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BIOMIMICRY: NEW NATURES, NEW ENCLOSURES

ABSTRACT:

Advocates of biomimicry, encourages a new industrial paradigm that ostensibly leaves behind the crude violence of Francis Bacon, the domination of nature-as-machine, and a history of toxic production processes that have given rise to a present and coming climate crisis. As part of a broader trend towards the conceptualization and development of a 'bioeconomy', we argue here that biomimicry produces 'nature' in new ways. At face value, these new approaches to valuing nature may seem less violent and exploitative. Yet, new natures can and are tortured in new ways. We argue that biomimicry produces 'nature' through well-worn logics of resource enclosure and privatization, focusing upon two fundamental shifts in how nonhuman life is figured and put to work: (1) The production of nature as intellectual property (as opposed to raw materials); (2) The production of nature as an active subject (as opposed to a passive receptacle or vehicle).

KEYWORDS: Nature-Cultures, Late Capitalism, Life, Environment, Machine, New Economy, Post-Industrial Society, Posthumanism

Every culture knows...life works.

-Janine Benyus, 2012

Introduction

Biology has become big business. Paralleling the rise of Post-Fordism and the 'information economy' in the latter half of the twentieth century, the global circulation of biological materials and bio-based services have enrolled life's most basic elements and processes within regimes of innovation, privatization and industrialization. Commonly referred to as the bioeconomy, this still expanding field casts the biological sciences as an engine of profit, giving rise to a variety of innovations, such as genetically modified agricultural products, the growth of biofuels from algae, and pharmaceuticals from microbiology. Beyond these specific techno-scientific productions, the bioeconomy has given rise to a powerful imaginary that is transforming how we consider, use, access, and legislate "life." Sheila Jasanoff has

referred to these effects as a kind of “ontological surgery” that displaces how the lines between nature and society are drawn and how their differences are enacted (2010: 160). As social, industrial and even ecological futures align with the demands of a capitalist economy through these bioeconomic practices, they also reconfigure the “intimate fabric of corporeality” that connects humans to the “seemingly indifferent stuff of the world that makes living possible” (Whatmore, 2013: 36).

In this essay, we explore these entanglements with capital through an examination of one element of the bioeconomy: biomimicry. This is an emerging field of technoscience that renders biological research a resource for innovation in industrial engineering. As we will show, the dominant commercial paradigm of biomimetic research, along with its guiding principles of producing “conditions conducive to life” stitch together diverse biological elements, their reproduction, and logics of capitalist accumulation. We argue that the biomimetic imaginary, produced and disseminated by organizations like Biomimicry 3.8 and its global collaborators, creates the conditions for new forms of enclosure, making ever more aspects of the world – human and non human alike – available to be churned through the circuits of capital accumulation. By exploring biomimicry through a critical political economy of enclosure, we show how nonhuman life is recast as an active and ‘wise’ producer as well as a passive resource available to be transformed into intellectual property, a fictitious commodity at the heart of our knowledge-based economy (Jessop, 2005). Biomimicry is not singularly important in this regard; there are other dimensions of the bioeconomy exhibiting similar transformations. Nonetheless, through our focus on biomimicry we highlight a conceptual apparatus—and its historical continuities—that have enabled biological life and its study to be enrolled within industrial production.¹

So long as we remain entangled in the thick web and ineluctable logic of capital accumulation, new enclosures will continue to channel the conditions through which the ‘knots of multi-specied life’ are tied (Haraway, 2008: 3). However, the imaginaries and practices to which biomimetic productions give rise cannot be reduced to the role that they play in furthering capital accumulation. As Donna Haraway’s work on encounter value makes clear, for example, the surplus of ‘life’ and its enfoldings can never fully be accounted for as a surplus for capital (2008). We conclude, therefore, by leaving open the possibility that new technological, ecological and social imaginaries of more-than-human (re)productivities can exceed biomimicry’s narrow construction as a condition for expanded accumulation. We end with a series of questions with which we hope to frame inquiries into the conceptual and even technical grounds of our struggle for a more liberatory, ecological-social-political metabolism with, through, and as a more-than-human world.

From Bioeconomy to Biomimicry

Throughout the late 20th and early 21st centuries, new connections between the life sciences, technological innovation, and the generation of profits have made the materials of ‘life itself’ an even more integral part of production practices (Rajan, 2006; Cooper, 2008; Braun 2008). The global circulation of biological materials and bio-based services in pharmaceutical, agricultural and other sectors of the biotech industry have integrated cell lines, protein sequences, reproductive materials, genetically modified crop seeds and experimental animal breeds and other elements of biology within an increasingly knowledge-based economy (Birch et al., 2010; Jessop, 2000, 2005; Tyfield, 2010). These scientific and technological advances have

given rise to what is now considered an essential sector for economic growth, its significance made clear in the active development of policies by the U.S. and other governments designed to ensure its solid foundation (OECD, 2009; National Bioeconomy Blueprint, 2012). The U.S. ‘Bioeconomy Blueprint’ (2012) estimates that national revenues from the bioeconomy exceeded \$175 billion in 2010. Other estimates double that number (Carlson, 2011) and the OECD projects the bioeconomy to become 2.7% of global GDP by 2030 (OECD, 2009).

