Microbial Geographies at the Extremes of Life

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Abstract This article explores world-making processes through which extreme frontiers of life are made habitable. Examining how notions of life are enlarged, incorporated, and appropriated in complex geopolitical contexts, the article argues that microbial worlds are becoming part of worlding processes and projects that further these frontiers. The emphasis on "microbial ontologies" is designed to draw attention to the increasing expediency of conceptualizing extreme earthly ecologies as analogues for other planetary worlds, as a way of tracing the relational trajectories of Antarctica and outer space, and to reflect on emerging modes of an extraterrestrial mode of thinking Earth. This article is informed by short-term ethnographic fieldwork in the Antarctic Peninsula with Chilean microbiologists engaged in the bioprospecting of extremophiles, to account for how extremophile organisms are made part of a market-driven search for bioactive components in areas highly sensitive to geopolitics at the same time as they become meaningful as proxies for extraterrestrial life. The article combines analysis, description, and fieldwork material, tracing the relational trajectories of Antarctica and outer space in very general terms and then discussing the intricacies of bioprospecting in Antarctica, where the question of who owns the microbial diversity existing outside of national territories remains ambiguous and contested.

Keywords worldings, proxies, extremophiles, bioprospecting, ethnography, Antarctic Peninsula

Extraterritorial/Extraterrestrial: Novel Kinds of Relativism at the Extremes of Life

The microscope and the telescope were the first modern sensing devices capable of amplifying human vision. Both instruments propelled experimental science forward in the seventeenth century, not only contributing to the development of a novel modern geographical imagination and a scrutinizing scientific "scopic regime"[1] but also providing a relational trajectory to the study of worlds then unknown both on Earth and in outer space. These were worlds that lay beyond known frontiers of life and scales of

1. I use the term "scopic regime" very broadly and in reference to Martin Jay's essay "Scopic Regimes of Modernity," 3.

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observation—from the microscopic to the telescopic—that up to then had not been possible. Galileo Galilei constructed one of the first refracting telescopes for astronomical purposes and discovered in 1610 the four largest Jovian moons: Io, Enceladus, Europa, and Ganymede. Half a century later Robert Hooke used a basic three-lens configuration in 1670 to observe, for the first time, what he called a "cell": the basic structural, functional, and biological unit of all known living organisms; and by 1683, Antonie van Leeuwenhoek had given the first descriptions of bacteria and protozoa.

Fast-forward four centuries and once again the microscopic and the telescopic coalesce in the search for life in extreme environments on Earth and beyond. The finding by Thomas Brook in the early 1970s of new forms of bacteria that were able to survive at near-boiling temperatures in the thermal vents of Yellowstone National Park (United States) paved the way in the late 1980s for a new form of microbiology concerned with studying and understanding extremophiles—organisms that are able to survive—and even thrive—at the extreme limits of geophysical and geochemical environmental conditions. From then onward the application of high-throughput molecular biology methods to natural microbial communities and assemblages has instigated a profound shift in how we "see" microbial worlds. With the rapid development of high-resolution molecular data, new windows have opened into worlds unknown and worlds within worlds. A key insight revealed by molecular microbiology over the past two decades, for instance, is that by developing highly efficient mechanisms, "microbial communities can flourish in the most diverse and extreme conditions, including extremes of temperature (>50°C; <4°C), pressure (>500 atm), pH (>12; <1), and salinity (>1.0M NaCl), as well as oxygen tension, high radiation, and nutrient depletion."[2] These mechanisms often involve the "development of novel metabolic pathways, the use of specialized enzymes (extremozymes) and/or the secretion of various biomolecules (extremolytes)."[3]

These key discoveries of extremophiles and developments in molecular microbiology in the 1980s and 1990s coincide and have been coupled with significant related "cosmological events": a succession of space probe flybys that began observing the Jovian system, including the most important, the Galileo mission in 1989,[4] the discovery of exoplanets in the 1990s, and the discovery of Martian meteorite ALH84001 in Antarctica,[5] which again boosted the search for habitable environments within and beyond

2. Arora and Bell, "Biotechnological Applications of Extremophiles," 498.

3. Ibid., 498.

4. NASA's Galileo mission has to date provided the most substantive data on Europa, data which strongly indicates the existence of an ocean beneath its thick ice cap, and one that, as reported by NASA, may well have an "earthlike" chemical balance. NASA has also recently reported the detection of "clay-like minerals" (phyllosilicates) on the icy crust of Europa as well as evidence supporting earlier suggestions of plate tectonics in Europa's thick ice shell—the first sign of such geological activity on a world other than Earth. Other studies also suggest that sea salt from a subsurface ocean may be coating some of Europa's geological features, meaning that the ocean is probably interacting with the seafloor, which might be an important indicator that Europa could be habitable for microbial life. NASA, http://solarsystem.nasa.gov/planets/europa/indepth (accessed June 1, 2016).

