# Synthetic Biology: Drawing a Line in Darwin's Sand

CHRISTOPHER J. PRESTON

*Department of Philosophy*
*University of Montana*
*Missoula, MT 59812*
*E-mail: Christopher.Preston@mso.umt.edu*

ABSTRACT

Maintaining the coherence of the distinction between nature and artefact has long been central to environmental thinking. By building genomes from scratch out of 'bio-bricks', synthetic biology promises to create biotic artefacts markedly different from anything created thus far in biotechnology. These new biotic artefacts depart from a core principle of Darwinian natural selection – descent through modification – leaving them with no causal connection to historical evolutionary processes. This departure from the core principle of Darwinism presents a challenge to the normative foundation of a number of leading positions in environmental ethics. As a result, environmental ethicists with a commitment to the normative significance of the historical evolutionary process may see synthetic biology as a moral 'line in the sand'.

KEYWORDS

Artefact, Darwinism, ethics, evolution, nature, synthetic biology

*Environmental Values* **17** (2008): 23–39. DOI: 10.3197/096327108X271932

CHRISTOPHER J. PRESTON

## 1. INTRODUCTION

Two years shy of celebrating the 150 year anniversary of the publication *Origin of Species* – a book without which it is hard to imagine either modern biology or modern environmentalism existing in any recognisable form – synthetic biology and nanotechnology threaten to usurp the most important principle of Darwinian natural selection. These emerging technologies strike at the very heart of the distinction between biotic nature and artefact. They create organisms that lack significant connections to the historical evolutionary process. With the threat provided by these technologies looming, those for whom the ideas of 'nature' and the 'historical evolutionary process' comes with any kind of normative punch have some serious self-reflection to do. Many environmental ethicists are about to lose the ground from underneath one of their favourite philosophical ideas.

This is not the first alarm call sounded about a challenge to the category of the natural. Bill McKibben, for example, gave warning in 1989 of 'the end of nature' due to anthropogenic climate disruption. Ideas, like animals and plants, McKibben warned, can go extinct. In McKibben's argument, the idea is 'nature', a term standing for 'the separate and wild province, the world apart from man to which he adapted and under whose rules he was born and died' (McKibben, 1989: 48). Following McKibben, other thinkers have sounded a similar warning. Keekok Lee has cautioned that 'deep technologies' such as nanotechnology and biotechnology are 'nature-replacing' and threaten the very existence of the natural world as we understand it (Lee, 1999, 2003). Pairing McKibben with other more complicated (though less literal) threats from deconstructive theory, Steven Vogel has also warned us to prepare for environmental philosophy 'after the end of nature' (Vogel, 2002).

Though the nuances of the arguments differ, each of these authors has sounded a clarion call alerting us to a deep loss. This paper is also a clarion call, but it is not about the loss of any particular object. It is about the loss of a connection to a process. Moreover, the connection being lost is one without which it is hard to conceive of certain positions in environmental ethics making any sense at all.

## 2. AT STAKE FOR ENVIRONMENTAL ETHICS

A large number of positions in environmental ethics rest on a substantial normative commitment to the value of what is biologically natural over what is artefactual. In environmental philosophy the term the 'natural' generally prompts some form of moral approbation while objects classed as 'unnatural' or 'artefactual' are viewed more suspiciously. Aldo Leopold introduced his landmark Sand County Almanac with a request for a re-appraisal of things 'unnatural, tame, and confined' in terms of things 'wild, natural, and free' (Leopold, 1949: ix). Contemporary environmental ethicist Holmes Rolston, III, captured a similar sentiment in his

statement that '[m]y concept of the good is not coextensive with the natural, but it does greatly overlap it', adding '[N]o one has learned the full scope of what it means to be moral until he has learned to respect the integrity and worth of those things we call wild' (Rolston, 1986: 49, 46). Both theorists point to the fact that the *naturalness* of wild nature carries moral weight.[1]

To sustain this line of thinking, the small matter of how to delimit the natural and mark it off from the non-natural (or artefactual) has always been central to environmental philosophy. Typically, environmental ethicists have put great stock in the distinction tidily made by Aristotle more than two thousand years ago. Aristotle characterised a natural object in *The Physics* as one which 'has within itself a principle of movement and of stationariness (in respect of place, or of growth and decrease, or by way of alteration)' (192b8-11)(Aristotle, 1941). Any change the object undergoes over time is determined from wholly within that object's nature. Acorns grow into oaks, silverback gorillas grow grey and arthritic, and mountains slowly erode. An artefact, by contrast, lacks 'the source of its own production … that principle is in something else external to the thing' (192b28). The external source to which Aristotle refers is the intentional action of a human. Artefacts thus display the presence of human intention. Natural objects do not. Keekok Lee, anchoring a good deal of her work entirely on Aristotle's distinction, usefully summarised the point this way:

> '[T]he natural' … refers to whatever exists which is not the result of deliberate human intervention, design, and creation in terms of its material efficient, formal, and final causes … The natural comes into existence, continues to exist, and goes out of existence entirely independent of human volition and manipulation … [B]y contrast, 'the artefactual' embodies a human intentional structure. (Lee, 1999: 82)