The growth of the bioeconomy has been predicated on the development of new means of owning and marketing lifeforms, necessitating further transformations in regulatory and market structures surrounding technoscience. These have included legal decisions such as *Diamond vs. Chakrabarty* (1980) and *Moore vs. Regents of the University of California* (1990), which enabled bacteria and living human cells to be redefined as property (Jasanoff, 2012). Alongside such changes to the legal code, transformations in the infrastructures that govern innovation, such as the Bayh Dole Act (1980), have enhanced links between corporate interests and university science (Rajan, 2006, 2012; Cooper, 2008). Together with the rise of a venture capital industry able and willing to invest in these emergent, speculative and potentially lucrative fields, these events have set the stage for life to figure productively within the logics of a neoliberalizing economy (Cooper, 2008).²

Biomimicry has emerged in consonance with this bioeconomy. Yet, unlike many of the other articulations of the bioeconomy, biomimicry is nothing new: the complex web of living things, human and nonhuman alike, has long served to animate curiosity, stir emotions and guide human creativity. Leonardo De Vinci’s unsuccessful flying machines were inspired by bird flight, as were the Wright brothers’ more successful airplanes. Georges de Mestral’s storied walk through a burr-filled forest inspired the eventual development of Velcro®. But, only over the

past two decades has biomimicry gained purchase as a discipline and organizational framework that bridges engineering, design and biological research. The Wright brothers may have been inspired by birds, but not with the level of detail and intensity of George Lesieutre's team of engineers at Penn State: they are presently studying how birds conserve energy by changing the shape of their wings during flight in order to develop airplanes that can accomplish the same.

As a field, biomimicry is diverse and, at times, less than coherent. Its practitioners can scarcely agree on the term's definition, on what level of fidelity to nonhuman life is required for a project to count as 'biomimesis' or to what ends its methods are best applied.³ All seem to agree, however, that it is an increasingly promising avenue of innovation and economic production. Drawing on 3.8 billion years of evolutionary 'research and development', environmentalists, the US Department of Energy (DoE), the Department of Defense (DoD) and a wide range of corporations are pursuing biomimicry as a guiding principle for innovation. Military journalist Robert Ackerman, for example, celebrated biomimicry's potential to remake 'nature' as the 'ultimate free market for selecting effective structures' for technological development and engineering (Ackerman, 2000). In fact, since the 1990s, DoD investment in the technology has driven its establishment in university laboratories and research institutions around the country. While few projects have made the transition from the bench to the battlefield (one notable exception includes Boston Dynamics' Big Dog robot), the Defense Advanced Research Projects Agency (DARPA) and other arms of the Pentagon continue to seed biomimetic research at institutions around the nation. These projects represent only a small fraction of research and development grants awarded by the DoD, yet they have nevertheless contributed heavily to the development of interdisciplinary biology and engineering programs at institutions of higher education, with notable examples including Centers for Biologically

Inspired Design at UC Berkeley and at the University of Georgia and the Wyss Institute for Biologically Inspired Engineering at Harvard.

The corporate side of biomimetic design is also growing, alongside a global network of consultancy firms that help to coordinate potential collaborations between biological knowledge and the needs of commercial engineers. In 2009, inventors submitted over 900 patents containing the term ‘biomimicry’ to the US Patent and Trademark Office (Global Biomimicry Efforts, 2010). Corporations engaging in biomimetic developments range across economic sectors with various levels of engagement. The consulting firm Biomimicry 3.8, the global leader in pioneering biomimetic design, has worked with over 150 corporations, including industrial giants like Boeing, Proctor and Gamble, Dupont and Nike, as well as architecture firms, universities and manufacturers of eco-friendly materials. Cities and local governments are promoting a biomimetic agenda as well. Led by initiatives at the San Diego Zoo, for example, San Diego city is pitching itself as a hub of biomimetic research and development. In 2011, the New York State Energy Research and Development Authority (NYSERDA) similarly began a biomimetic R&D program in New York State in the hope that biomimesis ‘may be able to help usher an entrepreneur from concept to commercialization better, faster, and cheaper’ (NYSERDA, 2013). A number of small startups specializing in biomimetic technologies have also begun to emerge. For example, NBDNano recently received venture funding for their work on a nanomaterial coating inspired by the namib desert beetle that will wick fresh drinking water directly out of the air. And in the San Fransisco Bay area, StartupNectar, a new incubator dedicated to early stage biomimetic entrepreneurs, is looking to support more of the same.

Biomimicry’s Imaginary

Biomimicry has been embraced by mainstream, pro-business environmentalism as evidence that economic growth and environmental stewardship need no longer be seen in opposition to one another (Dowie, 1995). Many of biomimicry's advocates dangle hopes of a biological based revolution in industrial manufacturing that can undo the toxic and resource intensive practices of the 20th century and lead to more efficient, ecologically sustainable material culture. Texts advocating for a new green economy such as *Natural Capitalism* (1999), *Cradle to Cradle* (2002), and *Earth the Sequel* (2008), all feature biomimicry as a key method for generating a more ecologically sustainable economy. Notable biomimetic examples include termite mound-inspired building designs that regulate their own internal temperature and dramatically reduce heating and cooling costs, butterfly wing-inspired computer screens that reflect light and save energy, and spider-inspired materials that transform how we make durable fabrics.