5. McKay et al., "Search for Past Life on Mars," 924.

our solar system and sparked a new wave of scientific writing on terraforming and planetary ecosynthesis. It seems worthwhile to also note here that all these events coincide with a considerable rise in bioprospecting activities in the Antarctic and other extreme ecologies such as the Atacama Desert. The microbiology of extreme environments has triggered a new stage in biological research where the study of extreme environments, emerging no-analog environments, and the theorization and speculation of hypothetical types of biochemistry on other worlds have brought together Earth, Mars, and the Jovian system in very interesting ways. Stefan Helmreich calls this "extraterrestrial relativism a relativism about 'nature' over culture,"[6] where the microbial creates a worlding topological entanglement between Earthly worlds and outer space worlds—or, as Helmreich puts it, where "the *extreme* and the *extraterrestrial* glide rhetorically into one another."[7] For Helmreich, the "shared semiotic terrain of the extreme and extraterrestrial now grounds a novel kind of relativism"[8] to which, in the case of Antarctica and perhaps in a different semiotic plane, we can also add the extraterritorial. On a parallel line of thought, David Valentine, Valerie Olson, and Debbora Battaglia have developed a novel anthropological take on how the "extreme" operates as a trope that signals a call to be more attentive and attuned to the ways in which the figure of the extreme "asserts and regenerates itself by tacking between, and bringing into relation, the ordinary and extraordinary."[9] In discussing how the notion of the extreme "has become a signifier securely attached to the problem of what humans, human practices, and human environments have become and are becoming, while simultaneously pointing to that which is to come,"[10] Valentine and colleagues argue that "the figure of the extreme shapes an analytic of limits and ever-opening horizons—epistemological and physical—that is provoking new understandings of humanness, environment, temporality, and of interspecies life as we think we understand it, here on Earth."[11] This is also a concern in Helmreich's work on "the anthropology of limit biologies," where the extreme has become "a frame for thinking about nature and its boundaries,"[12] and for pushing the very limits of how life forms on Earth and beyond can be conceived and are entangled with specific geo/biopolitical forms of organizing life. Thus, Antarctica is an extreme par excellence, and as Elena Glasberg argues, not only the "last place on Earth" but also the "first place for the technological development of new representational practices" to think with, speculate about, and anticipate space exploration.[13]

6. Helmreich, "Extraterrestrial Relativism," 1125.

7. Ibid., 1126.

8. Ibid.

9. Valentine, Olson, and Battaglia, "Extreme," 1008. For a brief account of the trajectory of the term "extreme environment," see also Helmreich, "Extraterrestrial Relativism" 1126.

10. Valentine, Olson, and Battaglia, "Extreme" 1008.

11. Ibid., 1007.

12. Helmreich, "Extraterrestrial Relativism," 1126.

13. Glasberg, *Antarctica as Cultural Critique*, 4.

Since the 1990s Antarctica has increasingly been endorsed as a proxy in speculative research on microbial life on other planets and in discussions about terraforming and ecosynthesis on other planets. The McMurdo Dry Valleys of Antarctica, for instance, epitomize this as their biological exploration has an essential similarity with that of Mars: the goal of detecting sparsely distributed biogenic material. Something comparable could be said of microbial bioprospecting in subglacial lakes in Antarctica, where these cryogenic environments act as analogues for past Martian lacustrine environments and of prospects of microbial life under Europa's icy crust, a primary candidate among astrobiologists for harboring biosignatures of microbial life, or what microbiologists refer to as "fingerprints of life."[14]

Both Antarctica and outer space are defined within international regimes as spaces outside the territory of nation-states and beyond the normative zones for human habitability.[15] Both are recognized today as future territories[16] vital for their biological and energy resources, and as a "natural" frame for a planet-scale earthly politics.[17] Antarctica and outer space are extreme environments and extraterritorial spaces that became new frontiers for science exploration during and after the International Geophysical Year (IGY) (1957–58). As Elizabeth DeLoughrey points out, Antarctica and outer space are "imaginatively, historically, and juridically interconnected."[18] Although international law identifies Antarctica and outer space as two of four global commons (the others being the high seas and the atmosphere), the fact is that both are governed and managed by specific treaties: the Antarctic Treaty System (ATS) and the Outer Space Treaty.[19] The ATS is a complex set of arrangements agreed upon by fifty-three nations

14. McKay et al., "Recognizing and Interpreting Biosignatures," 625. While it escapes the scope of this article, this is a theme I explored in the speculative documentary film *Nightfall on Gaia* (2015), which I produced as part of the ethnographic research carried out in several scientific stations in the Antarctic Peninsula. In the film, astrobiologist Xue Noon is confined within the fictional GAIA Antarctic Research Station in 2043 as she conducts extremophile bioprospecting in preparation for the first crewed mission to Europa. Like other films, for instance, Sebastián Cordero's *Europa Report* (2013), the link between Antarctica and Europa is made explicit, where Antarctica is presented as a proxy, a stand-in, a test bed, or a probe for the exploration of outer space ecosystems. *Europa Report* uses actual images from NASA flyovers and vividly brings to life the Galileo images of Jupiter's icy moon.

15. Antarctica has been a sphere of human endeavor for well over a century and outer Earth for just over fifty years. The human species is now physically present in Antarctica year round in the form of a thousand transient scientists and logistics personnel, a figure that expands to nearly five thousand in summer. On top of this, thirty thousand tourists visit the fringes of the Antarctic continent every year. On the other hand, humans have inhabited space with only relatively short absences for the last twenty years, and without interruption since 2000, through the crews of the International Space Station.

16. In both Antarctica and outer space there have been significant shifts with the emergence of new Asian polar powers (India, China, South Korea), which are also investing heavily in space and Moon exploration.

