliance upon it. My focus here is on the life-support system, the technological system that furnished human space cabin passengers with all their vital needs: breathable oxygen, nutrient stores, and waste removal. I zero in on the history of one type of technology in particular, the *bioregenerative* life-support system. This system proposed a spaceship cabin design in which simple organisms—most commonly algae—would inhabit the spacecraft and, through a series of interspecies symbioses, maintain cabin conditions and sustain astronaut life. These botanical life forms would recycle human waste products into nutrients, photosynthesize toxic gases into vital ones, and hydrolyze urine and sweat into potable water—the stuff of high modernist, space-punk alchemical dreams.⁶

Though it was researched extensively by NASA, the bioregenerative life-support system was ultimately never put into practice (for reasons explained below).⁷ But its history affords occasion to think more critically and carefully about the cultural iconography of the space cabin and the astronauts it contained. I am here interested in the kinds of historical possibilities that come into focus when we train attention on, as Maria Puig de la Bellacasa puts it, the “significant practices and experiences made invisible or marginalized by dominant, ‘successful,’ forms of technoscientific mobilization”—where here, the practices in question remain invisible by dint of their unrealizations.⁸ By homing in on the maintenance practices of the system and taking seriously the kinds of interspecies possibilities they would have engendered, this account does the work of recovering how, as Hustak and Myers (following Star) put it, the story “could have been otherwise”: the history of American spaceflight as we know it today was not at all inevitable, and in fact it could well have been a thoroughly multispecies affair.⁹ At the same

5. See, e.g., Fuller, *Operating Manual for Spaceship Earth*; Boulding, “Economics of the Coming Spaceship Earth”; Ward, *Spaceship Earth*. For more, see Anker, *From Bauhaus to Ecohouse*; Anker, “Buckminster Fuller as Captain of Spaceship Earth”; Höhler, *Spaceship Earth in the Environmental Age, 1960–1990*.

6. By high modernist, I mean the unflagging belief that took hold in the twentieth century in the authority of science and engineering as a means of effecting a rational social order. See Scott, *Seeing like a State*.

7. As will be explained in more detail, NASA's early flight programs sustained astronaut life through wholly artificial means: oxygen for breathing was carried on board in cryogenic tanks, carbon dioxide was removed from the air using a chemical purification system, and urine and waste were either stored or periodically vented off the spacecraft.

8. Puig de la Bellacasa, “Making Time for Soil,” 692. In this, the article is informed by the recent scholarly turn to excavating historically undervalued forms of labor in the history of technology through the alternating analytic lenses of “maintenance” and “care.” See Russell and Vinsel, “Hail the Maintainers”; Multispecies Editing Collective, “Troubling Species”; Puig de la Bellacasa, *Matters of Care*; Puig de la Bellacasa, “Matters of Care in Technoscience”; Puig de la Bellacasa, “Nothing Comes without Its World”; Martin, Myers, and Viseu, “Politics of Care in Technoscience”; Viseu, Myers, Martin, and Suchman, “Politics of Care in Technoscience”; Murphy, “Unsettling Care”; Denis and Pontille, “Material Ordering and the Care of Things”; van Dooren, “Care.”

9. Star, “Power, Technology, and the Phenomenology of Conventions,” as quoted by Hustak and Myers, “Involuntary Momentum.” See also Masco, “End of Ends.”

time, by exaggerating the ways that astronauts were (and are) in fact wholly dependent on a host of life-support systems for survival, the bioregenerative system draws attention to the ways that this history not only *could* have been otherwise but in fact *was* otherwise: the human in outer space is always already a problem of safely delivering a threatened body through an altogether inimical environment and back again. The techniques for maintaining life at its sheer limits of existence, whether real or imagined, thus afford occasion to resituate the historical place of the human in dominant accounts of spaceflight by foregrounding what was previously only acknowledged in passing (if at all) in the triumphalist narratives so integral to ideas like Spaceship Earth: an enfeebled human, utterly dependent on the various sociotechnical life-support systems of the cabin for survival.¹⁰ The space cabin, once an emblem of technoscientific supremacy, is here resignified as a place of *interdependency*.

In what follows, I plumb the history of American spacecraft engineering and design for instances of interspecies encounters even as they were imagined to transpire in the face of the most unyielding of environments. My story unfolds in two acts. I move first to examine single-organism bioregenerative systems (those that used algae), attending in particular to the ways that, in the closed world of the space cabin, the demands of physiology—of both the human and botanical kinds—assumed the mantle of world-making practices. I then turn to consider the story of the *multi-species* system, focusing here on the latent doctrine of “ecological faith” that underpinned its design.¹¹ To be sure, my intent here is not to deracinate the history of American spaceflight from its imperial and military genealogies. Indeed, as detailed below, this is a story propelled by the logic of weapons systems, the largesse of the US military, and the violence of atomic warfare—icons all of the long, bellicose American twentieth century and the tentacular reaches of technoscientific potency. But traversing this topology with an eye to the microtechnical, incongruities emerge. Drilling down to the level of maintenance foregrounds the fact that these practices *mattered*—they were literally a matter of life and death for the astronauts who would rehearse them. Ultimately, redistributing the narrative weight to give voice to the otherwise-muted registers of this history provides

10. As Roger Launius points out, outer space’s status as an extreme environment and the historical implications of this status have largely gone unexamined by environmental historians. See Launius, “Writing the History of Space’s Extreme Environment.” Though see Harrison, *Spacefaring*; Mindell, *Digital Apollo*; and Mackowski, *Testing the Limits*. At the same time, the *extreme* has recently emerged as a useful analytic in anthropology for thinking through the multiple valences of the relationship between “limits” and “horizons” that it brings into focus. See, e.g., Valentine, Olson, and Battaglia, “Extreme”; Valentine, Olson, and Battaglia, “Encountering the Future”; Battaglia, Valentine, and Olson, “Relational Space”; Olson, *American Extreme*; Battaglia, “Arresting Hospitality”; Valentine, “Atmosphere”; Helmreich, *Alien Ocean*; Helmreich, “Extraterrestrial Relativism”; Messeri, *Placing Outer Space*; and Olson, “Ecobiopolitics of Space Biomedicine.” See also Roosth, “Life, Not Itself.”

11. I use “multi-species” when discussing the historical object of analysis, and “multispecies” (no hyphen) to refer to the field of multispecies studies. See Kirksey and Helmreich, “Emergence of Multispecies Ethnography”; van Dooren et al., “Multispecies Studies.”

a means of denaturalizing the standard account by pointing to concrete moments when the meaning of spaceflight could have been otherwise. Seen through this lens, human frailness and fragility emerge as central elements of the otherwise-hubristic dream of space exploration and colonization.