Biomimicry's most vocal advocates have come to define the practice in their own terms not only as a method for creating more sustainable means of production, but as a way of 'revolutionizing' human consciousness and overturning the tenets of industrial production altogether. Janine Benyus, head of the consulting firm and education network 'Biomimicry 3.8,' is at the heart of that movement. She is the media-friendly 'guru' of biomimicry and a celebrated figure among mainstream environmentalists. In her 1997 book, *Biomimicry: Innovation Inspired by Nature*, Benyus featured a collection of scientists and engineers who are developing innovative materials through biomimetics. A host of biologists, naturalists, financiers, educators, and ecologically conscious designers have joined Benyus to usher in what can only now be called a global biomimicry movement (Harvey, 2009; see also Johnson, 2010).

More than improving upon the products that we have, or creating a better, greener version of commodities, Benyus insists that biomimicry will remake the very processes of material production by changing the *nature* of mass production in an industrial economy. In her view, biomimicry will transform industrial production by revolutionizing how the external, more-than-human world is apprehended and put to work. Benyus characterizes conventional methods of industrial production as the product of a Baconian ideology rooted in scientific rationality. She crusades against this system's naturalization of a materially and energetically intensive industrial economy. By justifying a merciless drive for improvement and progress, Benyus argues that this ideology has resulted in nothing short of a metaphorical and material enslavement of the lively world, along with attendant patterns of environmental degradation. For Benyus, such processes of production, their ideology of nature, and their progenitor subject, *Homo industrialis*, have all reached their limits. Neither human society nor our methods of production, she writes, are immune to the 'guidelines', 'standards', and 'operating conditions' of life on earth.

The biomimetic solution is not meant to forestall or delimit industrial production. Instead, it promises only to supplant Francis Bacon's vision of nature with another vision capable of recognizing 'life' as an agent of production in its own right. In her book, Benyus invites us to consider the production of Kevlar as a prime example of this 'heat, beat, and treat' process of industrial production and therefore an example of the ongoing, fundamental violence enacted against 'nature'. Dupont's aramid fiber material is an incredibly strong composite used in a wide range of products and industrial applications, including in fiber optic cables, industrial sealants and adhesives, aerospace and automotive components, and, most famously, body armor. From beginning to end, the production of Kevlar is extremely energy intensive and toxic. To make it, DuPont pours a petroleum-derived synthetic into 'a pressurized vat of concentrated

sulfuric acid’, boils it at extremely high heat, and then subjects it again to high pressure in order to force it into fibers (Benyus, 1997: 134). Benyus finds an alternative in the work of biomimeticist Christopher Viney. Viney is an engineer cum bioscientist who is studying the golden orb weaver spider (*Nephila clavipes*). Viney’s lab specimen, affectionately named ‘Tiny’, produces a silk fiber that is, ounce for ounce, five times stronger than steel and 30% more flexible than nylon. It maintains its strength and flexibility under extreme temperatures without compromising its structure (Yang et al., 2005). Most remarkable, Benyus tells us, is that Tiny creates this super-fiber without the excessive inputs of energy or outlays of toxic waste that goes into the production of Kevlar; the spider only uses ‘local’ inputs, taking in ‘flies and crickets at one end and process[ing] a high-tech material at the other’ (Benyus, 1997: 135). Viney hopes to concentrate and scale this spider-inspired production so as to make it commercially viable. If he can figure out a way to harness ‘nature’s chemistry’ through a successful mimicry of the spider’s own processes, he could weave the silk into a fabric five times as effective as Kevlar in withstanding stress.

Viney’s work offers a clear expression of biomimicry’s imaginary. Within it, nonhumans are reimagined as a guide for industrial innovation, through which the processes of production can no longer be thought in strictly anthropocentric terms. To make this transition, humans must learn to become ‘more affected’ by the skills and processes of nonhuman life. With such ‘collaborations’, biomimicry would seem to promise a welcome departure from anthropocentric hubris of Enlightenment thought, even prefiguring the ‘becoming-animal’ of industrial production through which the divisions between human and nonhuman—even self and other—erode (Caillois, 1974; Deleuze and Guatarri, 1984; Johnson, 2010). Accordingly, biomimicry’s discourse resonates with recent theoretical imaginaries popular in geography and sociologies of