17. See, e.g., Olson, "Political Ecology in the Extreme," 1027.

18. DeLoughrey, "Satellite Planetarity."

19. The ATS is made up of four major international agreements: the 1959 Antarctic Treaty, the 1972 Convention for the Conservation of Antarctic Seals, the 1982 Convention for the Conservation of Antarctic Marine Living Resources, and the 1991 Protocol on Environmental Protection to the Antarctic Treaty. The formal name

for the purpose of regulating relations among states in the Antarctic, and since the early 1960s has also provided lessons that are relevant to the governance of transboundary systems and international spaces beyond sovereign jurisdictions. It is widely recognized that "analogous and precedent-setting legal geographies of Antarctica and the deep seabed" inspired the regulation of space activities.[20] As critical legal geography scholars have pointed out, "law is not a neutral organiser of space, but is instead a powerful cultural technology of spatial production."[21] Antarctica and outer space are here once again conflated as the exploration of mineral and biological resources becomes increasingly viable in the case of outer space, and ever more pressing in Antarctica.

Searching for Extremophiles at the Frontiers of Life

Microbial life flourishes in almost every environment on Earth. It is also the keystone of astrobiological research for morphological biosignatures on other planets. However, for microbiologists it is an accepted axiom that only 1 to 5 percent of all existing microorganisms have been obtained in pure culture and tested for their biosynthetic potential. The rest have either not been discovered or are impossible to grow reproducibly in culture with current technology. This is particularly the case for Antarctica, which is oceanographically and biologically one the most isolated areas on the planet (largely due to the permanent occurrence of the Polar Front and the Antarctic Convergence) and which is known to comprise the largest proportion of unknown genes of anywhere in the world. The Antarctic's "extreme nature" suggests that its biota has successfully adapted to survive in these unique environments. By some estimates, biodiversity on Antarctic continental shelves exceeds that of comparable habitats in the Arctic and, in some cases, is as rich as other ocean habitats on the planet, except for coral reefs.[22] In some cases, biodiversity in sub-Antarctic islands possibly exceeds at different taxonomic levels that of the Galápagos and other tropical and temperate archipelagos.[23] Key to this newly discovered abundance of microbial life in Antarctica is the range of extremophile organisms—lovers of extremes—that thrive there. The distinctive biodiversity in Antarctica and its surrounding ocean has generated considerable interest in bioprospecting,[24] and the lack of data about these Antarctic organisms presents novel

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of the Outer Space Treaty, which forms the basis of international space law, is Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies.

20. Collis, "*Res Communis*?" 270.

21. Ibid., 270.

22. David and Saucède, *Biodiversity of the Southern Ocean*, 45.

23. Barnes et al., "Incursion and Excursion."

24. Generally speaking, contemporary global bioprospecting represents a market-driven search for bioactive components in such living organisms as animals, plants, microorganisms (bacteria, microbes), and fungi in order to develop new commercial products. It involves the search for useful organic substances and the collection and analysis of biological samples for sources of genetic and biochemical materials.

opportunities to discover new microorganisms, particularly extremophiles, for their potential uses in biotechnology.

The precise ways in which psychrophiles (bacteria adapted to extreme cold) have been employed in industry is the type of conversation topic that keeps us awake at night out on the Southern Ocean: a night that never actually falls as a blue light of dusky elongated shadows envelops everything and everyone until the Sun rises again at 3:00 a.m. It's the summer of 2014 and the Chilean Antarctic Institute (INACH) has hired the Chilean Navy's AP-41 transport ship *Aquiles* to conduct part of its fiftieth Antarctic Science Expedition. The expedition involves three weeks of scientific research in the Southern Ocean along the west coast of the Antarctic Peninsula (after which I would spend another three weeks stationed at the Julio Escudero Research Station on King George Island in the South Shetlands). The *Aquiles* is a bulky 337-foot, five-thousand-ton hulk on which, on this occasion, 166 passengers from fourteen nations are meandering through and wandering around the Southern Ocean. Of these, one hundred are Chilean navy officers and crew and thirty are scientists (mostly marine microbiologists and ecologists, predominantly from Chile, but also from the United Kingdom, South Korea, Germany, Malaysia, and the United States). Completing the list of passengers are the executive director and logistics personnel from the INACH, invited artists and journalists, a group of tourists hosted by the ship's commander, a high-profile delegation from the Malaysian government, and a high school student from Switzerland and her two teachers filming a reality television program.

The sleeping cabins are small aboard the *Aquiles*, a ship built to transport troops, but still invite intimate conversation. This is my third field trip to Antarctica and my first opportunity for intense, short-term ship-borne ethnographic work. For the next two weeks, we will be meandering through the South Shetland Islands at 66°S, very close to the Antarctic Circle.

It is the middle of the austral summer. I am sharing one of the small sleeping cubicles with a young Chilean biotechnologist working for Fundación Científica y Cultural Biociencia.[25] We are sleeping on a bunk bed, and some nights the conversation goes on for hours, dimly lit by an icy blue gloom let in by the porthole (the bull's-eye, as it is called in Spanish) that links our small cabin world with the Antarctic. The first couple of nights we talk about his research interests and micro/biotechnology project. In part these involve the harnessing of microorganisms for the bioremediation and biofiltration of metal-contaminated industrial liquids and waste, more specifically the biosynthesis of nanoparticles by psychrophilic Antarctic microorganisms. We talk about glycoproteins that function as an antifreeze in some Antarctic fish, preventing them from freezing to death in subzero marine environments. There is something affable, yet ominous, in the way he talks about the relevance of his research and the prospects of

25. Fundación Biociencia (www.bioscience.cl) is a private, nonprofit Chilean foundation founded in 2001 and a pioneer in research into extremophiles and in biotechnology development in Latin America.