Algae in the Atmosphere

From the vantage of the history of plants, the American postwar era could aptly be described as the “algae epoch.”¹² Long the object of study among botanists and biologists striving to unlock its enigmatic mechanisms of photosynthesis, algae circa mid-century gave rise to a host of technoscientific imaginings. Over the course of these photosynthesis researches, scientists ascertained that algae were relatively simple plants to grow and remarkably potent sources of protein. In the context of rising neo-Malthusian alarmism about food shortages in the face of global population boom, these findings assumed a broader salience: algae could be mobilized as a low-cost source of food for humans all over the globe. Seeking to harness this magic bullet potential, in the 1950s multiple major research organizations across the United States—including the Carnegie Institution, the Rockefeller Foundation, the National Institutes of Health, and the Atomic Energy Commission—invested significant research funds toward the development of large-scale algae cultivation technologies.¹³

By quenching famines and providing a cheap source of nutrients, algae promised to improve the human condition on Earth. At the same time, as one of the most efficient photosynthesizers on the planet, the plant seized the imaginations of those who aimed to secure *new* geographies of human existence: by supplying breathable oxygen and decomposing human waste, algae might impel sojourns to otherwise-unwelcoming places like the deepest trenches of the ocean or the outer bounds of the atmosphere. Thus, alongside these mid-century, large-scale harvesting initiatives, the US military awarded countless grants to biologists, botanists, nutritionists, and sanitation engineers to develop techniques for culturing algae in closed environments—the navy, for use in deep-sea submarines; the air force, for long-duration, high-altitude flights. Algae would effect a new kind of controlled environment, one in which the hyperartificial space of the closed world was infused with a blue-green botanical tint. It would furnish a method of deterritorializing the human soldier in the service of territorializing—and weaponizing—the extreme limits of the planet.

When NASA was established in October 1958, these algae research initiatives migrated to its aegis (although the air force never wholly abandoned its efforts). NASA’s

12. “Algae” refers to many different species. I here use it most commonly to refer to the *Chlorella* strain. For the history of photosynthesis research, see Nickelsen, *Explaining Photosynthesis*.

13. See Burrell, *Algal Culture*. For more on the global politics of nutrition in postwar international relations, see Cullather, “Foreign Policy of the Calorie.” For more on the history of algae and agriculture research in the context of neo-Malthusian fears, see Belasco, “Algae Burgers for a Hungry World?”; Belasco, *Meals to Come*; Cullather, “Stretching the Surface of the Earth”; Rao, “Imagined Reality”; Schlosser, “Malthus at Mid-Century.”

first two flight programs, Mercury (1958–63) and Gemini (1961–66), sent astronauts into orbit for short flight durations—between fifteen minutes and three weeks. These programs relied on “physicochemical” systems to sustain astronaut life: water, oxygen, and food were carried onboard to last the entirety of the mission. In the future, though, NASA’s ambitions included flights of longer durations and to more distant places—most notably with a series of manned Mars landings—when, because of weight concerns, it would no longer be feasible to bring full stores of supplies along. It was here that the bioregenerative system presented as an especially auspicious design alternative.¹⁴

These military and NASA research grants yielded several promising algae-based life-support instruments. Successful models included the “continuous culture chamber” from Jack Myers, a botanist at the University of Texas, Austin; the Recyclostat from Robert Krauss of the University of Maryland; and the Microterella, from sanitation engineers William J. Oswald and Clarence G. Golueke of the University of California, Berkeley. The devices all comprised the same components—an algae sample, an aqueous growing solution, and a light source to simulate solar energy—but targeted different life-support system functions. Using a dual bacteria-algae system, the Microterella would break down solid human waste and, as a byproduct, dispense drinkable water.¹⁵ This system, its designers believed, would be relatively straightforward and “highly dependable.”¹⁶ Designed to facilitate gas exchange between algae and astronaut, the continuous culture chamber and the Recyclostat were quite elaborate instruments. Algae’s capacity to synthesize oxygen declined significantly as it grew in density: a denser culture inhibited the algae cells at lower parts of the growth chamber from being exposed to the light source, and metabolism rates in general declined significantly as the plants matured. To maximize efficiency, these devices sought to maintain algae “always at one point on its growth curve”—a bloom state when it was most pure and most productive.¹⁷ Achieving this meant that the culture solution would require near-constant dilution with fresh growth medium and regular culling to remove mature algae cells and prevent the proliferation of mutant cells that could contribute to a more variable growth rate. The device also needed to maintain the algae in a state of continuous circulation within the growth tank to afford each cell equal exposure time to the light source.

When it came to sustaining the lives of other creatures, these models bore encouraging results. In 1958, Jack Myers’s continuous culture device kept two mice in a sealed glass container alive for over a month and, after several tweaks to their systems, others

14. See Kammermeyer, *Atmosphere in Space Cabins and Closed Environments*; Mattson, “Keeping Astronauts Alive”; Konecci, “Space Ecological Systems”; Bongers, “Sustaining Life in Space.” For more on the dream of a flight to Mars, see Lambricht, *Why Mars*; Conway, *Exploration and Engineering*.

15. Oswald and Golueke, “Man in Space.” For more on Oswald and Golueke, see Munns and Nickelsen, “Alatron versus the Fecal Bag.”

16. *Ibid.*, 459.

17. Myers and Clark, “Culture Conditions and the Development of the Photosynthetic Mechanism.”

encountered similar results.¹⁸ Scaling up to the human environment, though, meant contending with the devices' fundamental design flaw and control-obsessed NASA's greatest fear: instability. With so many interlocking components necessary to keep the algae in its most productive, pure state, the threat of system malfunction or failure loomed large.¹⁹ Even a cursory list of daily tasks that would demand an astronaut's attention here is telling. The astronaut's maintenance responsibilities would include: regulating growth chamber temperature, culling algae overgrowth, diluting the culture medium, analyzing pH levels and nutrient content of algae samples, repairing leaks and monitoring for accumulation of toxic gases, removing algae foam buildup, changing light bulbs to maintain consistency in light exposure, sterilizing the various cogs and stoppers of the system, and feeding the algae with vital nutrients not supplied by human waste products. That the system evinced watchfulness was due not to its own fragility but rather to that of the humans who would depend on it: algae proved unwieldy in its most productive bloom state but, if allowed to effloresce unencumbered, would readily progress to a more mature—but less predictable and more variable—state. The astronaut's long-term survival, then, was tethered to the purity of his life-support system, a purity that, in turn, hinged on the astronaut's sustained attention to both the hardware and wetware of the system. As one commentator quipped, the astronaut's continued existence would rest on his "horticultural efficiency"—his "skilled attention" and "green thumb."²⁰

It's worth pausing here to consider the system's parallels—discursive and material—with another system that counted the human among its instrumentalized constituent parts: the weapons system. Under the catchall phrase, "the human factor," military researchers had long fretted that the might and strength of military weapons might well prove boundless if not for the element of the human. Particularly in the context of high-altitude and high-speed flight, a soldier's biological and intellectual fallibilities—his capacity for motion sickness, hypoxia, frostbite, disorientation from vertigo, and his inability to rapidly coordinate various time-sensitive elements, just to name a few—became components to be accounted for in system designs.²¹ Researchers were acutely aware of the overlaps between the fields of military aerospace and extra-atmospheric biomedical research; indeed, as Maura Mackowski details, nearly the entirety of NASA's knowledge about living bodies in space stemmed from air force experiments and technoscientific innovations.²² Spaceflight engineers were thus well-primed to think of the astronaut in terms of frailty—a unit of uncertainty inscribed in an otherwise-seamless,

18. Myers, "Use of Photosynthesis in a Closed Ecological System"; Bowman and Thomae, "Algae Life Support System"; Krauss, "Physiology and Biochemistry of Algae"; Bowman and Thomae, "Long-Term Non-toxic Support of Animal Life with Algae."

