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Abstract

Nigel Clark's 'ex-orbitant globality' concerns the incalculability of other-than-human forces we typically fail to acknowledge, yet which haunt all considerations of environmental change. This article considers Gaia theory as a useful heuristic to register the ubiquity of bacteria to environmental activity and regulation. Bacteria are Gaia theory's fundamental actants, and through symbiosis and symbiogenesis, connect life and matter in biophysical and biosocial entanglements. Emphasizing symbiosis might invoke the expectation of a re-inscription of the human insofar as the ubiquitous interconnectivity of life ultimately connects everything to the human. I want to argue toward the opposite conclusion: that bacterial liveliness suggests a profound indifference to human life. As such, symbiosis does not efface difference, nor its vigorous refusal to be absorbed within human formulations of world-remaking, including environmental change. Bacterial indifference's radical asymmetry suggests the need for non-human centred theories of globality.

Key words

biology ■ environment ■ globality

JOHN URRY's (2007) recent talk on environmental issues cited *The Revenge of Gaia* (2006), in which James Lovelock discusses positive feedback 'tipping points' leading to significant and irreversible climate system changes (see also Hansen, 2008; IPCC, 2007). Urry's presentation prompted me to consider the utility of engaging with Gaia theory in the context of pressing environmental issues and Urry's forecast that sociology will only survive if it 'embodies the ambitions of one or more social movements' (2000: 18). The Union of Concerned Scientists' (1992) 'Warning to

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Humanity' states that overpopulation and environmental deterioration put the future of humanity at risk. The 2007 Intergovernmental Panel on Climate Change Fourth Assessment Report is a sober appraisal of the impact of global heating on humans. Climate change joins a welter of biospheric issues we are now accustomed to hearing about in tandem with *homo ecophagus* – 'man who devours the ecosystem' (Hern, 1990: 39): human overpopulation, species extinction, mono-agriculture and its attendant environmental degradation, passing the point of peak oil supplies and so on (Harding, 2006; Lovelock, 2006; Smil, 2002; Strahan, 2007; Wilson, 1992, 1993, 2004).[1]

While Lynn Margulis, one of Lovelock's collaborators, believes that acknowledging Gaia theory is now more acceptable in 'polite scientific society', *Nature* and *Science* labelled Gaia theory a 'pseudo-science' (Schneider et al., 2004: xiii), and social theorists and scientists alike largely dismiss Gaia theory on the grounds of its adoption within new age/spiritualist movements. My interest in this article is not to evaluate Gaia theory as a truth claim within science, but rather to ask whether it might be utilized as a heuristic to further develop ways of theorizing globality. Globality is a way of conceptualizing the earth using a complex, dynamic and open-systems approach (Sachs, 1999; Urry, 2003). It configures social life through immutable and intense interconnections. Margulis and Lovelock's long-standing research collaboration (Lovelock and Margulis, 1974; Margulis and Lovelock, 1975, 1976, 1977, 1981; Watson et al., 1979) connects microcosmos to macrocosmos, to recognize the biosphere as a highly complex, responsive and organized homeostatic system, subject to irreversible change. As such, studies of globality, I argue, might usefully engage with Gaia theory, and in particular its emphasis on the ubiquity of bacteria to environmental activity, not least through life/nonlife integration. Bacterial flows of matter and life through immutable and intense interconnections are facilitated through symbiosis and symbiogensis. Symbiosis refers to the long-term relationship between different species and symbiogenesis refers to the generation of new organs, tissues or species through symbiosis (Margulis, 1981).[2] While social theorists are most familiar with symbiotic animal relationships (such as the crocodile and plover), bacteria are in fact the most important environmental actants whose myriad ongoing symbiotic relationships sustain the biosphere, not least through their connection of living to nonliving matter. As such, this analysis attempts to advance what social theorists call an 'enlivened nature', which attends to forms and activities of life and cosmos not entirely conscripted or re-inscribed within the Cultural (see for example Hird, 2004; Kirby, 2006, 2008; Wilson, 1999).