biotechnology more generally. In his field of applied research these glycoproteins have potential applications in a number of commercial processes, including enhancing freezing tolerance in commercial plants, extending the shelf life of frozen foods, improving surgery techniques through the freezing of tissues (cryogenic industries), and improving opportunities for fish farming in cold climates.[26]

After a few nights at sea we are approaching the first field site. It's slightly below 0˚C when we cross Neptune's Bellows and sail directly into the caldera of a restless undersea volcano whose top pokes out in an arc above the surface. After mooring we find ourselves on a Zodiac[27] with another three Chilean scientists (microbiologists and marine ecologists) speeding to shore to take samples. This is the first of four sampling trips in which I was to accompany the scientists. It feels good to be on land for a few hours. After days of overpowering smells aboard the ship, it feels nice to breathe in the strong aroma of organic matter. We have arrived at Deception Island (62°57′S, 60°38′W), one of the South Shetland Islands in the Antarctic Peninsula. This island is an Antarctic Specially Managed Area or ASMA[28] and a visually striking site. In 1820 British and American sealers explored and named this island, where barren volcanic slopes and ash-layered glaciers embrace areas of long-term geothermal activity. Defying oblivion on its beaches are the archaeological remains of a short-lived fur sealing industry in the 1820s and the remnants of a large Chilean-Norwegian whaling enterprise in the early twentieth century. We are inside a large, horseshoe-shaped, flooded caldera, the crater of a volcano that last erupted in 1970, closing the scientific stations that had been active there. These days it is one of Antarctica's tourism hot spots as well as home to Argentinean and Spanish research bases. Deception Island is also testimony to how Antarctica, after its discovery in 1820, became gradually and inexorably implicated in the colonial-imperial geographies of exploration and discovery of the late nineteenth and early twentieth centuries.[29]

Historically, the Southern Ocean has been a key source of raw materials vital for medical and industrial uses, from seals to whales and plankton to microbes. As Antarctic archaeologists Andrés Zarankin and María Ximena Senatore have argued, at the end of the nineteenth century the continent was incorporated swiftly into a world capitalist system through "strategies enacted at global and local scales in which industrial companies competed in the search for goods and supplies, especially marine resources,

26. See Joyner, "Bioprospecting as a Challenge," 199.

27. A Zodiac is an inflatable, lightweight, rigid boat with its sides and bow made of flexible tubes containing pressurized gas. It is the most common mode of transport by sea across short distances in Antarctica.

28. This ASMA is managed by a group comprising representatives from several Antarctic Treaty Consultative Parties: Argentina, Chile, Norway, Spain, the United Kingdom, and the United States. Advisers include the Antarctic and Southern Ocean Coalition (ASOC) and the International Association of Antarctica Tour Operators (IAATO).

29. Chaturvedi, "Biological Prospecting," 293.

such as seals and whales."[30] This argument is important for understanding how humans' early presence in Antarctica, before the 1940s, was not so much driven by states wishing to expand their sovereignty—a process which came about later, in the mid-twentieth century—but the result of capitalist imperatives: that is to say, driven largely by private companies that sought to extend the boundaries of exploitable lands deep into the sub-Antarctic regions in search of greater profits. The Chilean Whaling Society of Magallanes, which operated from 1906 to 1916, was one of the largest. In 1907 it expanded its operations to Deception Island, a place that was soon to become the center of whaling operations in the western Antarctic.[31] For six years whaling vessels under the Chilean flag exploited the riches of this Antarctic territory. The success of these whaling operations was largely based on the harpoon cannon, which had recently been invented by Svend Foyn, a Norwegian whaling and shipping magnate.

Now, a century later, whales have given way to microbes; harpoon guns have given way to Petri dishes and microbial detection array instruments to test their functionality for sampling soils in outer space; and telescopes have given way to flybys and robotic sampling missions. And at Deception Island, whalers have given way to microbiologists aboard a Chilean Navy ship, working for state-run research institutes and organizations, universities, or private biotechnology companies. If a century ago, at the twilight of the so-called heroic age of Antarctic exploration, it was "animal capital"[32] that defined the arrangement through which Antarctica became caught up in an emergent world capitalist system; today, in the early twenty-first century, an age of genomics, stem cell research, and reproductive technology, zoopolitics has given way to marine "microbiopolitics,"[33] where "life itself" has become enmeshed in market dynamics. Microbial extremophiles are the dominant life forms in polar environments, and novel configurations of technology (laboratory techniques such as cell cultivation and DNA sequencing) and regulation (legal instruments through which biotechnology exchanges unfold) have led to new forms of *biocapital*[34] that depend upon a "form of extraction that involves isolating and mobilizing the primary reproductive agency of specific body parts, particularly cells."[35] The circuits through which marine microbes are made meaningful and fashioned as currency for biotechnology differ significantly from twentieth-century zoopolitics by which whales became a tool of statecraft and capital expansion. This is what Helmreich calls "blue-green capitalism"—an "excess of circulating life" at the intersection of "financial and microbial geographies," which come to define the risky practices of Antarctic bioprospecting.[36]

30. Zarankin and Senatore, "Archaeology in Antarctica," 43.
31. Pastene and Quiroz, "Outline of the History of Whaling in Chile," 89.
32. Shukin, *Animal Capital*.
33. Paxson, "Post-Pasteurian Cutures," 16.
34. See Franklin, "Ethical Biocapital."
35. Franklin and Lock, "Animation and Cessation," 8.
36. Helmreich, *Alien Ocean*, 108. See also Baker, "Biosecurity."