19. Myers and Clark, "Culture Conditions and the Development of the Photosynthetic Mechanism."

20. Ward et al., "Use of Algae and Other Plants in the Development of Life Support Systems."

21. See Mindell, *Between Human and Machine*; Galison, "Ontology of the Enemy."

22. Mackowski, *Testing the Limits*. See also Mindell, *Digital Apollo*; Pitts, *Human Factor*.

integrated environmental system.²³ As NASA administrator Joseph Saunders put it succinctly: “Man is the weakest link in the weapons system. I hope this will not be true for the biologic organism in the bioregenerative [life-support] system.”²⁴

Yet this command-and-control military discourse of *weakest links* and *horticultural efficiency*, forceful as it may be, points to the essential reality of the bioregenerative system: vulnerable bodies (in this case: both human and non) in the extreme environment of outer space. This was a system forged by organisms who readily “involved” themselves in each other’s lives to the extent that the existence of one was intimately linked to the existence of another.²⁵ Astronauts would share their most intimate bodily productions—urine, excrement, sweat, carbon dioxide—in exchange for vitality. To be sure, this intimacy was not of a purely harmless ilk—ultimately, these transactions were extractive in nature. Yet there was reciprocity in this extraction, a manifestation of what Isabelle Stengers calls the “reciprocal capture” of symbiosis: the sustained mutual interest in the other’s well-being, if only as a way to sustain the self.²⁶ Considered through the lens of self-interested attachments and extractive intimacies, the space cabin’s patina as a place of pure control begins to fade. Instead, we find a space cabin configured as a *space of encounter*, in which the comminglings of human biology and algae physiology emerge as place-making practices: techniques of daily intimacy that, as Lisa Messeri puts it, “scale down the cosmos to the level of human experience.”²⁷ And in the context of the closed environment of the space cabin, these place-making practices scale back up to the level of *world-making* practices, as conditions that structure the everyday unfoldings of life in outer space.²⁸

NASA Gets Ecological

All the while, administrative clamor for a bioregenerative system was escalating. By the early 1960s, the United States by all accounts was abysmally lagging behind the Soviet Union’s space-related achievements. With President Kennedy’s 1961 vow to land an American astronaut on the moon by the end of the decade, NASA amplified its operations across nearly every aspect of space travel-related research. In the bioregenerative systems context, NASA continued to award research contracts to botanists and biologists but also endeavored to expand these efforts by bringing a new scientific discipline into the research fold: ecology. American ecology at the time was in the midst of something of a renaissance. United under the guise of “systems ecology,” the field was actively distancing itself from the more descriptive work of previous generations and was

23. See also Olson, “Ecobiopolitics of Space Biomedicine.”

24. Saunders, introduction.

25. Hustak and Myers, “Involuntary Momentum.”

26. Stengers, *Cosmopolitics I*, 35–36.

27. Messeri, *Placing Outer Space*, 2.

28. *Ibid.*; Tsing, *Mushroom at the End of the World*. See also Valerie Olson’s work on the space system as a “technology of reality.” Olson, *American Extreme*.

instead focused on reframing itself as a science with explanatory power.²⁹ This new ecology, anchored in the study of ecosystems, was part of a broader trend in the postwar social, natural, and life sciences in which cybernetics, systems, signals, and feedback loops trafficked as the foundational conceptual vocabulary.³⁰ Accordingly, ecologists moved to conceive the planet less in terms of species diversity or biogeography (categories that emphasized difference) and instead in terms of the universal system dynamics that underpinned even the most seemingly disparate terrestrial environments—the dynamics that, they believed, maintained ecosystems in a steady-state equilibrium. From these efforts emerged a distinct understanding of the ontology of the natural world, as one defined by the interplay between complexity and stability: the more complex a system—the more mechanisms it developed to maintain itself in equilibrium—the less susceptible it was to perturbations and the more readily it could recalibrate back to its stable state.

At the forefront of this turn to ecological systems were brothers Howard and Eugene Odum. Their avowed commitment to the explanatory power of the relationship between stability and complexity is difficult to overstate.³¹ In the 1950s, at the behest of the US Atomic Energy Commission (AEC), the brothers conducted a survey of a coral reef in Enewetok Atoll, one of several sites in the South Pacific where the AEC was executing its ongoing nuclear test program.³² Considered against the backdrop of the crippling devastation and destruction generated by the atomic bombs detonated at Hiroshima and Nagasaki, the Odums' findings were striking: in the wake of a multimegaton thermonuclear explosion, the reef had largely recovered, appearing within a year about the same as it had before the blast. For the Odums, this phenomenon of self-restoration was evidence of the profound invincibility of the reef's steady-state stability; over the course of millions of years, they concluded, the region had clearly established a series

29. See, e.g., Odum, "New Ecology." For more on the history of ecology in the United States, see Hagen, *Entangled Bank*; Worster, *Nature's Economy*; Bocking, *Ecologists and Environmental Politics*; Bocking, *Nature's Exports*; Golley, *History of the Ecosystem Concept in Ecology*; Kingsland, *Evolution of American Ecology*.

30. See Hayles, *How We Became Posthuman*; Kay, *Who Wrote the Book of Life?*; Keller, *Refiguring Life*; Hayles, *Chaos Bound*; Lilienfeld, *Rise of Systems Theory*; Pickering, *Cybernetic Brain*.

31. Both Howard and Eugene Odum are seminal figures in the history of American ecology and are considered to have pioneered the discipline as a science of systems. For more on the Odums, see Golley, *History of the Ecosystem Concept in Ecology*; Hagen, *Entangled Bank*; Taylor, "Technocratic Optimism, H. T. Odum, and the Partial Transformation of Ecological Metaphor after World War II." It's worth noting that the meaning of terms like *stability* and *complexity* were far from universally agreed-upon terms. In addition, as the Odums' critics were quick to point out, this emphasis on the stability/complexity entanglement constituted a deeply teleological idea of the natural world.