science, where an analysis of deeply entangled networks similarly highlights the poverty of the nature-society divide constituted by Enlightenment thought. This literature identifies the active contributions of non-living and non-human entities in the production of our world. It rejects staid divisions between nature and society, humanity and its dominion, forging new forms of attunement to and ‘response-ability’ toward the world and the vitality found within it (Haraway, 1994; 2008; Bennett, 2010; Latour, 2013). As Sarah Whatmore has noted, this growing body of literature shares a “commitment to an ontological or more-than-human conception of knowledge practices and knowledge politics (2013: 46).” Latour, Karen Barad, and others have similarly suggested a turn away from critique, to embrace instead a more generative, experimental approach (Latour, 2004; Dolphijn and van der Tuin, 2012). In this spirit, biomimicry’s development of a more-than-human form of production would appear to offer just such an experimental advance. But, as we describe below, while biomimicry may promote new more-than-human relations, it nevertheless fails to give rise to ‘new political practices’ (Paulson, 2001, quoted in Whatmore, 2013). Despite an active attempt to dismantle anthropocentric narratives of production and stories of human domination over nonhuman life, biomimicry reveals how more-than-human assemblages often remain entangled with very specific logics of capital accumulation, resource privatization and enclosure. These traces of more mechanistic, utilitarian engagements with the nonhuman world, persist as if by habit, patterned by the conventional wisdom of an acquisitive, profit-seeking market society. While life has never been a stable referent capable of being made subject to our will or that of the objects and imaginaries we’ve created (Latour, 1993; 2013), it remains essential to identify--and critique--the ways in which life is routinely cast in economic terms, contributing to an impoverished future imaginary that is narrowly aligned with visions of technoscientific progress.

This shift is plainly evident in Benyus's writings. For example, in a passage describing a biomimetic research program that entails mimicking the process of photosynthesis, Benyus asks rhetorically, why biomimeticists would bother re-creating what 'nature' has already accomplished. She then explains, 'With all due respect to plants, sugar and starch are not what we humans had in mind (plants already do a fine job of making those for us). What does interest us is the possibility of producing hydrogen gas from sunlight and water' (84). She continues to explain that a cheap and abundant source of hydrogen would supplant our dependence on fossil fuels, hence allowing industrial society to continue apace. As this nonchalant attempt to speak for 'us humans' makes clear, Benyus disavows the domination of nature, but does not give up the division between nature and society upon which such narratives rest. Nature remains conceptualized as the 'first nature' of Enlightenment thought, a universal and extensive world 'out there' for human civilization to work on and through.

Much turns on the unspoken recontextualization implied by the concept of mimesis. While the mimetic faculty may still enable an opening up of oneself to as of yet unencountered and thoroughly other forms of life (Taussig, 1996; Caillois, 1974), Benyus' use of the concept, and that of biomimicry more broadly, remains thoroughly utilitarian. Instead of opening forms of production up to various alterities, it opens the other up to a predefined program of industrial development and commercial advance. While these trends should surprise no one, they nevertheless call for investigation into how exactly how these processes take shape. In what follows, we explore how the biomimetic imaginary remakes the Enlightenment production of nature as a source of limitless, immaterial inspiration for very particular sets of commercially interested actors. This process, of entangling knowledge of nonhuman life with capital, begins with what we will now explain as a process of enclosure.

New Enclosures, New Productions of Nature

Political ecologists have well documented the rise of the bioeconomy around new forms of accumulation by dispossession, privatization or enclosure. While these concepts may not all be completely analogous, it is not our intention here to dissect their theoretical or conceptual differences. Rather, we want instead to flag their commonality, referring to the many processes by which not-yet commodified entities can be transformed into fictitious commodities through political, legal, or what Robert Brenner terms, ‘extra-economic means’ (Poylani, 2001; Brenner, 1989). To be clear, enclosure, or the broader process that Marx identified as primitive accumulation, prepares the conditions for wage-labor relations and therefore for the forms of value production most often associated with critical appraisals of capitalism. Enclosure is, accordingly, the logical antecedent to such accumulation, an extra-market transformation that makes the production of surplus value possible by making its constituent elements - land, labor, capital - available to one another in the first place (Marx, 1993; DeAngelis 2004).

Of course, the choice of the term ‘enclosure’ is not innocent, as it traces a lineage more or less directly back to the British mechanism of agrarian dispossession that went by the name, and which transformed this countryside over the course of hundreds of years, emptying it of the multitudinous array of common right property regimes that provided a central material underpinning of the feudal economy (Thompson, 1991; Neeson, 1993). While a minority perspective understands enclosure, or the broader process of ‘primitive accumulation’, as a periodizing concept set prior to the ascent of capitalist property relations, it is more commonly

understood as an ongoing process that in different capacities and forms preceded, initiated and continues to accompany ongoing capital accumulation.

The present status of enclosure is still a matter of debate. Some argue that the process is unfinished and ongoing (DeAngelis, 2004; Goldstein, 2012) while others add that the process has somehow been transformed, now operating in new ways (Katz, 1998; McCarthy, 2004; Smith, 2007). This latter work looks specifically at how the process of enclosure functions as what Neil Smith calls a production of nature. This process creates new targets for accumulation, such as those unearthed by bioprospecting or fabricated through new regulatory regimes. As both Cindi Katz and Neil Smith argue, such practices render a universalized category of ‘first nature’ external to humans as an accumulation strategy. Unlike prior forms of enclosure, which extended across space to capture ever more territory, these new enclosures penetrate into the depths of what society understands as nature, and as life. They go, as Neil Smith writes, ‘all the way down’.