My compass is Nigel Clark's (2005) thoughtful exploration of what he calls 'ex-orbitant globality': precisely the incalculability of other-than-human forces that typically pass below human radar and yet haunt all considerations of environmental change. With Clark (2005: 170), I want to begin to think through some of the myriad implications of our 'unprecedented social entanglement with the biophysical world'. Emphasizing symbiosis might suggest a return or re-inscription of the human insofar as ubiquitous interconnectivity ultimately connects everything to the human. I want to argue toward an opposite conclusion, however: that bacterial liveliness suggests a profound indifference to human life, suggesting a 'remainder of incalculability' (Clark, 2005: 181) exempt from human influence. Indeed, symbiosis does not necessarily efface difference, nor the latter's vigorous refusal to be absorbed within human formulations of world-remaking, including environmental change. Bacterial indifference's radical asymmetry suggests the need for non-human centred theories of globality.

Gaia Theory: Brief History, Principles and Critique

Employed by NASA to develop life-detecting equipment for the 1975 Viking mission, Lovelock and Dian Hitchcock determined, before the mission literally took off, that the atmospheres of these planets precluded life (Lovelock, 1995). Lovelock and Hitchcock reasoned that what makes the difference between the Earth's atmosphere and that of Mars or Venus (or any other planet in our solar system) is *life*. Lovelock had three choices: God created the atmosphere for humans (and changed it dramatically over time); the dramatic atmospheric change is a matter of pure chance (the 'Goldilocks theory': Mars is too cold, Venus is too hot, and Earth is just right); or life itself produces the atmosphere in which it survives. The original Gaia hypothesis involved the biotic regulation of the Earth's temperature, its acidity-alkalinity, and the composition of its reactive atmospheric gases, especially oxygen. Lovelock currently defines Gaia as:

> . . . a biotic-planetary regulatory system. Over 30 million types of extant organisms, descendant from common ancestors and embedded in the biosphere, directly and indirectly interact with one another and with the environment's chemical constituents. They produce and remove gases, ions, metals and organic compounds through their metabolism, growth and reproduction. These interactions in aqueous solution lead to modulation of the Earth's surface temperature, acidity-alkalinity and the chemically reactive gases of the atmosphere and hydrosphere. (cited in Margulis, 2004: 8–9)

In other words, biota alter their physical environment to maintain conditions conducive to life, despite destabilizing effects such as increasing solar energy (Free and Barton, 2007). To say that the biosphere is Gaian is to say that, since its formation, the evolution of the Earth (and all of its inhabitants) has been a consequence of profound, immutable and inextricable associations between life and nonlife, and that most of these associations take place irrespective of human input. Two American Geophysical Union Chapman Conferences (1988, 2000) and the Amsterdam Declaration (issued by a joint meeting of the International Geosphere Biosphere Programme, the International Human Dimensions Programme on Global Environmental Change, the World Climate Research Programme, and the International Biodiversity Programme) support the principle that the Earth's biosphere is a product of biota interacting in ongoing complex feedback systems.[3] Scientists also agree that the Earth's climate is affected by life in at least two major ways: life alters the composition of the atmosphere; and life changes how solar energy heats up and is distributed around the Earth's surface, for instance in the ways in which land plants (dependent upon microbes) improve the absorption and distribution of the Sun's energy, producing more water, and provide greater leaf surfaces to evaporate rainwater.

Scientists pursuing earth systems research focus on life–nonlife complex systems. For instance, Schwarzmann and Volk (1991) show that microbes facilitate rock weathering by as much as one thousand times. Lowman's research suggests that plate tectonics is a fundamentally Gaian phenomenon. While the Earth's major concentric layers – the liquid core, the convecting mantle and the outer crust – were formed by the same kinds of processes found on other (silicate-rich) planets:

> . . . the broad aspects of the Earth's geology as it is now – continents, ocean basins, the oceans themselves, sea floor spreading and related processes – are the product of fundamentally biogenic processes, acting on a crustal dichotomy formed by several enormous impacts on the primordial Earth. The fundamental structure of the Earth, not just its exterior and outer layers, thus appears to have been dominated by water-dependent – and thus life dependent – plate tectonic processes. (Lowman, 2002: 279)

Harding and Margulis (forthcoming) argue that water is a biotic co-production: the Earth has more than 10^4 times the quantity of water than a planet without life would be expected to have, and these researchers argue that microorganisms are responsible for the Earth's water retention. Volk's research on cycling ratios describes the biosphere as a 'wasteland world' in which one organism's waste is another's sustenance, to be used as food or any other 'stuff' of living (oxygen, for instance, is bacterial waste):