32. As many scholars have detailed, the environmental sciences in the United States have long been entwined with the history of the nuclear program. See, e.g., Creager, *Life Atomic*; Kwa, "Radiation Ecology, Systems Ecology, and the Management of the Environment"; Bruno, "The Bequest of the Nuclear Battlefield"; Rothschild, "Environmental Awareness in the Atomic Age"; Bocking, *Ecologists and Environmental Politics*; Masco, "Bad Weather." For more on the epistemological implications of the Odums' military-sponsored ecological research in the South Pacific, see DeLoughrey, "Myth of Isolates."

of “self-regulating interactions” that yielded armaments with which to return to its pre-exposure state. The coral reef at Enewetok constituted an unparalleled case of the “survival of the stable.”³³

It was this link between stability and complexity that laid the foundation for both Odums’ bioregenerative life-support system designs. It also informed their trenchant critique of the algae approach. That the algae system, structured around a single organism, was unstable came as no revelation to them. “From what we know about our own biosphere life system,” Eugene Odum asserted, “it is evident that no one species is ever ‘reliable’ (i.e., stable) unless it is functioning as part of an ecosystem containing other symbiotic organisms”—the system, in other words, was inherently not diverse enough to establish the mechanisms necessary for maintaining stability.³⁴ Instead, the Odums proposed the *multi-species* life-support system, a system in which a variety of organisms, all known to coexist in the same ecosystem in the natural world, would be reassembled and reorganized into the spaceship environment to form what they argued would be an “integrated, self-maintaining system.”³⁵ These organisms would be selected not for any particular species-specific traits, but instead for their functional role in ecosystems—their role as metabolizers of waste, producers of energy, consumers of detritus, etc. The key to designing these systems, then, lay in identifying the “minimum number of functional components and the minimum diversity . . . needed for stability in an ecosystem.”³⁶ The Odums’ method would be one of trial and error: “Introduce men into a closed system of 2-1/2 acres per man along with multiple compatible species . . . continue the seeding pressure until a self-stabilized, fully competitive system begins to be sustained.” Eventually, they continued, “biogeochemical circuits would become organized by selection, and the constant pressure of maintaining a man present would provide a return circuit for him as part of a new climax ecosystem for space.”³⁷

Though it was entirely artificial, the multi-species life-support system was informed by the same engineering principles that formed the chassis of the ecosystems of the planet—the “complexes for survival and maintenance.”³⁸ Moreover, by mimicking environments known to have existed in the natural world for millions of years in steady-state equilibrium, the multi-species system would have the added benefit of demanding little by way of inputs or maintenance on the part of the astronaut; the stability of this equilibrium, when translated into the space cabin setting, would intrinsically confer reliability. So assured were the Odums in the soundness of a design plan anchored in the stability-complexity entanglement that they eschewed the need to understand the component parts of the system in exact, numericized terms. “In an

33. Odum and Odum, “Trophic Structure and Productivity,” 318.

34. Odum and Beyers, “Proposal to the NASA Biospace Program.”

35. Cooke, Beyers, and Odum, “Case for the Multispecies Ecological System,” 129.

36. Odum and Beyers, “Proposal to the NASA Biospace Program.”

37. Odum, “Limits of Remote Ecosystems Containing Man.”

38. *Ibid.*

ecosystem . . . of which man is only one,” Howard Odum (writing with his postdoc Robert Beyers) argued, “this role of one species does not need to be so precise.”³⁹ In fact, in many ways, quantification would be impossible: no one element could truly be “tested” since, as they put it, “the ‘success’ of an organism” depended as much on the size and diversity of its biological environment as on its “internal physiology.”⁴⁰ The multi-species system spurned total scientific knowledge in favor of an acceptance of the inevitable *limits* of human epistemology. Instead, the Odums’ was a design cavalierly entrenched in a doctrine of belief, of faith and trust—in the soundness of the ecological theories upon which it was founded and the capacity of humans to harness said theories for the closed world of space.

A generous reading would note that, in its steadfast commitment to producing an environment that could maintain itself in the face of perturbations, the multi-species system was at least in theory conceptually aligned with NASA’s central engineering tenet: control theory.⁴¹ Control theory is a field of engineering concerned with the automation of nonlinear systems. At the basic level, it deals with the dynamics between system inputs and outputs as mediated through a sensor monitoring system: the sensor controls the system inputs to make its *actual* outputs as identical as possible to the *desired* outputs. Nearly every aspect of American spaceflight engineering drew in some way on control theory.⁴² The shuttle launch system, for example, involved a complex of monitor systems that automatically adjusted vehicle pitch and yaw to maintain it at predetermined positions and velocities during liftoff, thereby greatly reducing the need for human piloting during flight.⁴³ In this schema, the multi-species system could be thought of as control theory taken to the logical extreme: a system so naturally attuned to automation that the human factor would be completely eliminated. The engineering telos of perfect smoothness in systems operations was here subverted to be a telos of ecosystems—nature, that most perfect of systems engineers.

NASA administrators, though, were less than enchanted. After denying Howard Odum’s initial grant proposal, they awarded his brother Eugene a meager one in 1964

39. Odum and Beyers, “Proposal to Environmental Biology Section.”

40. Odum and Beyers, “Proposal to the NASA Biospace Program.”

41. It was also not without precedent. Although it was constructed along the opposite design approach—modify the body of the astronaut to make him more equipped for space, rather than modify his environment to make it more hospitable to sustaining human life—the notion of the cyborg, as it was originally proposed in the early 1960s, was formulated around the same principle of technoscientifically engineering biological processes of steady-state stability to adapt the organism for life in space. See Clynes and Kline, “Cyborgs and Space.” See also Gray, *Cyborg Handbook*.

42. For more, see Keller, “Organisms, Machines, and Thunderstorms.”

43. Indeed, as David Mindell points out, astronauts ultimately did very little “flying” in the piloting sense, generally only manning the vehicle during landings (giving credence to the infamous quip put to print by Tom Wolfe that astronauts were in fact nothing more than “Spam in a can”). See Mindell, *Digital Apollo*; Wolfe, *Right Stuff*.

but declined to renew it after its three-year period concluded. Perhaps understandably, in NASA's view the proposals had displaced the astronaut and his well-being to such an extent that the system became one in which it was "immaterial as to which species gains ascendancy"; the Odums' system of complexity was interpreted as one concerned only with the maintaining of "some life existing in some balance."⁴⁴ "Spaceflight," as one administrator decried, "is not interested in the ecosystem."⁴⁵

For his part, Howard Odum was incensed by what he saw as the nearsightedness of NASA. More than a decade later, he was still complaining about their obstinacy:

Despite our efforts for several years . . . we were unable to convince the NASA decision process that a complex ecosystem was the stable way to supply gaseous support for humans in space. NASA was receiving advice from physiologists whose whole training was pure culture and reductionist. They regarded multiple species self-organization as poor science because it involved *processes and elements not to be understood completely*.⁴⁶

Processes and elements not to be understood completely. The logic of the multi-species life-support system was the paragon of the Odums' technocratic dream of ecologically informed spaceflight: harness the most natural of phenomena—the steady-state equilibria that endowed planetary ecosystems with stability—to engender the most artificial of environments. It was, at its heart, a reproach—simultaneously humble and hubristic—to the high modernist engineering fantasy of space travel: why presume the capacity to disarticulate the interstitial workings of ecosystems, themselves the product of millions of years of ever more divergences and nonlinear unfoldings? For the Odums, the planet's masterful skill in self-correcting back to a state of equilibrium in the face of disturbances—even those incurred at the scale of an atomic bomb—was evidence enough to trust that, when marshalled for the built environment, nature's foundational ecological processes would continue to endure.