If scarcity (real or imagined) is what motivates instances of accumulation by dispossession or enclosures, exemplified by ruthless efforts across the globe to accumulate farm land and mineral rights and to monetize access to increasingly scarce potable water (Bakker, 2007; Swyngedouw, 2006; Bond, 2010), then it is surplus (real or imagined) that motivates these newer instances of enclosure in the bioeconomy. These new forms of enclosure are no longer strictly territorial, targeting a wide array of matter and practices. While the social science literature has paid much attention to the enclosure of formerly public or common resources such as water, wildlife, fisheries, or forest, ‘new enclosures’ also include forms of matter once considered incompatible with the very notion of privatization (Shiva, 2002; Robbins and Luginbuhl, 2006; Correia, 2006; St. Martin, 2006). The recent creation of regulatory markets and

the patenting of intellectual property has enabled the creation of a new frontier for accumulation, one that includes ‘impossible subjects of enclosure’ (McCarthy, 2004: 337) ranging from living bodies, cells, DNA, nano particles and air molecules to regulatory commitments and various other forms of knowledge (Katz, 1998; McCarthy, 2004; Prudham, 2007; Robertson, 2012; Sunder Rajan, 2012; Jansanoff, 2012). Biomimicry, as we will show, is one of these frontiers, whose ‘impossible subject’ is a well organized, complex and infinitely productive 3.8 billion year old research and development effort, undertaken by none other than ‘nature’ itself.

While the rise of the bioeconomy sets up new relationships among biological matter, immaterial processes, and capitalist production, Goldstein argues that the extension of processes of privatization to such objects does not in itself constitute a *new* dimension of enclosure (Goldstein, 2013). Rather, it fulfills the much earlier seventeenth century promise, voiced then as a discourse of agricultural improvement, now as a more grandiose narrative of natural, or even planetary improvement. Then, as now, enclosure required a twofold transformation: first, a qualitative (intensive) one through which land was remapped as potential private property and second, a quantitative (extensive) expansion of control over this newly produced terrain (Goldstein, 2013). Accordingly, these early enclosures and all those subsequent, entail the production of nature as a landscape of *potential* (but not-yet) capital. Goldstein calls this *terra economica*; a whole earth available to be put to profitable use, or otherwise wasted.

The new enclosures represented by biomimicry entail just such a production of *terra economica*, albeit with some important differences that help shed light on just what is ‘new’ about these most recent forms of enclosure. In the following two subsections, we present evidence of this novelty, charting how biomimicry contributes to the creation of a new nature, one still omitted from the category of society, even as it is made internal to production. It does so

by remaking nonhuman life as a form of intellectual property (as opposed to raw material), to be uncovered and harnessed as an active producer of knowledge (as opposed to a passive object of consumption).

1. Biomimicry's Nature As Intellectual Property

With the shift from an industrial nature characterized by material resources to one focused instead upon immaterial inspiration, the biomimetic imaginary produces life's extant objects—in the form of organisms, cells, DNA, etc.—through a lens of intellectual property. This parallels similar movements within the disciplines of neurology, micro-biology, bio-technology, and genetics (Jasanoff, 2012). So for instance, forests are no longer considered a source of lumber (raw material) but instead, due to the diversity of lifeforms held within, they become a repository of “nature's wisdom,” or “research and development,” which can only become valuable by first entering into the realm of social production as intellectual property.

While intellectual property has become an increasingly ubiquitous dimension of our socio-economic system (and with authorial integrity playing a fundamental role in our own lives as academics), it is easy to lose site of the peculiar forms of sociability underlying this legally-constituted relationship. Whereas commodities are produced to be sold, this is not the case for land or labor, which Karl Polanyi (2001 [1944]) terms fictitious commodities. The same goes for knowledge: it too is a fictitious commodity, an extension of the lively world that can never be fully reduced to the dead uniformity of the commodity form. If, to follow Marx, we consider knowledge to ultimately derive from the accumulated efforts of a collectively thinking social body; to emerge in and as part of what he terms the general intellect (Marx, 1993), then owning

or possessing an idea becomes impossible. The integrity of an idea as a divisible, stable and controllable part of this general intellectual wealth is always in jeopardy – ideas by their very nature proliferate; they cannot exist as knowledge without being more than singular, without being infinitely reproducible within the general circulation of ideas and those sharing amongst them. Hence the legal and financial fictions of intellectual property are an effort to ascribe some form of property rights to an otherwise unruly and uncontrollable dimension of the collectively laboring (and thinking) social body.

Just as capital prefers to sell wage labor – the capacity to work – and not the wage laborers themselves (though chattel slavery does still persist), the same is true of knowledge: intellectual property is regularly bought and sold, as opposed to the intellect itself. Biomimicry engenders an important shift in this regard, away from the status of nonhuman entities as raw material. Whereas the value of raw material is derived from the particular use of particular materials for particular processes of production (no matter how generalized this process has become – one tree can only be turned into one batch of furniture) the value of intellect-as-property lies in its applicability to production generally. Hence Tiny the spider’s utility – to continue with our above example – is not as a silk-maker, but as a teacher. The expectation is that she will instruct us how to make materials more effectively, improving our industrial processes without ever challenging our industrial agenda.