> [The Earth is] one big wasteworld.. . . Regarding the atmosphere's CO_2, more than 99 percent of the entire reservoir has recently been ejected by a living respirer rather than a volcano. For nitrogen, more than 99% has been discharged from living denitrifiers rather than volcanoes. And for methane and many other trace gases, more than 99% has been expelled from living prokaryotes rather than volcanoes. The atmosphere is one giant waste dump. (Volk, 2004: 31)

There have been numerous criticisms of Gaia theory, for instance that it cannot be falsified (see Barlow and Volk, 1992) and that 'weak' versions of the reciprocal effect of living and nonliving matter on each other do not constitute theory because they are accepted fact (Kirchner, 1989). The main criticism, however, is that Gaia theory characterizes the biosphere as a superorganism, which renders it nonDarwinian in general and teleological in particular.[4] Lovelock's computer-animated Daisy World demonstrates that life can regulate itself through positive and negative feedback.[5] Nevertheless, Gaia theorists do maintain that the Earth resembles a superorganism by maintaining biological control through homeostasis as an emergent property.[6] Evolutionary theorists argue that the Earth cannot be an evolving superorganism unless it has other superorganisms (planets) to compete with in natural selection, and that organisms cannot regulate anything beyond their own phenotypes (Dawkins, 1982; Doolittle, 1991; Ehrlich, 1991; Wilson and Sober, 1989).[7]

Social theorists share a concern with iterations of evolutionary theory that both define the individual (or gene) as the unit of selection and the unit's 'character' as one of relentless selfishness and competition, which assumes natural selection never favours traits that enhance the environment (Lenton, 2004). As Schneider et al. argue:

> . . . biologists, especially neo-Darwinians, have argued that the Earth understood as a global ecosystem actively 'managing' environmental parameters for the benefit of life as a whole is incompatible with the view of living organisms as competitively and selfishly inclined toward narrowly definable survival and reproductive success. (2004: xiii)[8]

For proponents of Gaia theory, species that, in the process of maximizing their own survival and that of their offspring, *also* benefit the environment have a selective advantage:

> . . . soon after its origin, life was adapting not to the geological world of its birth but to an environment of its own making. There was not purpose in this, but those organisms which made their environment more comfortable for life left a better world for their progeny, and those which worsened their environment spoiled the survival chances of theirs. Natural selection then tended to favour the improvers. If this view of evolution is correct, it is an extension of Darwin's great vision and makes neo-Darwinism a part of Gaia theory and Earth system science. (Lovelock, 2004: 3; see also Volk, 2003)

Organisms do not consciously construct the environment for their own benefit, according to Gaia theory, but rather those organisms that benefit their environment will have a selective advantage.[9]

This said, the characterization of the biosphere as an autonomous individual superorganism remains a conceptual problem. To foreshadow the analysis at the end of the article, this characterization circumscribes symbiosis to interactions between fully formed autonomous individuals that precede interaction. Symbiosis entails unfathomably messy entanglements that constitute temporal assemblages that sometimes emerge as symbiogenetic singularities. It is not difficult to see why symbiogenesis has attracted the attention of social theorists such as Haraway (2008), Parisi (2004), Sapp (1994) and others. Describing symbiosis as the 'filthy lesson' of our human connection with the world, Keith Ansell Pearson argues that symbiosis 'continues to play a subversive role in biology since it challenges the boundaries of the organism' (1997: 132). And, I argue, what makes Gaia theory such a potentially useful heuristic for thinking about globality is the very indifference of these symbiotic entanglements to the human or humanized.

Gaia and Symbiosis

As briefly outlined at the beginning of the article, Gaia theory's focus on the salience of microorganisms to the biosphere offers opportunities for theories of globality. Taking this principle seriously immediately effects a reorientation away from organisms – aka animals – 'big like us' (Margulis, personal communication). As Lovelock reminds us: 'the cuddly animals, the wild flowers, and the people are to be revered, but they would be as nothing were it not for the vast infrastructure of the microbes' (1995: xix). Bacteria are von Helmholtz's (2007) 'less glamorous backstage machinery that actually produces the show'.