The idea of a verdant wilderness spaceship was certainly a fanciful one. It was also one that, from the historian's perspective, elucidates a certain paradox implanted in the logic of the algae system. The multi-species system was organized around what we might call a virtue of "naturalness," a conviction in the wisdom of nature's evolution-derived designs. This naturalness would yield a life-support system that neared total automation and, by extension, significantly reduce demand for the astronaut's maintenance labor. Put differently, in the multi-species system, astronauts and their nonhuman confreres would need only to passively cohabit in order to survive. By contrast, the algae system was designed as a system of purity—"pure culture and reductionist," as Howard Odum so derided it. A pure culture, unencumbered by mutant cells, irregular growth cycles, or the presence of other microorganisms, would deliver the dual effects of maximizing system efficiency and reducing its potential mechanical malfunctions

44. NASA and American Institute of Biological Sciences, *Bioregenerative Systems*, 137.

45. *Ibid.*, 139.

46. Odum, "Model of a Closed Terrarium with People"; emphasis added.

to a small range of unpredictable behaviors on the part of the algae. At the same time, this inexorable insistence on purity was what made the system an unstable one: the permanency of algae's youthful bloom state hinged on its continuous upkeep. More than mere cohabitation, this aspiration for control, for maintaining the algae in its pure but unstable state, would precipitate inhabitation.⁴⁷ In other words, these interspecies symbioses and networks of intimacy were *structured into the very hardware of the system*. I think of the bioregenerative system, then, as a profoundly human and humanizing system, foregrounding—by design—the mucky substrates and gelatinous productions that are inextricable from what it means to be alive, and what it means to be human. Part and parcel of the interspecies world-making practices of the space cabin, the system also effected a new ontology of the human in space: “the astronaut,” broken down and reinscribed within the life-support ecosystem, would emerge as a new *form of life*, a way of being in the world in which a sense of one's self would be anchored in relationality, in which the act of inhabiting would demand a radical dependency.⁴⁸ “Life,” inextricable from its milieu as Canguilhem teaches us, here assumes a new valence of meaning, becoming a phenomenon distributed, spatialized, and schematized across the space cabin environment.⁴⁹

Conclusion

In the end, neither life-support system was ever incorporated into NASA space cabin designs. The multi-species system was quickly deemed too unworkable and never progressed beyond the Odums' experimentation phase, and confidence in the viability of the algae-based system quietly waned as concerns about the system's overall reliability continued to mount; by the mid-1970s, NASA's support for algae research had winnowed to just a few lingering contracts that dealt with basic questions of photosynthesis.⁵⁰

47. Here I am indebted to Lisa Messeri's work of theorizing “the inhabitable” as both a place-making practice and as a kind of potentiality, a way of imagining the conditions necessary for an exoplanet to be deemed inhabitable. See Messeri, *Placing Outer Space*. I build on her work by thinking through what it might mean to render the cabin “inhabitable” in the multispecies studies sense, which construes “inhabiting” not as the passive coexistence between species, but the active and coparticipatory making of worlds. See, e.g., Haraway, *Companion Species Manifesto*; Haraway, *When Species Meet*; Haraway, *Staying with the Trouble*.

48. Here, I follow Stefan Helmreich's move to consider how scientific knowledge about life forms (in his case, pelagic microbes) stages new forms of life in broader social and cultural contexts. See Helmreich, *Alien Ocean*.

49. Canguilhem, “Living and Its Milieu.” See also Helmreich, *Alien Ocean*; Olson, “Ecobiopolitics of Space Biomedicine.”

50. As of this writing, NASA continues to research potential uses of plants in space, but these experiments are concerned more immediately with cultivation for agricultural purposes. For more, see Gitelson and Lisovsky, *Man-Made Closed Ecological Systems*. The Soviet Union, by contrast, came much closer to actual implementation of a bioregenerative system, conducting multiple long-term experiments involving humans and algae in closed systems throughout the Cold War. The most extraordinary of these was Bios-3, a sealed underground facility constructed in Siberia in 1972 that harbored three crew members for one year using plants as the only source of oxygen. See Salisbury, Gitelson, and Lisovsky, “Bios-3.”

Recently, historians have detailed the ways that the American space program's ideological goal of territorial conquest shaped the conditions of possibility for particular forms of knowledge across a wide range of disciplines, compellingly showing, for example, how seemingly benign fields like architecture and design came to be enlisted as technoscientific handmaidens to a nationalist project of colonizing outer space.⁵¹ My critique here has been through an obverse but complementary approach. By pointing to the ways the story could have otherwise unfolded, the machinic and biological relations attendant to spaceflight—whether real or imagined—yield a disjunctive meeting point between the quotidian practices of daily cabin life and the historical processes of erasure deployed to enact particular techno-culturo-imperial fantasies. They afford occasion to decouple the space cabin's discursive signification of human supremacy and yoke it instead to associations of fragility.⁵² They also refract back to assume potency in the Earthly realm, reaffirming the irreducible truth that, as Natasha Myers puts it, “we are of the plants”: humans' sheer existence, terrestrial or beyond, rests on the continued provision of vital chemicals copiously, but exclusively, generated by the photosynthetic powers of botanical creatures.⁵³ Underpinning the rhetorical bravado of the preternatural cowboy-astronaut are a host of interspecies and sociotechnical maintenance practices that sustain a biologically feeble human in the extreme, and extremely threatening, environment of outer space. Indeed, as Peter Sloterdijk reminds us, “perfect smoothness” is only possible in idealization, while in reality, “the rough and the real converge”: considered through its practices, the history of spaceflight becomes one riddled with precarity, instability, and fallibility.⁵⁴ In the spaceship cabin, interdependence is, literally, the way of life.

LEAH V. ARONOWSKY is a PhD candidate in history of science at Harvard University. Her current research examines the history of the concept of the biosphere in the American environmental sciences, focusing on how it took shape in the postwar era as a framework for retheorizing the relationship between “life” and “the environment.”

Acknowledgments

I am grateful to Sophia Roosth, Devin Kennedy, Marc Aidinoff, Matt Hersch, and the anonymous reviewers for their close and careful readings of earlier versions of this article. I also thank Thom van Dooren and Jamie Lorimer for shepherding this article into print. Research for this article was supported by a University of Florida Smathers Libraries Travel to Collections grant.

51. See, e.g., Scott, “Earthlike”; Höhler, *Spaceship Earth in the Environmental Age, 1960–1990*; Anker, “Ecological Colonization of Space.” See also Scott, *Outlaw Territories*; Easterling, *Extrastatecraft*.

52. Indeed, even in the context of space travel today, sterile as it may be, scholars have uncovered encounters of contingency and sociality between cohabitating botanical and human life forms in the space cabin. See, e.g., Battaglia, “Diary of a Space Zucchini”; Ford, “Cultivating an Outer Space Ecology”; Oman-Reagan, “Social Life of Plants, in Space.”