Rendering Microbial Geographies: From Earthly Bioprospecting to Planetary Ecosynthesis

Paleoecology and ecological modeling have turned their interest to "novel" environments evolving on Earth. Using a range of climate- and species-distribution-model algorithms, several likely future no-analog communities and ecosystems—that is, those that have no current equivalent—are being predicted to dominate on Earth from AD 2100.[37] This is to me intricately linked to a renewed impetus in astrobiology for the search for a new genesis of life, that is, biotic and abiotic life that so far has not been included in the universal tree of life: Archaea, Bacteria, and Eukarya. As research on extremophiles continues to generate new speculation about the limit capacities of living things, the modest microbe has become "a figure for thinking through the presents and possible futures of nature."[38]

Marine microorganisms are critical players in the Earth System and key entities for rethinking life in the Anthropocene. Most significantly, they also play a pivotal role as bits of synthesized DNA in the *making* of (synthetic) life and are also key indicators for conceivable "alien life." More than forty years after being named by NASA exobiologist Robert MacElroy in 1974, very little is still known about *extremophiles*:[39] microorganisms that not only are able to support environmental conditions usually fatal to most eukaryotic cells but can also thrive in extreme environments and biotopes combining several stress factors, where usually no other microorganisms are found. This is extremely important when considering how global environmental change is affecting the magnitude of biogeochemical fluxes and ocean chemical inventories, leading to shifts in the chemistry and biology of anoxic marine zones.

This biological imaginary of optimism and potential emerged loud and clear from the ethnographic interviews and "agential conversations"[40] I carried out at sea and at several research stations: the prospect of discovering new organisms offers biotechnology the great promise of finding new geochemical and genetic properties that might be developed for science and commercial activities.[41]

37. Williams and Jackson, "Novel Climates," 475.

38. Paxson and Helmreich, "Perils and Promises," 166.

39. MacElroy, "Some Comments on the Evolution of Extremophiles." Almost immediately after coining the term *extremophiles*, MacElroy published a first attempt at developing a relational ontology with possible microbial life on Mars; see Averner and MacElroy, "On the Habitability of Mars."

40. Interview data was important to sample a range of career rationales among Chilean scientists and their views on their work in Antarctica. Following Müller and Kenney the interviews were reframed as "agential conversations" in the way they "created situated moments of reflection, connection, and disruption that could serve as a basis for responding to these problematic conditions affecting researchers in the life sciences and beyond" (Müller and Kenney, "Agential Conversations"). These conversations were also critical in unveiling a different "architecture for perception" (see Charles Goodwin, cited in Helmreich, *Alien Ocean*, 43) that was noticeable between marine scientists and the Chilean navy crew, among whom not only a clear division of labor was enacted but also a well-defined division of perception about the value of Antarctica and the role of science.

41. Joyner, "Bioprospecting as a Challenge," 197.

As Helmreich's anthropological work on "microbial seas" attests, microbes can be thought of as "embodied bits of vitality"[42] that define a new resource frontier in marine microbiology and ecology, where genomics and bioinformatics afford new multiscalar associations "linking genomes to biomes"[43] and where the planet's coating of microbes —particularly in the oceans—has become a new source of genetic material of untapped biotechnological promise.

As the hunt for new medicines and biotechnological applications turns to the Antarctic and the deep seabed, a new imaginary is emerging of the Antarctic as a biotechnological cornucopia of discoverable genetic riches. Drawing on Veronica Davidov's analysis of the commonly deployed imaginary of the Amazon as a pharmacopia,[44] I contend that a similar metaphor could be used in the Antarctic, notwithstanding that the biodiversity of the Amazon might not be comparable to the Antarctic, and the fact that the politics of bioprospecting in the Amazon are significantly different due to the existing and deep Indigenous knowledge and traditional understandings of uses of plants, fungi, and soils. For Davidov, the Western imaginary of the Amazon as a pharmacopia is a discursive variation on the environmental imaginary of the Amazon as the "lungs of the world"—a vulnerable entity of high import and in need of protection. Both the "lungs of the world" and the pharmacopia imaginaries, Davidov argues, construct the Amazon as a global commons. While the "lungs of the world" narrative is conceptually anti-extractivist—Davidov contends—it does legitimate to a degree a different contemporary form of extraction in the Amazon: that of bioprospecting.[45] The Antarctic is often still considered the "last wilderness on Earth" and the "continent for peace and science"; these narratives are also conceptually against any form of extractivist activity. The ATS, for instance, bans any form of mineral prospecting in the continent and values Antarctica for its wilderness, which needs to be protected. Just like the Amazon in Davidov's analysis, where value is attributed to its containment and intactness as a space in need of being salvaged, the pharmacopia narrative is becoming an emergent narrative construction in the Antarctic as new—and legitimized—forms of extraction such as bioprospecting are being practiced in ways that are seen not to conflict with the "continent for peace and science" narrative in the way that oil or mineral extraction, or even contested visions of territorial claims, do.[46]

42. Helmreich, *Alien Ocean*, 6.

43. This relational ontology goes even deeper. In the most comprehensive study to date about the structure and function of the global ocean microbiome—which analyzed novel sequences from viruses, prokaryotes, and picoeukaryotes from sixty-eight locations across the globe containing over thirty-five thousand species—it was revealed that over 73 percent of microbial abundance in oceans is shared with the human gut microbiome; this points to the "extreme genetic fluidity of bacteria" from the human gut to oceans and to other planetary ecosystems. For detailed information and analysis, see Sunagawa et al., "Global Ocean Microbiome."