LUCA – the last universal common ancestor – was bacterial (Crackraft and Donoghue, 2004). For 85 percent of earth's history, the biota consisted solely of microorganisms. Bacteria are, by several orders of magnitude, the most numerous of all organisms on earth: there are about 5×10^{30} bacterial cells on earth and a further 10^{18} circulate in the atmosphere (attached to particles such as dust) (Dexter Dyer, 2003). Bacteria are far more biochemically and metabolically diverse than 'all plants and animals put together' (Sagan, 1992: 377). Bacteria sustain the chemical elements crucial to life on earth – oxygen, nitrogen, phosphorous, sulphur and carbon, and some 25 other gases – through ongoing (re)cycling processes that enable flora and fauna to thrive (Sagan and Margulis, 1993).[10] While animal metabolism is defined by consumption (animals must consume already-made organic matter), bacteria evolved earth's metabolic production economy: phototrophs convert solar energy; chemotrophs convert chemical energy; lithotrophs gain electrons from elements (such as hydrogen and sulfur) or simple organic compounds (such as water and hydrogen sulphide); and organotrophs convert complex organic substances (such as proteins in dead biomass and carbohydrates in grasses and grains) (Smil, 2002).[11] In short, bacteria provided (and continue to provide) the environment in which different kinds of living organisms *can* exist.

Bacteria are Gaian because they make up the bulk of living biota, and because they are responsible for most biospheric activity. Bacteria achieve this through avid replication (both vertical heritable genetic exchange and lateral gene transfer), quick reproduction – unimpeded by environmental constraints: a reproducing *E. coli* bacterium would equal the weight of the earth's crust in 1.75 days; a single cyanobacterium on a sterile earth could oxygenate the atmosphere in 40 days – and organization into highly communicative and adaptive colony structures (Ben-Jacob, 1995, 1998, 2003; Ben-Jacob et al., 2004, 2006; Crespi, 2001; Vernadsky, 1997 [1926]: 64). As communities, bacteria 'form one global, exceedingly diversified, yet functionally unified peculiar being' (Sonea and Mathieu, 2000: 9–10).

Bacteria are also particularly successful because they create and sustain symbiotic relationships. The number and diversity of planetary symbioses involving bacteria is beyond calculation. For instance, cyanobacteria exist in both unicellular and colonial forms (their blooms can be seen from space) and live symbiotically with protists, worms, sponges and other land and aquatic plants (Dexter Dyer, 2003). Bacteria fix nitrogen for more than 17,000 kinds of leguminous plants (Smil, 2002). Without hindgut bacteria, these 'tropical cows' would not be able to process (break down and make available to the biosphere in recycling) one-third to two-fifths of the phytomass in their environments (Smil, 2002).[12] The biosphere did not become a frozen wasteland thanks to bacteria that decompose cyanobacteria living in ocean sediments, thus releasing methane that attracts solar energy. Symbiosis reveals a much more intimate relationship between organism and environment: in the case of symbiogenesis, the environment literally becomes the organism (Hird, 2009).[13]

Bacteria weave all organisms into material, cultural and social co-constructions through ongoing symbiotic and symbiogenetic relations. As such, they are central yet largely under-theorized protagonists within biophilosophy. We know little of the bacteria that create and sustain 'webs of domestication' involving plants such as corn and animals such as humans and steers (Pollan, 2007; Tsing, 2005, forthcoming) in the beef and agricultural industries. Little is written about bacteria's influence on the geography of nations through the formation and movement of plate tectonics (Lowman, 2002), or the colonization of new and old world peoples through viral and bacterial contagion. *Treponema pallidum* incited Europeans to engage in already enmeshed cultural and social selections: isolating syphilitic patients, killing infected female prostitutes, developing medical treatments such as silver nitrate eye drops and so on (Hird, 2008; Mitchell, 2002; Van Loon, 2000, 2005). Indeed, Van Loon argues: 'communities are formed on the basis of endemic parasitism' (2000: 250). Referring to evidence that human immune systems collaborate with bacterial infection, Haraway writes: 'Disease is a relationship' (2000: 75; see also Theriot in Hilts, 1997). Analyzing the complex history of the Second World War, the malarial epidemic and famine in Egypt in 1942, Mitchell notes that the protagonists in social explanations of these events are always human: 'it is not that social analysis necessarily ignores disease, agriculture, chemicals, or technology, but that these are externals – nature, tools, obstacles, resources – whose role is essentially passive' (2002: 29). Mitchell argues that the *Plasmodium falciparum* that hitched a ride in the bodies of mosquitoes: 'do not just interact with the activities of human agents. They make possible a world . . . they shape a variety of social processes' (2002: 30).