Just as earlier (and ongoing) forms of enclosure reduced the myriad productivities of land into an endlessly capacious drive towards profit, so too with biomimicry-as-enclosure: the myriad forms of knowledge embodied in ecological systems are reduced to a divisible, isolatable field of potential intellectual property. Patents replace fences and hedges, but the effect is much the same. The production of *terra economica* here expands, not simply through an attachment to

a wider array of objects, but through a qualitative transformation of how such objects are apprehended as potential capital.

This enclosure via intellectual property enables the expansion of *terra economica*'s logic to potential and as-yet-unrealized capacities of nonhuman life and therefore to the planet as a whole. While early enclosures produced a whole earth available to be mined as a material resource (a process which continues apace), biomimicry and more broadly the bioeconomy instead produce a *generally industrious nature*, available to be understood and mimicked. We borrow the term *general industriousness* from Marx, who used it in his writings that have been posthumously published as the *Grundrisse* (1993). The term betrays Marx's most Promethean tendencies; his excitement for the techno-social possibilities afforded by a system of production dedicated to general, self-reproducing wealth (money-as-capital), as opposed to meeting particular needs. 'Money as aim here becomes the means of general industriousness... In this way the real sources of wealth are opened up... the individual's industriousness knows no bounds (Marx, 1993: 224)'. For Marx, the pursuit of general social wealth opens up new, and newly productive capacities of the collective social body. Innovative ideas – embodied in the concept of a general intellect – and innovative technologies, products and infrastructures altogether comprise a general industriousness heretofore unimaginable in the history of human society. Generally industrious nature is not therefore simply, as Neil Smith implies, a nature more 'deeply penetrated' by capital, but a terrain understood to be productive at a general scale, a more-than-human extension of the general social productivity attributed to the laboring population – a concept whose anthropocentrism can hence be firmly laid bare.

2. From Raw Material To Active Subject

By upsetting traditional hierarchies of life, Benyus and other key thinkers in the biomimicry movement hope their new paradigm can recast the role of nature in society, ushering in a less exploitative and more nurturing regime of more-than-human productive sociabilities. By hailing the non-human as active bearers of nature's wisdom, the domination of nature as machine supposedly gives way to a collaboration with nature as innovator. In what *Biomimicry 3.8* considers 'true' biomimetic form, Tiny the spider (or NBDNano's as-of-yet unnamed namid beetle) would not be farmed for her silk (or in the beetle's case, her water collecting capacity) or merely utilized to 'do the work for us'. Nor are they to be enslaved as lab specimens. Instead, these life forms are being honored as teachers and as guides.⁴ Their wisdom, once productively realized, will revolutionarily transform our vision of and relationship to the natural world by disrupting traditional hierarchies of life in which humans appear at the apex (Johnson, 2010). Drawing to mind Bruno Latour's notion of the 'Parliament of Things' (1993), Benyus's vision of nonhuman life recasts this engagement with an active nature as a "parliament of species," a democratic body in which we humans hold only one seat, and must learn to collaborate with our non-human counterparts.

Of course this 'collaboration' must be carefully scrutinized. Biomimetic engineering promises to transform the relationship between nonhuman life and production by transforming the former into a field of traits capable of inspiring the latter. 'Nature's' participation in the process of industrial innovation is contingent on its own disassembly: species and individual organisms are not important. For instance, Tiny the spider becomes valued not for what she is, but for what she does and how she does it. The spider's body is not alive in some transcendent sense, but its liveliness is dissected, pulled apart, and reconstituted as an assemblage of

capacities. In the wild and in the laboratory, she becomes a collection of parts—glands, molecules, proteins, ducts, spinnerettes—that conspire to produce a potentially useful and commercially viable material. As Labban (2014) has recently written in the context of mineral extraction, such engagements with capital’s expansion do not ‘leave the territoriality of [the organism] intact: It shatters it, splinters it, and rearranges it in novel and continuously changing uneven configurations’ (566). As the capacities of non-human actants are repositioned within the frame of technological engineering, creatures like Tiny re-connect with the social field in new ways, becoming more than either wildlife or objects of science; but exemplars of an enterprising nature (Dempsey, forthcoming). Tiny will leave her ecosystem behind, to realize her entrepreneurial potential in Viney’s laboratory, where together, man and spider will innovate industrially profitable technologies. As an extension of this new iteration of *terra economica*, Tiny is no longer a spider situated within a complex ecosystemic web of life. Instead, she has become a silk-making expert in biomimicry’s innovation ecosystem. While this biomimetic engagement with nonhumans may be very different from a Baconian exploration of what nature is, or for what it can be used, the results are all too similar, falling back upon well-worn tropes of an external and machinic collection of resources, available to be dissected, discerned and dominated by an industrious human civilization. Rather than a fully collaborative more-than-human experimental practice, we find that nature, contra society, remains a repository of productive capacities meant to further techno-industrial progress.