44. Davidov, "Amazonia as Pharmacopia."

45. Ibid., 243.

46. Ibid., 245.

Bioprospecting has been underway in Antarctica since the late 1980s and to date has been "largely driven by the success of Antarctic science, which has been given an entrenched and privileged role in the international Antarctic governance regime provided by the Antarctic Treaty System over the past half century."[47] As Joyner observes in reports to Antarctic Treaty Consultative Meetings in 2008 and 2009, more than two hundred research organizations and companies from at least twenty-seven states are undertaking research for commercial purposes in the Antarctic.[48] According to these reports, as noted by Joyner, most of the interest on genetic resources from Antarctica comes from "the pharmaceutical/medical technology industries (20 percent), followed by the food and beverage industry (20 percent), molecular biology and biotechnology (18 percent), industrial applications (12 percent), chemical processing (11 percent), cosmetics and personal care (6 percent), aquaculture and agriculture (6 percent), culture collection or library (3 percent), and environmental remediation (1 percent)."[49]

Bioprospecting also raises distinctive geopolitical issues in Antarctica by virtue of its peculiar historical and legal arrangements. The ATS does not directly regulate bioprospecting activities in the Antarctic.[50] To the extent that rules for bioprospecting now exist, they stem from the host governments under which the researching company or groups of scientists are carrying out the bioprospecting. Nonetheless, certain provisions of the Antarctic Treaty, such as the 1991 Protocol on Environmental Protection to the Antarctic Treaty, and the 1982 Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) have relevance for bioprospecting, and these may provide the seeds for future regulatory regimes.[51] As Meduna observes, the extraction and use of any resources from the Antarctic Treaty area is highly controversial because such extraction "has the potential to impact the Antarctic environment, and the use of Antarctic resources always awakens the dormant argument on Antarctic sovereignty and sovereign rights."[52] This problem has many precedents to a potential dispute in Antarctica and in outer space, as clearly articulated by Hayden in her study of a "bioprospecting imaginary" in Mexico. As she pondered: "In what idiom—territoriality, nationalism, cosmopolitanism, authorship—will biological collections be attached to social relations, interests, and claims?"[53]

47. Hemmings, "Does Bioprospecting Risk Moral Hazard?" 5. See also Herber, "Bioprospecting in Antarctica"; Hemmings, "From the New Geopolitics"; and Hemmings, "Commercial Harvest in Antarctica."

48. Joyner, "Bioprospecting as a Challenge," 200.

49. Ibid., 200.

50. The fact of the matter is that bioprospecting is already an ongoing activity in Antarctica, especially in the Southern Ocean, where numerous genetic resources have already been extracted and patented. At the global level, the Agreement on Trade-Related Aspects of Intellectual Property Rights, the Convention on Biological Diversity, and the United Nations Convention on the Law of the Sea are the normative legal instruments for regulating bioprospecting. See also Guyomard, "Ethics and Bioprospecting in Antarctica."

51. Joyner, "Bioprospecting as a Challenge," 204.

52. Meduna, "Search for Extremophiles."

53. Hayden, *When Nature Goes Public*, 368.

While it is unlikely that microbiological sampling would have any profound effect on Antarctic ecosystems, it is still somewhat equivalent to a capitalist form of extraction. As Hemmings also argues, without some institutional separation between scientific practices as actor and science as independent adviser, bioprospecting may "risk moral hazard for science in the Antarctic Treaty System."[54] This certainly includes both microbiologists looking for enzymes and genetic material to patent or use in biotechnology and astrobiologists sampling for anaerobic extremophiles.

In other words, several unresolved bioprospecting issues could pose serious challenges for the Antarctic Treaty Consultative Parties as a group, particularly, though not exclusively, between claimant and nonclaimant states. One fundamental issue is the lack of a consensus definition of biological prospecting as a research activity. To make the point: all the research undertaken by the microbiologists I followed for several weeks in the Antarctic Peninsula was carried out within a zone the Food and Agricultural Organization (FAO) calls Area 48. This area provides a prime example, as Eric Ziegelmayer poignantly contends, "of the centuries-long and still-accelerating trend of industry to consume ever-greater volumes of raw materials from ever more distant sources."[55] Examining the geopolitics of Area 48 offers a persuasive indication of *how* the early (and, in the opinion of many, looming) exploration of outer space and other planets and moons in our solar system will likely be carried out: that is, through a complex assemblage of science, military, and commercial interests. Some of these big questions and potential quarrels over Antarctic bioresources (and potentially mineral resources) cross over into the exploration and potential exploitation of resources in outer space. At present, more evidence of possible microbial life in Enceladus had been found in the way of hydrogen molecules in vents, which on Earth are the main source of energy (food) for microbes. Who owns the microbial diversity existing outside of national territories, on and offshore, in Antarctica, is an equivalent question to the one that will need to be asked, and answered, if microbial life is found elsewhere in our solar system.