Indifferent Globality and 'Other Worldliness'

For Margulis, the biosphere as superorganism arises as an emergent property of complex symbiotic durations (Bergson, 1998). While Lovelock developed the term 'geophysiology' to describe Gaia's biospheric regulation, Margulis adapted Maturana and Varela's concept of autopoiesis – self-making – to describe life as excessive to replication (as in neo-Darwinian formulations). Autopoiesis refers to the 'autonomous organization of dynamic processes occurring within a closed operational whole' (Fleischaker and Margulis, 1986: 53). That is, Margulis argues that autopoiesis, not vertical inheritance, defines life. In two main texts, *Autopoiesis and Cognition* (1980) and *The Tree of Knowledge* (1987), Maturana and Varela developed autopoiesis in response to the epistemological problem of representation: for Maturana and Varela, 'everything said is said by an observer' (1980: xxii; see also Varela and Johnson, 1976; Varela et al., 1974; Maturana, 1979; Maturana and Varela, 1980, 1987). An organism's environment exists 'only through interactive processes determined solely by the organism's own organization' (Hayles, 1999: 136). In other words, the organism's own autopoietic organization 'brings forth a world': 'the living organization is a circular organization which secures the production or maintenance of the components that specify it in such a manner that the product of their functioning is the very same organization that produces them' (Maturana and Varela, 1987: 48). Organisms interact with their environments through 'structural couplings' that take place in the present: 'past, future and time exist only for the observer' (1987: x, 18). What is clearly appealing for Gaia theory is the absence of replication as life's defining teleology. 'A living system', write Maturana and Varela, 'is not a goal-directed system: It is, like the nervous system, a stable state-determined and strictly deterministic system closed on itself and modulated by interactions not specified by its conduct' (1987: 50).[14] Gaia, for Margulis, is autopoietic insofar as it is a system that produces the components that produce its own organization.

However, insofar as autopoiesis stresses the individuated self that creates its own environment, it undermines symbiosis and symbiogenesis, which operate through assemblages proliferated more through contamination and contagion than the interaction of autonomous entities. Luciana Parisi's abstract sex (2004), for instance, describes species reproduction as an event born of symbiotic sensibilities that defy organic–inorganic, nature–technology bifurcations as they affiliate, infect, cannibalize and sometimes merge within and between stratifications of particles, membranes, DNA, RNA, protein, cells and organisms, what Deleuze and Guattari (1987) call 'molecular sexes' or 'n-1 sexes'. Symbiosis, according to Parisi:

> . . . delineates the potential becomings of matter: the power of nature-matter-body to mutate, to be affected by new assemblages of bodies (a bacterium, a human being, an egg cell, a microchip) that in turn affect the organization of society, culture, economics and politics. (2004: 196; see also Hird, 2009)

Saying that bacteria are allopoietic (components whose functions are subordinated to the goals of the system) within an autopoietic biosphere seems distinctly 'big-like-us'.[15] 'Autopoietic machines', write Maturana and Varela, 'have individuality; that is, by keeping their organization as an invariant through its continuous production they actively maintain an identity which is independent of their interactions with an observer' (1980: 80). For autopoiesis theory, a system's boundary disintegration is equivalent to death: put another way, 'closure and recursivity. . .play a foundational role in autopoietic theory' (Hayles, 1999: 146). Yet boundary disintegration and openness are *integral* to symbiogenesis. Considering the comparison of an amoeba and a human, Hayles writes: 'either an amoeba and a human have the same organization, which would make them members of the same class, in which case evolutionary lineages disappear because all living systems have the same organization; or else an amoeba and a human have different organizations, in which case organization – and hence autopoiesis – must not have been conserved somewhere (or in many places) along the line' (Hayles, 1999: 152; Schrader, 2008).

Are we left, then, with one indelibly boundary-disintegrated interconnected superorganism? On the one hand, symbiosis suggests no outside – no Platonic Man – to our indelibly interconnected biosphere. This might seem to fuel an implicit human immanence within environmental discourses that there are no entanglements that escape human inscription (Clark, 2005; Urry, 2003). Indeed, the list of human entanglements with nature at the outset of this article runs the danger of suggesting that humans prescribe the totality of environmental change. Yet this is not a world of our own making: it is immanent in the Deleuzian sense that it knows no boundaries and is always ex-orbitant, leading Clark to reflect upon social theory's characterization of the relationship between humans and the world, and ask what 'refusal resides in the idea that "nature" – Western thought's primordial other – has been irretrievably lost' (2005: 171)?