53. Myers, “Photosynthesis.”

54. Sloterdijk, *Globes*, 770.

References

- Anker, Peder. "Buckminster Fuller as Captain of Spaceship Earth." *Minerva* 45, no. 4 (2007): 417–34.
- . "The Ecological Colonization of Space." *Environmental History* 10, no. 2 (2005): 239–68. doi:10.1093/envhis/10.2.239.
- . *From Bauhaus to Ecohouse: A History of Ecological Design*. Baton Rouge: LSU Press, 2010.
- Battaglia, Debora. "Arresting Hospitality: The Case of the 'Handshake in Space.'" *Journal of the Royal Anthropological Institute* 18 (2012): S76–S89.
- . "Diary of a Space Zucchini: Ventriloquizing the Future in Outer Space." *Platypus: The CASTAC Blog*, July 7, 2014. blog.castac.org/2014/07/diary-of-a-space-zucchini-ventriloquizing-the-future-in-outer-space/.
- Battaglia, Debora, David Valentine, and Valerie Olson. "Relational Space: An Earthly Installation." *Cultural Anthropology* 30, no. 2 (2015): 245–56. doi:10.14506/ca30.2.07.
- Belasco, Warren. "Algae Burgers for a Hungry World? The Rise and Fall of Chlorella Cuisine." *Technology and Culture* 38, no. 3 (1997): 608–34. doi:10.2307/3106856.
- . *Meals to Come: A History of the Future of Food*. Berkeley: University of California Press, 2006.
- Bocking, Stephen. *Ecologists and Environmental Politics: A History of Contemporary Ecology*. New Haven, CT: Yale University Press, 1997.
- . *Nature's Experts: Science, Politics, and the Environment*. New Brunswick, NJ: Rutgers University Press, 2004.
- Bongers, Leonard. "Sustaining Life in Space: A New Approach." *Aerospace Medicine* 35 (1964): 139–44.
- Boulding, Kenneth E. "The Economics of the Coming Spaceship Earth." In *Environmental Quality in a Growing Economy; Essays from the Sixth RFF Forum*, edited by Henry Jarrett, 3–15. Baltimore: Johns Hopkins University Press, 1966.
- Bowman, Russel O., and Fred W. Thoma. "An Algae Life Support System." *Aerospace Engineering* 19 (1960): 26–30.
- . "Long-Term Nontoxic Support of Animal Life with Algae." *Science* 134, no. 3471 (1961): 55–56.
- Bruno, Laura A. "The Bequest of the Nuclear Battlefield: Science, Nature, and the Atom during the First Decade of the Cold War." *Historical Studies in the Physical and Biological Sciences* 33, no. 2 (2003): 237–60. doi:10.1525/hsps.2003.33.2.237.
- Burlew, John Swaim, ed. *Algal Culture: From Laboratory to Pilot Plant*. Washington, DC: Carnegie Institution, 1953.
- Canguilhem, Georges. "The Living and Its Milieu." Translated by John Savage. *Grey Room* 3 (2001): 7–31. doi:10.1162/152638101300138521.
- Casper, Monica J., and Lisa Jean Moore. "Inscribing Bodies, Inscribing the Future: Gender, Sex, and Reproduction in Outer Space." *Sociological Perspectives* 38, no. 2 (1995): 311–33. doi:10.2307/1389295.
- Clynes, Manfred E., and Nathan S. Kline. "Cyborgs and Space." *Astronautics* (1960): 29–33.
- Conway, Erik M. *Exploration and Engineering: The Jet Propulsion Laboratory and the Quest for Mars*. Baltimore: Johns Hopkins University Press, 2015.
- Cooke, G. Dennis, Robert Beyers, and Eugene Odum. "The Case for the Multispecies Ecological System, with Special Reference to Succession and Stability." In *NASA and American Institute of Biological Sciences, Bioregenerative Systems*, 129–39.
- Creager, Angela N. H. *Life Atomic: A History of Radioisotopes in Science and Medicine*. Chicago: University of Chicago Press, 2013.
- Cullather, Nick. "The Foreign Policy of the Calorie." *American Historical Review* 112, no. 2 (2007): 337–64.
- . "'Stretching the Surface of the Earth': The Foundations, Neo-Malthusianism, and the Modernising Agenda." *Global Society* 28, no. 1 (2014): 104–12. doi:10.1080/13600826.2013.848190.
- Cunningham, Walter. *The All-American Boys*. New York: Macmillan, 1977.
- DeLoughrey, Elizabeth M. "The Myth of Isolates: Ecosystem Ecologies in the Nuclear Pacific." *Cultural Geographies* 20, no. 2 (2013): 167–84. doi:10.1177/1474474012463664.
- Denis, Jérôme, and David Pontille. "Material Ordering and the Care of Things." *Science, Technology, and Human Values* 40, no. 3 (2014): 338–67. doi:10.1177/0162243914553129.

- Easterling, Keller. *Extrastatecraft: The Power of Infrastructure Space*. Brooklyn, NY: Verso, 2014.
- Eugene Odum Papers—Institute of Ecology. UGA 97-045. Hargrett Rare Book and Manuscript Library, University of Georgia.
- Ford, Melanie. "Cultivating an Outer Space Ecology: Introducing the On-Orbit Gardener." *EnviroSociety*, November 21, 2016. www.envirosociety.org/2016/11/cultivating-an-outer-space-ecology-introducing-the-on-orbit-gardener/.
- Fuller, R. Buckminster. *Operating Manual for Spaceship Earth*. Carbondale: Southern Illinois University Press, 1969.
- Galison, Peter. "The Ontology of the Enemy: Norbert Wiener and the Cybernetic Vision." *Critical Inquiry* 21, no. 1 (1994): 228–66.
- Gitelson, J. I., and G. M. Lisovsky. *Man-Made Closed Ecological Systems*. London: Taylor and Francis, 2003.
- Golley, Frank B. *A History of the Ecosystem Concept in Ecology: More than the Sum of the Parts*. New Haven, CT: Yale University Press, 1993.
- Gray, Chris Hables, ed. *The Cyborg Handbook*. New York: Routledge, 1995.
- Hagen, Joel Bartholemew. *An Entangled Bank: The Origins of Ecosystem Ecology*. New Brunswick, NJ: Rutgers University Press, 1992.
- Haraway, Donna Jeanne. *The Companion Species Manifesto: Dogs, People, and Significant Otherness*. Chicago: Prickly Paradigm, 2003.
- . *Staying with the Trouble: Making Kin in the Chthulucene*. Durham, NC: Duke University Press, 2016.
- . *When Species Meet*. Minneapolis: University of Minnesota Press, 2008.
- Harrison, Albert A. *Spacefaring: The Human Dimension*. Berkeley: University of California Press, 2001.
- Hayles, N. Katherine. *Chaos Bound: Orderly Disorder in Contemporary Literature and Science*. Ithaca, NY: Cornell University Press, 1990.
- . *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics*. Chicago: University of Chicago Press, 1999.
- Helmreich, Stefan. *Alien Ocean: Anthropological Voyages in Microbial Seas*. Berkeley: University of California Press, 2009.
- . "Extraterrestrial Relativism." *Anthropological Quarterly* 85, no. 4 (2012): 1125–39. doi:10.1353/anq.2012.0064.
- Hersch, Matthew H. *Inventing the American Astronaut*. New York: Palgrave Macmillan, 2012.
- . "Return of the Lost Spaceman: America's Astronauts in Popular Culture, 1959–2006." *Journal of Popular Culture* 44, no. 1 (2011): 73–92. doi:10.1111/j.1540-5931.2010.00820.x.
- Höhler, Sabine. "The Environment as a Life Support System: The Case of Biosphere 2." *History and Technology* 26, no. 1 (2010): 39–58. doi:10.1080/07341510903313048.
- . *Spaceship Earth in the Environmental Age, 1960–1990*. London: Pickering and Chatto, 2015.
- Howard T. Odum Papers. George A. Smathers Libraries—Special and Area Studies Collection, University of Florida.
- Hustak, Carla, and Natasha Myers. "Involuntary Momentum: Affective Ecologies and the Sciences of Plant/Insect Encounters." *Differences* 23, no. 3 (2012): 74–118. doi:10.1215/10407391-1892907.
- Kammermeyer, Karl, ed. *Atmosphere in Space Cabins and Closed Environments*. New York: Appleton, Century, Crofts, 1966.
- Kay, Lily E. *Who Wrote the Book of Life? A History of the Genetic Code*. Stanford, CA: Stanford University Press, 2000.
- Keller, Evelyn Fox. "Organisms, Machines, and Thunderstorms: A History of Self-Organization, Part Two. Complexity, Emergence, and Stable Attractors." *Historical Studies in the Natural Sciences* 39, no. 1 (2009): 1–31. doi:10.1525/hsns.2009.39.1.1.
- . *Refiguring Life: Metaphors of Twentieth-Century Biology*. New York: Columbia University Press, 1995.
- Kingsland, Sharon E. *The Evolution of American Ecology, 1890–2000*. Baltimore: Johns Hopkins University Press, 2005.