I followed Chilean microbiologists on sampling trips, closely observed them while they constructed DNA sequences in labs and turned genes into data, discussed with them how they used the object-oriented, high-level programming language Python to implement key algorithms and data structures to analyze genomes and DNA datasets, and then followed them again to international conferences where they presented their findings and their visions of biotech futures. For some of these scientists the use of microorganisms is an eco-friendly and exciting approach to biotechnology. They regard their work as essential to fostering new understandings of the limits and possibilities of

54. Hemmings, "Does Bioprospecting Risk Moral Hazard?"

55. Ziegelmayer, "Capitalist Impact on Krill," 48. For Ziegelmayer, the incorporation of Antarctic ecology within the global agro-food regime has been underway for decades, as commodities move into longer and more complex chains, generating a new global division of labor and expanding the spatial dimension of production. As capital seeks increasing volumes of raw material and competition for protein of whatever form becomes more and more critical, the Antarctic is subjected to amplified exploitation (whether of fish, krill, or microorganisms).

Figure 1. Chilean microbiologists prospecting extremophile microorganisms, Antarctic Peninsula, 2014. Credit: Elias Barticevic (INACH).

life. It is hard to disagree. But I was struck by how many of them—particularly PhD students and postdocs—seemed oblivious to and often uninformed about the "wicked" problems posed by bioprospecting in the Antarctic, as well as heedless of current debates surrounding the implications of what Corinne Hayden has termed the patenting of "life itself."[56] Many of the younger researchers seemed convinced that they were carrying out research within Chilean waters as part of the Chilean Antarctic Territory. Or at least unpreoccupied about these political implications. This view was buttressed by the fact that science in Chile is funded and supported by its national Antarctic program and other state agencies and public universities with the main interest being exploring the potential of metagenomic approaches as a tool for bioprospecting through targeted sampling efforts in the hope of finding novel functional gene activity.

At different points in time and in diverse locations, I posed the same questions to them: How do they think that benefits from their research ought to be shared or distributed? To what extent might these issues threaten security, institutions, and processes that provide and improve scientific and political cooperation in the Antarctic? Their answers resonated again and again with Davidov's analysis of Amazonia: the pervasive

56. Hayden, *When Nature Goes Public*.

cultural fantasies of the Antarctic as a genetic pharmacopia function as a narrative that legitimizes a form of "acceptable" use and extraction of Antarctic bioresources in a science-policy milieu where the Antarctic is publicly—and juridically—constructed and imagined as the last wilderness, the continent of science and peace, an inalienable space to be protected and conserved.[57]

These geopolitics and ethics of earthly bioprospecting certainly relate to and inform current modes of thinking about terraforming and planetary ecosynthesis. While roaming around the sub-Antarctic islands, following biologists and ecologists on sampling trips and in their laboratory work, and living at several research stations on King George Island, I kept coming back to the descriptions of how extremophilic microbes are regarded by American microbial biologists and oceanographers in Helmreich's ethnography: "as potential ancestors of all life, helpful monitors of climate control, raw material for new life-saving drugs; and, on the other [hand], beings always erasing the trace of their own origins, entities indifferent and adaptable to human ecological disaster, vehicles of seaborne disease."[58]

Antarctica as Proxy for the Terraforming of Other Worlds

During a conversation at Julio Escudero Station in late February 2013, a marine microbiologist who was in his seventh consecutive summer season there is checking his news feed in a laptop and comments that NASA astrobiologist David S. McKay had just passed away. McKay was a key proponent of the existence of past life on Mars based on his analysis of the ALH84001 meteorite found in Antarctica. This leads to an engaging conversation about terraforming and ecosynthesis in Mars, of possible biosignatures of life in Europa and of Antarctica as earthly proxy and analogue for life off Earth. As noted at the start of this article, Antarctica is undoubtedly different from the rest of the planet. It is quasi-extraterrestrial in its extreme ecology and lack of sustenance for human life. Despite being anything but lifeless, sterile, or still, as it has been historically constructed, Antarctica's off-limits condition links it intricately to outer space. US environmental historian Stephen J. Pyne has argued that because Antarctica is "inextricably different" ("extraterrestrial") in its lack of sustenance for human life, it has gained renewed expediency to simulate alien microbe-scapes as model ecosystems.[59] This framing takes place against the backdrop of relentless processes of environmental modification in Antarctica occurring due to global environmental changes in Earth dynamics and to human by-products. This ecological modification and transformation of the atmo-bio-geosphere is what Joseph Masco has termed "terraforming planet Earth": "the unintended aftermath of cumulative industrial, military, and financial projects, remaking

57. I am drawing on Veronica Davidov's analysis and applying it to the context of Antarctica. See Davidov, "Amazonia as Pharmacopia," 246.

58. Helmreich, *Alien Ocean*, x–xi.

59. Pyne, "Extraterrestrial Earth," 147.

Figure 2. Julio Escudero Station, Chilean Antarctic Institute, 2013. Credit: Elias Barticevic (INACH).

bodies and atmospheres on a planetary scale, and in ways that we have yet to fully account for, let alone govern."[60] For Masco, "given the ever present material reality of environmental toxics, there is no need to project geoengineering with its specific planetary optic into a distant future or require travel to other worlds. We can look closer to home for an example of a planetary atmospheric politics. There has been a long-term terraforming project conducted on planet earth—one that is drawn from the cumulative effects of industry, militarism, and capitalism."[61]