In fact, what I think symbiosis does is to recognize that humans are not the central players in climate (or any other biospheric) regulation.[16] Bacteria routinely cross species and geo-political boundaries, effectively trumping deep ecology arguments that environmental change respects no (human) national or political boundaries. Indeed, the flows of matter/life precede and dwarf those biophysical, economic, social and cultural overflows of national boundaries on which globalization theories concentrate (Beck, 1999; Franklin et al., 2000; Hardt and Negri, 2001; Newman, 1999; Urry, 2000). A challenge, then, is to configure globality in which microbes (and to a lesser extent, fungi, flora and nonhuman fauna) make up the bulk of, to paraphrase Bruno Latour, the biospheric 'parliament of things' (2000: 144). It is not just a redistributed parliament, but one whose totality is excessive to human domains. As Graham Harman reminds us: 'all reality is political, but not all politics is human' (2009). Humans might ultimately render the biosphere inhospitable for humans and other animals, but this shifted biosphere will certainly survive human extinction.[17] We may, in other words, precipitate global heating, but we are not capable of extinguishing the biosphere altogether: Gaia is indeed a 'tough bitch' (Margulis, 1995: 140).[18]

Yet neither does symbiosis corroborate social theoretical characterizations of sociable life as cooperative: lichen might well be the symbiotic emergence of a fungus attacking an alga for nutrients, after, say 25,000 times. Symbiosis defines a long-standing relationship that generates novelty: the relationship may be formed through cooperation, parasitism or a combination of means. Indeed, Gaia theory's key insight here is the indifference of nonhuman life to human life; in other words, humanity's utter dependence upon, and vulnerability to, nonhuman life and nonlife.

Making a deep kinship claim between species predicated on 'multidirectional flows of bodies and values', Haraway reflects upon humanity's symbiogenetic genealogy and dependence:

> I love the fact that human genomes can be found in only about 10 percent of all the cells that occupy the mundane space I call my body; the other 90 percent of the cells are filled with the genomes of bacteria, fungi, protists, and such, some of which play in a symphony *necessary to my being alive at all*, and some of which are hitching a ride and doing the rest of me, of us, no harm. I am vastly outnumbered by my tiny companions; better put, I become an adult human being in company with these tiny messmates. To be one is always to become with many. (2008: 3, my emphasis)

Haraway's frequent return to eating, in *When Species Meet* (2008), is no accident: the human gut presses the characterization of companion species well beyond one of mutual knowing and voluntary exchange. The human intestine is the mostly densely populated organ of the body, and the site of the most intense human–bacterial relationships (Hooper et al., 2001). In our guts, bacteria influence our biology by modulating the expression of genes that shape various physiological functions (Hooper et al., 2001: 884; see also Corthesy et al., 2007; Eckburg et al., 2005; Gerard et al., 2007; Mai and Morris, 2004; Wexler, 2007; Xu and Gordon, 2003).[19] Moreover, human gut bacteria communicate with our guts by sensing human hormones and adjusting themselves accordingly (Cohen et al., 2001; Lyte, 2004). The relationship between the diverse multitudes of bacteria and the human gut is asymmetrical: our tiny messmates are not there to facilitate human food digestion. They can find sustenance in myriad other places whereas we face veritable starvation without them. Addressing this asymmetry at a planetary level, Carl Woese reminds us that: 'if you wiped out all multi-cellular life forms off the face of the earth, microbial life might shift a tiny bit . . . If microbial life were to disappear, that would be it – instant death for the planet' (in Blakeslee, 1996). Bacteria precede humans relating with them and the vast majority of microbial intra-actions have nothing to do with humans (Barad, 2007). Humans do not even *know* about the vast majority of intra-actions that take place on Earth.[20]

All of which suggests, as Clark argues, that we need to be mindful of the 'premature foreclosure on the implications of "other-worldly" difference' (2005: 181). 'There are forces', he writes, 'whose passage or non-passage through the appropriating circle of human influence will likely remain opaque to us whose role in inducing transformations of the earth will continue to carry a remainder of incalculability' (2005: 181). If there is a Gaia-inspired ethics of globality here, it is one that suggests perhaps a retreat – Lovelock would like to restrict human occupation to small geographic islands subject to heavy environmental surveillance (likely more Orwellian than Newby's Green Leviathan) – or a consideration of which lines of connection we keep open to the 'other-wordly'.