The apparent simplicity of Aristotle's distinction enabled environmental philosophers like Leopold and Rolston to latch on and layer it with their normative additions. This emphasis on the significance of non-humanised nature has been particularly prominent for non-anthropocentric environmental philosophers, those who argue for the protection of nature independent of any valuable human uses or experiences it might provide. Robert Elliot, for example, has pointed out how 'we value the forest and river in part because they are representative of the world outside of dominion, because their existence is independent of us' (Elliot, 1982: 86). Eric Katz has claimed simply that 'value exists in nature to the extent that it avoids modification by human technology' (Katz, 1992: 265). Bill Throop and Ned Hettinger, championing the value of wildness, claimed 'something is wild in a certain respect to the extent that it is not humanized in that respect' (Hettinger and Throop, 1999: 140). All of these thinkers have pointed to the fact that the *naturalness* of wild nature, in Aristotle's sense of its independence from human intention, carries moral weight. Leopold, Rolston, Elliot, Katz, Hettinger

and Throop all reflect in their work the widespread environmentalist intuition that there is moral significance to nature unmodified by humans.

The apparent simplicity of Aristotle's distinction turns out, of course, to be an illusion. The problems inherent in distinguishing the natural from the artefactual have long been known to environmental philosophers. In his 1874 essay 'Nature', John Stuart Mill noticed immediately what appears to be the most central paradox.[2] On the one hand, all human actions are natural because humans have a natural origin and none of their actions transcend natural laws. Yet at the same time, Mill saw how everything a human does, by Aristotle's definition, leaves nature in a non-natural state.[3]

Mill's recognition of this central paradox was just an early hint of a whole raft of problems for environmentalists' use of Aristotle's nature/artefact distinction. The distinction simply cannot do the work modern environmentalists want it to do. Some human actions, like eating and digesting, seem relatively natural. Others, like talking on cell phones and flying to the moon may not be. Adding to the complexity, human intention is clearly responsible for creating some artefacts that are environmentally harmful and others that are environmentally beneficial. A hut made of clay and thatched grass in Africa's Rift Valley is an artefact because it contains human intention no less than the M25 motorway or the Glen Canyon dam. Yet few environmentalists find such a hut as environmentally pernicious as these latter cement and concrete modifications of nature. A restored wetland or a landscape created by a prescribed burn are clearly artefacts on Aristotle's terms, likely containing more human planning and theoretical sophistication than, say, a Walmart parking lot. Yet environmentalists will advocate for the restored wetlands and forests while campaigning against the parking lot. Measured by the amount of human intention they reflect, environmental blessings such as photovoltaic panels or modern wind turbines have much more in common with PCBs and polluting SUVs than they do with pristine watersheds and free roaming wolves. Aristotle's distinction seems completely incapable of capturing such differences. The distinction appears to be far too crude to serve an environmentalist's normative agenda adequately.[4] For these and other reasons, Vogel might turn out to be right in his suggestion that environmentalists relinquish their use of the distinction between the natural and the artefactual.

Despite its problems, the idea of nature unmodified by human activity is so central to environmentalism that it is almost impossible to imagine letting it go. Certainly the history of the North American environmental movement could hardly be so abruptly rewritten. The emotional connections run deep. As a matter of political reality, the idea that wild nature is morally significant is one that motivates millions. Images of polar bears prowling arctic ice-flows, humpback whales breaching in front of snow-capped mountains, and lionesses lounging with their young on the African savannah adorn the walls of bedrooms and boardrooms across the world. Denying the moral significance of the biologically natural is almost inconceivable for environmentalists.

In addition to the politics of the matter, there are also important non-pragmatic reasons to retain the Aristotelian idea of 'nature'. Nature unmodified by human intention may be increasingly hard to find today but, as a matter of historical fact, there were close to 4.6 billion years of geological history on Earth that preceded the arrival of our first, artefact-creating ancestor, *Homo habilis*, approximately 2 million years ago. During these 4.598 billion years of earth's history there were independent processes at work ultimately responsible for creating everything environmentalists find of value today. For 4.598 billion years, there really did exist – as a matter of historical fact – something one could call 'nature' in an unproblematically Aristotelian sense.

For almost 80 per cent of that long reach of time, there was also something one could call the 'natural historical evolutionary process' slowly working its effects on living beings. As Charles Darwin explained in 1859, natural variations appearing in successive generations of biological organisms would tend to be preserved if those variations provided survival and breeding advantage. Over the millions of years of evolutionary history before the arrival of early hominids, Darwinian processes were responsible for creating great biological diversity and complexity, progenitors of the same diversity and complexity environmentalists seek to preserve today. It is for good reason that many environmental philosophers think this historical process morally important. Part of the reason we protect wildlands, claims Holmes Rolston, III, is that they provide 'the profoundest historical museum of all, a relic of the way the world was during 99.9% of past time' (Rolston, 1988: 14). Eugene Hargrove, pushing a quite different aesthetics-based approach to environmental protection, also suggests 'nature aesthetically is not simply what exists at this point in time; it is also the entire series of events and undertakings that have brought it to that point. When we admire nature, we also admire that history' (Hargrove, 1989: 195). This blending of historical fact and normative overlay is why the idea of non-humanised nature, despite the objections of Steven Vogel and the gloomy outlook of Bill McKibben, still serves a valuable purpose. The pertinent question to ask is how today's environmentalist might effectively use Aristotle's distinction between nature and artefact in the light of its numerous acknowledged problems.