Far from dismantling Enlightenment notions of nature, biomimicry extends them to all of life in new ways. The recasting of nonhuman life as an active agent of ‘research and development’ parallels a shift in the capitalist economy more generally over the past century: from an accumulation of labor power to the accumulation of knowledge. This biomimetic

imaginary does not simply identify the commercial utility of specific natures to do specific tasks, like an ox pulling a cart, or a tree becoming a chair. Rather it seeks to exploit (or ‘harness’) the general utility of a generally industrious nature to demonstrate a general capacity to act.

Marx portended this transformation, describing it as a shift from the formal to the real subsumption of labor to capital. In both the *Grundrisse* and *Capital, Volume One*, general industriousness emerges through the transition from small scale manufacture to machinic production. As Marx describes, this shifted the central agents of production from laboring bodies augmented by various instruments and tools to machines maintained and superintended by laborers. The bodies of these laborers were thus pushed to the periphery of the production process. Yet the intellectual capacities of this population provided the resources necessary for the creation and maintenance of that machinery in the form of scientific and technological innovations, for which capital takes credit as if it, and not the accumulated knowledge and capacities of the social body, is responsible.

Some scholars are referring to this as the real subsumption of nature, a process that is by no means new, but whose particularity is significant. Boyd, Prudham and Schurman argue that it entails a transition from extraction to cultivation; the former is primarily geological, the latter is primarily biological, and marked by the genetic revolution in agribusiness as well as all of the many new technologies and processes we have named above as the bioeconomy. Neil Smith (2007) counters that there is not in fact anything distinctly new in the transformation they have identified – both extraction and cultivation are longstanding dimensions of nature’s production and of the justification for enclosure. For Smith, the real subsumption of nature to capital has to do with a shift from external nature to social nature. We can take Smith’s insight further: the rise of a generally industrious nature entails more than a shift from geological to biological

extraction, from one techno-industrial sector to another. It also involves a new ideological framing of nonhuman life; an attempt to unseat Baconian conceptions of nature as a passive dominated object, offering instead a reconceptualization of nature as a realm of active, collaborative participants.

Hence, biomimicry ‘teaches’ us how to improve our own actions, or productions, by ‘tapping in’ to its innovations, knowledge, and intellect. By turning to animal life as material for inspiration and innovation (rather than merely consumption), every aspect of life—including its as yet unrealized potentials—becomes employable: apes, spiders, the knowledge of indigenous communities, all are potentially active workers in the post-industrial innovation economy, all are bearers of an ancient intellect that we have as yet failed to tap.

Here, biomimicry’s advocates take a cue directly from post-industrial management texts that encourage the active, creative participation of the labor force in processes of production. Paeans to the creative economy, from Toyotism to the ubiquity of flexibility and the embrace of precarious employment, paint a portrait of a post-industrial economy that has moved beyond the crass exploitation of dead end jobs and debilitating manual labor. The laboring population is no longer comprised of subservient employees. Instead, we are all creators, entrepreneurial selves in a post-industrial world of surplus.

The majority of ‘designers’ in this post-industrial economy are overworked and contingently employed ‘creatives’ who spend their days collaborating on projects that further the mission of their corporate clients and employers. Benyus suggests that biomimeticists put nature to work in the same way – that they collaborate with nature to further their mission of commercial or military success. Tiny may help Viney develop a material dramatically better than Kevlar, but what does Tiny, or her ecosystemic community for that matter, stand to gain? In this

thoroughly neoliberal discourse, such matters are irrelevant, as the ‘parliament of species’ is hardly an empowered, or democratic body. Here, arguments for nature-as-mentor run parallel to those of Thomas Friedman, who envisions a world made flat by the leveling meritocratic effects of global entrepreneurship and digital technology. Missing in both is all of the supporting work – both paid and unpaid, human and non-human – that makes this virtuous production possible, as well as the wasted remainder – those cast out of any creative and productive circuits of social production altogether; criminalized, excluded, or even left to die.

From Terra Economica to Alternative Biomimetic Futures

Biomimicry is about re-making who we are, how we see, and what we do to make our industrial lives possible. Against Enlightenment visions of nature as a machine to be ‘tortured for its secrets’, biomimicry reimagines nature as a mentor to be partnered with and revered. As we’ve shown, there is an unresolved tension here: the rhetoric of biomimicry’s advocates suggests that we produce ‘conditions conducive to life’ but its political economy demands instead the perpetuation, even expansion, of still-violent processes of enclosure.

In practice, biomimicry conscripts a more-than-human world into the business of economic and social development, making life’s continuation entangled with capital’s expansion. Nature’s unfathomably complex web of living and non-living entities may produce many innovative capacities. But by rendering this complexity as a series of aliquot parts, each of which holds an innovative wisdom to be potentially unlocked, tapped, commercialized (or as is often the case with biomimetic research, militarized), a very specific conception of nature emerges. This is an enclosed nature where the whole, generally industrious world bares potentially useful

intellectual property that must be harnessed. Accordingly, the biomimetic imaginary reconceptualizes nonhuman life as *terra economica*, a repository of potential – and potentially limitless – capacity.