Notes

I gratefully acknowledge the anonymous reviewers of this article and the Editors of this special issue, whose insightful comments prompted substantial revisions.

1. John Gray (2004) refers to humans as 'homo rapiens'.

2. Donna Haraway (1990) extends the original definition of symbiosis to include long-term relationships between living matter and machines/technologies.

3. For the Chapman Conferences see: http://www.agu.org/pubs/crossref/1988/88EO01043.shtml and http://www.ldeo.columbia.edu/res/pi/NAO/conference/chapman_conf.html. For the Amsterdam Declaration see: http://www.iheu.org/amsterdamdeclaration (all consulted December 2009).

4. Csányi (1989; Csányi and Kampis, 1985) argues that metabolism and reproduction are actually temporal and spatial (respectively) forms of replication, but that replication at local microbial levels can give rise to regulation at the biospheric level. Other scientists focus on thermodynamics rather than 'the population of one' problem, arguing that nonequilibrium thermodynamics accounts for the biosphere's evolution: the biosphere is an autocatalytic metabolism that emerges spontaneously and evolves, creating life as the fastest means of maximizing entropy. Schull (1990) goes further: he argues that species intelligence is an emergent property of evolutionary selection. Salthe (1990) goes beyond the neoDarwinian pale: he argues that as a 'developing thermodynamically open autonomous system', the biosphere will inevitably become senescent. See also Schneider and Sagan (2005).

5. Daisy World is a computer program demonstrating a non-teleological feedback cycle in which white (light reflecting) and black (light absorbing) daisies regulate the temperature of planet Daisy World, where regulation is defined as 'the return of a variable to a stable state after a perturbation', and self-regulation includes both positive and negative feedback (Lenton, 2004: 16; see also Watson and Lovelock, 1983). Regulation occurs without daisy forethought or 'consciousness' as to the optimal environment in which to thrive (Lenton, 1998; Lenton and Lovelock, 2000).

6. The term 'homeostasis', rather than 'equilibrium', is used to reflect the fact that while positive and negative feedback mechanisms affect stability, 'tipping points' can change the set point of any given system. Lovelock (2006) argues that human action is forcing a tipping point that will raise the global temperature to one much less hospitable to humanity.

7. For responses to these criticisms see Lenton (2004).

8. Lovelock (2004) notes that his Gaia metaphor was created around the same time that evolutionary biologist William Hamilton coined the powerful 'selfish' and 'spiteful' gene metaphors, similarly open to misinterpretation.

9. Nitrogen-fixing bacteria, for instance, increase their own supply of available nitrogen, and in so doing they increase the amount of nitrogen in their environment

to be used by other organisms such as plants. The selective advantage reduces as more 'leaked' nitrogen is released, producing a homeostatic system of nitrogen-fixers and nonfixers. Lovelock's Daisy World and Robert Axelrod's (1984) 'tit-for-tat' research on altruism show that cooperative behaviour can evolve, even in the presence of 'cheats' (there is a significant difference between the existence of 'cheats' and their survival). More generally, social evolution theory demonstrates 'how collective behaviour arises from individual self-interest' – a synthesis of individualism and collectivism, or what Sachs et al. call 'by-product reciprocity' and what microbial ecologists call 'syntrophy' (Free and Barton, 2007; Joseph, 1991: 69; Sachs et al., 2004). Some evolutionary theorists, while not advocating reconciliation between the modern synthesis and Gaia, do suggest Gaian science's utility in provoking new lines of inquiry. For example, John Maynard Smith writes:

> No Darwinist could accept the 'Gaia' hypothesis, according to which the Earth is analogous to a living organism, because the Earth is not an entity with multiplication, variation and heredity. However, we should not be too contemptuous of that idea, logically flawed as it is, until we can give a better account of the long-term stability of the biosphere than is at present possible. (Barlow and Volk, 1992: 691)

10. Methanogens, for instance, exist only in the absence of oxygen, and live by decomposing organic matter and converting carbon to carbon dioxide and methane, which is then recycled into the atmosphere. During the Achaean, methanogens produced almost as much carbon as photosynthetic bacteria removed (see Smil, 2002).