In effect, atmospheric scientists and geoscientists have been observing, modeling, and simulating a series of gradual yet relentless processes of ecological modification in Antarctica. Many of these processes coincide with the post-1950 acceleration of change in Earth System indicators and will most likely have upsetting consequences for life on Earth. But paradoxically some of these changes imply that in a relatively short period of time, conditions might become more favorable for permanent human habitation of the southern polar continent. What's at stake here is how we might think about what I argue is a process of the terraforming of Antarctica. In a similar way to how Valentine, Olson, and Battaglia mobilize the notion of extreme as "acts of extending the world, where that extension represents the inclusion of what is known and unknown, what can be felt as well as intuited, quantified as well as imagined,"[62] I think the notion of terraforming Antarctica can be correspondingly mobilized as the southern polar region is being shaped: made habitable to humans. I am not arguing for a notion of terraforming in Antarctica as proposed, for instance, by Fogg: a process of planetary engineering, specifically directed at enhancing the capacity of an extraterrestrial planetary environment to support human life and create an open planetary ecosystem emulating all the functions of the biosphere of Earth to allow for human habitability.[63] I am not picturing

60. Masco, "Terraforming Planet Earth," 65.
61. Masco, "Terraforming Planet Earth," 329.
62. Valentine, Olson, and Battaglia, "Extreme," 1011.
63. Fogg, *Terraforming*.

terraforming in its original understanding as "ecocolonization" (although the arrival of invasive species and the colonization of polar environments by terrestrial biota is accelerating).[64] I am talking more about a course of action that describes these almost imperceptible but relentless processes of Earth-shaping at play in the southern polar region and which are radically altering Antarctic ecosystems. So here I am hoping the notion of terraforming is elastic enough to push the limits of what we understand as Earth-shaping. I am picturing this in line with the way McKenzie Wark reads Kim Stanley Robinson's *Mars Trilogy* as "a Brechtian estrangement device to open up a space for thinking about the organization of Earth."[65] Maya, one of the characters in Robinson's novel *Green Mars*, laments: "We exist for Earth as a model or experiment. A thought experiment for humanity to learn from."[66] Or as Wark puts it: "Perhaps Earth is now a Mars, estranged from its own ecology."[67]

Conclusion

It is close to midnight on January 31, 2014, at Julio Escudero Research Station. A few hours before a few of us had returned from celebrating New Year's Day at China's Great Wall Station only 2.5 kilometers away. We are observing the sunset as the night sky becomes littered with dots of light. Little did we know that perhaps at that moment we were being pictured from Mars, 55 million kilometers away (fig. 3).

After six weeks living in the Antarctic and returning for a third consecutive summer, my sense of belonging to this place and to this transient community was growing stronger by the day.[68] It made me wonder over and over again about how we tend to think of life on Earth at low and middle latitudes—but only in rare cases at high latitudes—as the normative model for habitable worlds. Antarctica challenges this view, given its quasi-extraterrestrial conditions for human habitability and the abundance of microbial communities thriving at the limits of life. And so, the relentless transformation of Antarctica into a habitable world invites reflection on how the Antarctic acts as or is enacted as a proxy for modes of thinking about terraforming other planets for human habitability and bioprospecting resources on asteroids and other celestial bodies. As Arora and Bell argue, the future of extremophile biotechnology and extreme environment research offers novel insights "into the evolutionary processes governing life on Earth and other planets, but can also help humans live outside their own 'extreme envelope.'"[69] At stake, is also how slowly but relentlessly, Antarctica is being

64. See for instance, two key recent articles: Chown et al., "Changing Form of Antarctic Biodiversity," and Hughes and Convey, "Non-native Species."

65. Wark, *Molecular Red*, 179.

66. Robinson, *Green Mars*, 376, cited in Wark, *Molecular Red*, 186.

67. Wark, *Molecular Red*, 186.

68. See also Salazar, "Geographies of Place-Making in Antarctica"; and O'Reilly and Salazar, "Inhabiting the Antarctic."

69. Arora and Bell, "Biotechnological Applications," 513.

Figure 3. Earth in the Martian sky. Image taken by NASA's Mars rover Curiosity at the Dingo Gap inside Gale Crater on January 31, 2014, showing Earth and its moon. Credit: NASA/JPL-Caltech/MSSS/TAMU.

"de-extremized" through worlding processes that are making Antarctica familiar. Art curator Annick Bureaud, reflecting on human settlements in Antarctica, has termed these processes "the extremophilization of the human and humanization of extremophiles."[70] This two-way process also seems connected to Valerie Olson's argument that by examining critically how the solar system becomes constituted as an ecological system connected in dynamic material and symbolic ways to terrestrial life and worlds, extreme spaces present challenges not to humanness or life forms per se but to the conditions of being biological, ecological, and emplaced.[71] Olson sees not an extraterrestrial relativism but more an emerging form of ecosystemic relativism that results from people increasingly engaging with such "outer spaces" as distinctively ecological on their own terms rather than biologically dangerous or geopolitically treacherous. Antarctica and outer space are never unspoiled by politics: they are played on by both a microbiopolitics and a cosmopolitics. As my ongoing work at the base of the globe attempts to explain, Antarctica is a crucial site for examining practices of future imagining in social terms, and for anthropological engagement with these practices, where novel ethnographic work in Antarctica might open up new paths for thinking and practicing an "anthropology off the Earth."[72]

70. Bureaud, "Inhabiting the Extreme," 187.

71. Olson, "Political Ecology in the Extreme."

72. See Battaglia, Valentine, and Olson, "Relational Spaces," 252. See also Salazar, "Speculative Fabulation." See also my and Istvan Praet's introduction to this special section.

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