- Kirksey, S. Eben, and Stefan Helmreich. "The Emergence of Multispecies Ethnography." *Cultural Anthropology* 25, no. 4 (2010): 545–576. doi:10.1111/j.1548-1360.2010.01069.x.
- Konecni, Eugene. "Space Ecological Systems." In *Bioastronautics*, edited by Karl E. Schaefer, 274–304. New York: Macmillan, 1964.
- Krauss, Robert W. "The Physiology and Biochemistry of Algae, with Special Reference to Continuous-Culture Techniques for *Chlorella*." In NASA and American Institute of Biological Sciences, *Bioregenerative Systems*, 97–110.
- Kwa, Chunglin. "Radiation Ecology, Systems Ecology, and the Management of the Environment." In *Science and Nature: Essays in the History of the Environmental Sciences*, edited by Michael Shortland, 213–49. Chalfont St. Giles: British Society for the History of Science, 1993.
- Lambright, W. Henry. *Why Mars: NASA and the Politics of Space Exploration*. Baltimore: Johns Hopkins University Press, 2014.
- Launius, Roger D. "Writing the History of Space's Extreme Environment." *Environmental History* 15, no. 3: 526–32. doi:10.1093/envhis/emq053.
- Lilienfeld, Robert. *The Rise of Systems Theory: An Ideological Analysis*. New York: Wiley, 1978.
- Mackowski, Maura Phillips. *Testing the Limits: Aviation Medicine and the Origins of Manned Space Flight*. College Station: Texas A&M University Press, 2006.
- Martin, Aryn, Natasha Myers, and Ana Viseu. "The Politics of Care in Technoscience." *Social Studies of Science* 45, no. 5 (2015): 625–41. doi:10.1177/0306312715602073.
- Masco, Joseph. "Bad Weather: On Planetary Crisis." *Social Studies of Science* 40, no. 1 (2010): 7–40. doi:10.1177/0306312709341598.
- . "The End of Ends." *Anthropological Quarterly* 85, no. 4 (2012): 1107–24. doi:10.1353/anq.2012.0061.
- Mattson, Howard. "Keeping Astronauts Alive." *International Science and Technology* 54 (1966): 28–37.
- McCurdy, Howard E. *Space and the American Imagination*. Washington, DC: Smithsonian Institution Press, 1997.
- Messeri, Lisa. *Placing Outer Space: An Earthly Ethnography of Other Worlds*. Durham, NC: Duke University Press, 2016.
- Mindell, David A. *Between Human and Machine: Feedback, Control, and Computing before Cybernetics*. Baltimore: Johns Hopkins University Press, 2002.
- . *Digital Apollo: Human and Machine in Spaceflight*. Cambridge, MA: MIT Press, 2008.
- Multispecies Editing Collective. "Troubling Species: Care and Belonging in a Relational World." *RCC Perspectives: Transformations in Environment and Society*, no. 1 (2017).
- Munns, David P. D., and Kärin Nickelsen. "The Algatron versus the Fecal Bag: Reconsidering the Space Program from the Ground Up," unpublished manuscript, n.d.
- Murphy, Michelle. "Unsettling Care: Troubling Transnational Itineraries of Care in Feminist Health Practices." *Social Studies of Science* 45, no. 5 (2015): 717–37. doi:10.1177/0306312715589136.
- Myers, Jack. "The Use of Photosynthesis in a Closed Ecological System." In *Physics and Medicine of the Atmosphere and Space*, edited by Otis Benson and Hubertus Strughold, 388–96. New York: Wiley, 1960.
- Myers, Jack, and L. B. Clark. "Culture Conditions and the Development of the Photosynthetic Mechanism: An Apparatus for the Continuous Culture of *Chlorella*." *Journal of General Physiology* 28, no. 2 (1944): 103–12.
- Myers, Natasha. "Photosynthesis." Theorizing the Contemporary, *Cultural Anthropology* website, January 21, 2016. culanth.org/fieldsights/790-photosynthesis.
- NASA and American Institute of Biological Sciences. *Bioregenerative Systems: A Conference Held in Washington, DC, November 15–16, 1966, Sponsored by National Aeronautics and Space Administration and the American Institute of Biological Sciences*. Washington, DC: Scientific and Technical Information Division, Office of Technology Utilization, National Aeronautics and Space Administration, 1968.
- Neufeld, Michael J. *Spacefarers: Images of Astronauts and Cosmonauts in the Heroic Era of Spaceflight*. Washington, DC: Smithsonian Institution Scholarly Press, 2013.