11. Bacteria also combine these specialisms: for instance, photolithotrophs such as green and purple sulfur bacteria, cyanobacteria, phytoplankton, algae and land plants, thrive on solar energy and elemental and organic compound elements. Chemolithotrophic metabolism literally keeps the biosphere's biogeochemical cycles of carbon, nitrogen and sulfur functioning (see Dexter Dyer, 2003).

12. Termites, in turn, form symbiotic relationships with ants (see Smil, 2002).

13. Asking what bacteria have to do with humans is, in Gould's (1996) terms, asking the wrong question, or, as Cary Wolfe puts it referring to humanism: 'the "human" that we know now, is not now, and never was, itself' (2003: xxiii). Of all the cells in a human body, 10 percent are eukaryotic (derived from bacteria) and 90 percent are bacteria (Sapp, 2003: 235). For Lewis Thomas: 'a good case can be made for our non-existence as entities. We are not made up, as we had always supposed, of successively enriched packets of our own parts' (1974: 86). Human bodies are also symbionts: the number of microbes in our bodies exceeds the number of cells in our bodies by 100 fold. That is:

> . . . human animals live in symbiosis with thousands of species of anaerobic bacteria, six hundred species in our mouths, which neutralize the toxins all plants produce to ward off their enemies, four hundred species in our intestines, without which we could not digest and absorb the food we ingest. (Lingis, 2003: 166)

14. Maturana and Varela (1987: 11) write explicitly that 'reproduction and evolution are not essential for living organisms'.

15. Maturana and Varela developed the term 'allopoietic' to recognize the way that systems work within systems such that smaller system functions are subordinated to the goals of the larger system (Hayles, 1999: 141).

16. For example, photosynthesis, the ability to split carbon dioxide into carbon and oxygen, led to the 'oxygen Holocaust' – the single greatest mass extinction of living organisms on Earth – that resulted when oxygen-producing bacteria multiplied and spread, killing the vast majority of organisms for which oxygen was poisonous (Smil, 2002).

17. Lovelock notes that Gaia's current biodiversity is transient and subject to gradual and abrupt changes. The mass extinction in the late Permian (about 250 million years ago), thought to have been caused by giant volcanic eruptions, killed more than half of the families of marine species, 70 percent of vertebrate genera and countless species of rooted plants. Other nonhuman-precipitated mass extinctions took place in the Precambrian, Cambrian, Ordovician, Devonian, Permian and End-Cretaceous.

18. Lovelock's attitude toward humanity borders on ambivalence. He writes:

> We must moderate our passion for human rights and being to recognize the rest of life on Earth. The risk to individuals of cancer from exposure to nuclear radiation or to products of the chemical industry is personally important but should not be our most urgent concern. First in our thoughts should be the need to avoid perturbing what seems to be an unstable and failing superorganism. Above all, we do not want to trigger the jump to a new but unwanted stable climate. (1995: 228)

19. 'Probiotic' drinks are based on the premise that the bacteria in these drinks will introduce 'good' bacteria into the human intestine, thereby 'rebalancing' the microflora. For a review of the lack of evidence that probiotic drinks actually work, see Tannock (2004).

20. One way to think about this is to consider whom we invite and whom we overlook when we meet others in ethical encounters. Thus far, we seem mainly directed toward the human protection of particular animals such as polar and panda bears, which obscures the vast number of microbial symbiotic relations that sustain their survival. The flagship species approach makes limited sense insofar as it uses a charismatic species that appeals to humans to conserve the less 'telegenic' organisms that share its habitat. E.O. Wilson likens the attempt to reassemble an endangered or extinct ecological community – because of their nearly limitless number of bacteria, species, symbioses and niches – to unscrambling an egg with two spoons (in Wilkinson, 2007: 55). Valuation exercises – assigning a monetary value to biospheric services such as trees' respiration of oxygen – are entirely formulated from the perspective of services for humans (Smil, 2002). We might reason that our preference for organisms 'big like us' turns out to make sense given that microbes are much better survivors than their lumbering animal offspring. But I think that it also bears witness to our human configuration of difference (of what gets to count as other) of both degree and kind in meetings with others (Haraway, 2008).

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