This entails a necessary and often unspoken process of selection as the world and its lifeforms are isolated, selected and reproduced for a decidedly capitalist future. The female golden orb weaver (Tiny the Spider) may make the cut, but what about her less ‘productive’ mate, whose smaller body produces a finer silk, or the venomous brown recluse, who will be more difficult to include safely within Benyus’ Parliament of Species? The ideal of a biomimetic future may be all inclusive, but the biomimetic future being enacted is a biopolitical one, in which conditions are made conducive to some lives and not others. Any promise that biomimetic production will constitute more ‘symbiotic relationships, much more mutualism, [and] much more cooperation’ seem unlikely as biomimetic processes and products are enclosed and deployed as private property.

Biomimetic research is produced and reproduced within circuits of capital investment that comprise their own self-reproducing eco-system. This social-spatial logic of uneven development has been well documented. Distinct flows of resources and waste – both human (surplus populations) and non human (toxins, pollutants, trash) – have created a world in which small pockets of affluence can shield themselves from the vast landscapes of extraction and primary production that provide their conditions of possibility.

Within this context, the logic of the market takes on an active – and actively unacknowledged – role in the production of life, as entrepreneurial innovators attempt to determine which lifeforms get reproduced, how, and for what ends. Hence, biomimetic research is actively engaged in producing our connections to nonhuman forms of life, by fundamentally

altering the terms of its—and our—continued reproduction. This is ultimately the problem with biomimicry: though its stated intention is to learn from, respect and honor nature, by doing so through the available investment options for industrial R&D, the reproduction of life becomes intimately entangled with the reproduction of capital.

For us, this inquiry provides a powerful starting point for considering how we might carefully experiment with more-than-human productions of life in non-instrumental, non-anthropocentric ways. As part of that beginning, it remains important to consider how biomimicry—as well as life's many surpluses and the fleshy encounters that constitute them—exceeds these narrow bounds of enclosure, and may remain capable of reproducing more than just capital (Haraway, 2008).

In the context of what is now being increasingly acknowledged as the onset of the Anthropocene, such reconfigurations of human and nonhuman forms of production seem more necessary than ever. Saddled with the increasingly inhospitable biosystemic conditions of our making, fundamental transformations in the production of life – both in theory and in practice – take on a heightened urgency (Saldanha, 2013; Yusoff, 2013). And so, despite the necessary caution, we want to conclude with some brief reflections – or perhaps they are projections – on the promising and unexpected arrangements with and for life that projects such as biomimicry might open for us. A generally industrious vision of more-than-human productive capacities offers new possibilities for the constitution of viable alternatives to future imaginaries sculpted solely out of liberal humanism. Like Donna Haraway (2007), Benyus encourages us to forge more-than-human alliances that may precipitate the making of new worlds. But as Whatmore, Isabel Stengers and others have suggested, moving forward to constitute new forms of knowing and making will require active experimentation where nature is no longer a viable and stable

category of thought. To follow that provocation, we may need to explore new interfaces between biology and technoscience without recourse to biomimicry's ideology of 'nature's' endlessly productive genius. What remains then is an imperative to experiment with but also challenge the habituated practices that have allowed us arrive at such an unwelcome planetary condition. There is no pristine nature to mimic, but we can redefine the ways we produce in a more-than-human world. These are the terms of our struggle.

And so we take from Benyus, from biomimicry, and more broadly from the promise of the bioeconomy, a gesture towards the possibilities of a new form of production, one that elegantly manipulates the more than human world for all life, as opposed to capital. We have no conclusions to make, but end instead with a series of essential questions that this investigation has opened for us: What can (re)productive, technologically mediated metabolisms of life look like?; How can we imagine a form of production that can both reproduce desirable lives and unmake the infrastructure of our ecologically catastrophic social formation? What forms of knowing – both embodied and immaterial – do we want to mobilize in our ongoing processes of world-making?

¹ This essay results from a convergence between our respective research projects. Johnson has spent over five years researching the emergence of biomimetic technologies. She has conducted ethnographic research with two biomimetic laboratories as well as archival research on the history of the field over the past twenty years. Her work has linked biomimicry's success as a field to transformations in U.S. military strategy, corporate interests, and the environmental movement. She has written on the ways that biomimicry fits into STS and animal studies debates. Goldstein has spent the last three years conducting ethnographic research with cleantech entrepreneurs and investors, and has also been conducting a critical discourse analysis of mass market texts advocating in one form or another for a 'green' variant of capitalism. Together, we are concerned with how more-than-human futures unfold.

² The Venture Capital market was flush with cash after a 1978 modification to the Employee Retirement Income Security Act (ERISA) that allowed for pension funds to make riskier

investments with up to 10% of their portfolio – explicitly allowing them to invest in venture funds for the first time.

³ The relationship between the mimetic faculty and innovation is a particularly sticky source of friction among practitioners, many of whom prefer the term “bio-inspiration” and argue that human ingenuity remains superior to biological forms. These debates offer up a fruitful site for theorizing mimetic and innovation practices, which we sadly must defer to a later paper. For the purposes of this one, readers should consider mimesis as the practical engineering of inspirational forms found in the nonhuman world.

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