- Nickelsen, Kärin. *Explaining Photosynthesis: Models of Biochemical Mechanisms, 1840–1960*. Dordrecht: Springer, 2015.
- Odum, Eugene P. "The New Ecology." *BioScience* 14, no. 7 (1964): 14–16. doi:10.2307/1293228.
- Odum, Eugene P., and Robert Beyers. "Proposal to Environmental Biology Section, Biospace Program." N.d. Box 44, "Odum-Beyers Grant" Folder, Hargrett Rare Book and Manuscript Library, University of Georgia, Athens.
- . "Proposal to the NASA Biospace Program." 1964. Box 44, "Odum-Beyers Grant" Folder, Hargrett Rare Book and Manuscript Library, University of Georgia, Athens.
- Odum, Howard T. "Limits of Remote Ecosystems Containing Man." *American Biology Teacher* 25, no. 6 (1963): 429–43. doi:10.2307/4440415.
- . "Model of a Closed Terrarium with People." N.d. (circa 1980). Box 40, "Models of a Closed Terrarium with Humans" Folder, Howard T. Odum Papers, Special and Area Studies Collections, George A. Smathers Libraries, University of Florida, Gainesville, Florida.
- Odum, Howard T., and Eugene P. Odum. "Trophic Structure and Productivity of a Windward Coral Reef Community on Eniwetok Atoll." *Ecological Monographs* 25, no. 3 (1955): 291–320. doi:10.2307/1943285.
- Olson, Valerie A. *American Extreme*. Minneapolis: University of Minnesota Press, forthcoming.
- . "The Ecobiopolitics of Space Biomedicine." *Medical Anthropology* 29, no. 2 (2010): 170–93. doi:10.1080/01459741003715409.
- Oman-Reagan, Michael P. "The Social Life of Plants, in Space." *Astrosociological Insights* 4, no. 2 (2015): 4–8.
- Oswald, W., and C. Golueke. "Man in Space—He Takes along His Wastes Problem." *Wastes Engineering* 32 (1961): 456–59.
- Pickering, Andrew. *The Cybernetic Brain: Sketches of Another Future*. Chicago: University of Chicago Press, 2010.
- Pitts, John A. S. *The Human Factor: Biomedicine in the Manned Space Program to 1980*. Washington, DC: Scientific and Technical Information Branch, National Aeronautics and Space Administration, 1985.
- Puig de la Bellacasa, Maria. "Making Time for Soil: Technoscientific Futurity and the Pace of Care." *Social Studies of Science* 45, no. 5 (2015): 691–716. doi:10.1177/0306312715599851.
- . *Matters of Care: Speculative Ethics in More Than Human Worlds*. Minneapolis: University of Minnesota Press, 2017.
- . "Matters of Care in Technoscience: Assembling Neglected Things." *Social Studies of Science* 41, no. 1 (2011): 85–106.
- . "'Nothing Comes without Its World': Thinking with Care." *Sociological Review* 60, no. 2 (2012): 197–216. doi:10.1111/j.1467-954X.2012.02070.x.
- Rao, Mohan. "An Imagined Reality: Malthusianism, Neo-Malthusianism, and Population Myth." *Economic and Political Weekly* 29, no. 5 (1994): PE40–PE52.
- Roosth, Sophia. "Life, Not Itself: Inanimacy and the Limits of Biology." *Grey Room* no. 57 (2014): 56–81.
- Rothschild, Rachel. "Environmental Awareness in the Atomic Age. Radioecologists and Nuclear Technology." *Historical Studies in the Natural Sciences* 43, no. 4 (2013): 492–530. doi:10.1525/hsns.2013.43.4.492.
- Russell, Andrew, and Lee Vinsel. "Hail the Maintainers." *Aeon*. Accessed March 2, 2017. <https://aeon.co/essays/innovation-is-overvalued-maintenance-often-matters-more>.
- Salisbury, Frank B., Josef I. Gitelson, and Genry M. Lisovsky. "Bios-3: Siberian Experiments in Bioregenerative Life Support." *BioScience* 47, no. 9 (1997): 575–85.
- Saunders, Joseph. "Introduction." In NASA and American Institute of Biological Sciences, *Bioregenerative Systems*, vii–viii.
- Schlosser, Kolson. "Malthus at Mid-Century: Neo-Malthusianism as Bio-Political Governance in the Post-WWII United States." *Cultural Geographies* 16, no. 4 (2009): 465–84. doi:10.1177/1474474009340096.

- Scott, Felicity D. "Earthlike." *Grey Room* 65 (2016): 6–35. doi:10.1162/GREY_a_00206.
- . *Outlaw Territories: Environments of Insecurity/Architectures of Counterinsurgency*. New York: Zone Books, 2016.
- Scott, James C. *Seeing like a State: How Certain Schemes to Improve the Human Condition Have Failed*. New Haven, CT: Yale University Press, 1998.
- Sloterdijk, Peter. *Globes: Spheres Volume II: Macrospherology*. Translated by Wieland Hoban. South Pasadena, CA: Semiotext(e), 2014.
- Sobchack, Vivian. "The Virginité of Astronauts: Sex and the Science Fiction Film." In *Alien Zone: Cultural Theory and Contemporary Science Fiction Cinema*, edited by Annette Kuhn, 103–15. London: Verso, 1990.
- Star, Susan Leigh. "Power, Technology, and the Phenomenology of Conventions: On Being Allergic to Onions." *Sociological Review* 38, no. S1 (1990): 26–56. doi:10.1111/j.1467-954X.1990.tb03347.x.
- Stengers, Isabelle. *Cosmopolitics I*. Translated by Robert Bononno. Minneapolis: University of Minnesota Press, 2010.
- Taylor, Peter. "Technocratic Optimism, H. T. Odum, and the Partial Transformation of Ecological Metaphor after World War II." *Journal of the History of Biology* 21, no. 2 (1988): 213–44. doi:10.1007/BF00146987.
- Tsing, Anna Lowenhaupt. *The Mushroom at the End of the World: On the Possibility of Life in Capitalist Ruins*. Princeton, NJ: Princeton University Press, 2015.
- Valentine, David. "Atmosphere: Context, Detachment, and the View from above Earth." *American Ethnologist* 43, no. 3 (2016): 511–24. doi:10.1111/amet.12343.
- Valentine, David, Valerie A. Olson, and Debbora Battaglia. "Encountering the Future: Anthropology and Outer Space." *Anthropology News* 50, no. 9 (2009): 11–15. doi:10.1111/j.1556-3502.2009.50911.x.
- . "Extreme: Limits and Horizons in the Once and Future Cosmos." *Anthropological Quarterly* 85, no. 4 (2012): 1007–26. doi:10.1353/anq.2012.0066.
- van Dooren, Thom. "Care." *Environmental Humanities* 5, no. 1 (2014): 291–94. doi:10.1215/22011919-3615541.
- van Dooren, Thom, Ursula Münster, Eben Kirksey, Matthew Chrelew, and Anna Tsing, eds. "Multispecies Studies." *Environmental Humanities* 8, no. 1 (2016).
- Viseu, Ana, Natasha Myers, Aryn Martin, and Lucy Suchman, eds. "The Politics of Care in Technoscience." *Social Studies of Science* 45, no. 5.
- Ward, Barbara. *Spaceship Earth*. New York: Columbia University Press, 1966.
- Ward, C. H., S. S. Wilks, H. L. Craft, and C. H. Wilks. "Use of Algae and Other Plants in the Development of Life Support Systems." *American Biology Teacher* 25, no. 7 (1963): 512–21. doi:10.2307/4440442.
- Wolfe, Tom. *The Right Stuff*. New York: Farrar, Straus, and Giroux, 1979.
- Worster, Donald. *Nature's Economy: A History of Ecological Ideas*. 1977. Cambridge: Cambridge University Press, 1994.