## 3. KEEPING THE NATURE/ARTEFACT DISTINCTION SIGNIFICANT

Keekok Lee, leaning heavily on both Aristotle's distinction and the moral overlays described above, makes an attempt to establish the continued significance of the nature/artefact distinction by using it to criticise two types of powerful contemporary technology. In a pair of works focusing on what she calls 'deep technology', Lee asks us to distinguish the effects of 'nature-replacing technologies' from the effects of what are simply 'nature-polluting technologies' (Lee, 1999, 2003). Nature-polluting technologies, Lee claims, can be harmful

towards nature but only in the sense that they adversely impact nature's ecological functioning. Since the early days of the industrial revolution and the spewing of airborne particulates into the air above cities such as Manchester and Pittsburgh it has been clear that technologies have the potential to interfere with both environmental and human health. But this damage, Lee claims, is relatively superficial. Better, less polluting and remediating technologies can usually mitigate these negative effects. In Manchester and Pittsburgh, the air quality has improved considerably as a result of a combination of better laws and new technologies.

According to Lee, other technological threats are not so easily defeated. Molecular nanotechnology and biotechnology, she claims, manipulate nature at such a fundamental level that they pose an altogether different kind of problem. Rather than just modifying nature, these 'deep technologies' replace nature with something entirely different. Nanotechnology re-orders nature at the level of the atom or the molecule (approx. $1x10^{-9}$ to $1x10^{-7}$m). Biotechnology manipulates nature at the level of the DNA molecule. By working at these fundamental levels, Lee claims that nanotechnology and biotechnology effect a transformation of nature of an entirely different kind.

The threat of these technologies is not, according to Lee, primarily in their potential to pollute. In fact, there is some hope that molecular nanotechnologies can substantially reduce pollution through more efficient energy generation and better sensing and remediation of toxins.[5] The real cost of nanotechnology and biotechnology, according to Lee, lies in their capacity to 'systematically transform naturally occurring beings (whether biotic or abiotic) to become artifactual ones' (Lee, 1999: 1). These technologies don't just work with natural materials to change them into objects that can be put to some use. They transform the natural materials themselves, changing natural kinds into artefacts. 'Humans in the possession of nanotechnology', Lee states with concern, 'are in a position to systematically replace natural abiotic with artificial kinds if and when it suits their purposes to do so' (Lee, 1999: 118). A structure made out of carbon nanotubes, synthesised at the molecular level, is more of an artefact than a wooden table. Its very molecular arrangement has been synthesised. Similarly, thinks Lee, Bt corn, genetically manipulated to resist pesticides, is the deepest kind of biotic artefact. Its very genome is the product of human intention.

As 'nature-replacing' technologies, Lee claims both nanotechnology and molecular biotechnology constitute 'a radical threat to the ontological category of the natural' (Lee, 1999: 114). Ultimately resting her sense of loss entirely on a traditional usage of Aristotle's distinction, Lee points out that these technologies represent 'the ultimate humanization of nature' (Lee, 1999: 118). Such a result, according to Lee, threatens a dramatic 'ontological impoverishment' (Lee, 1999: 119). In other words, we lose entities that are morally preferable and replace them with entities that are morally less valuable.[6] For reasons connected directly to Aristotle's nature/artefact distinction and the moral superiority

of 'the natural', Lee thinks molecular nanotechnology and molecular genetics should be opposed.

## 4. LESSONS FROM LEE

Lee's objection to deep technologies contains both insight and difficulties. The insight is that if environmentalists are going to retain Aristotle's distinction in any useful way then they are going to have to refine the context in which they use it. In particular they are going to have to figure out a means for discriminating between human modifications of nature that are in some sense problematic and modifications that are superficial or even, in the case of artefacts such as restored wetlands, desirable. Lee's strategy, that of searching for specific types of manipulation of nature more fundamental than others, seems like a helpful direction to go. I follow the same general direction below. The difficulty is to figure out just what is to count as a more fundamental transformation. And here Lee does not do so well.

In the case of abiotic nature, the suggestion that the creation of new kinds by molecular nanotechnology is morally problematic is contentious in the light of existing accepted practices. Synthetic chemistry has been creating new kinds of materials for at least two centuries through the rearrangement of molecular structures. According to Joachim Schummer, the creation of new materials in this field occurs at a rate of 900,000 kinds a year (Schummer, 2001). Plastics are themselves new kinds. And while environmentalists are correctly leery (for prudential reasons) of the kinds of harm plastics might cause the environment, it seems doubtful that plastics are ontologically pernicious in themselves. There is little reason to think (as Lee does) that molecular nanotechnology should provide any more of a moral challenge than existing synthetic chemistry. In fact, the late nano-pioneer Richard Smalley, in a long-standing debate with nano-engineer Eric Drexler, insisted that nanotechnology is essentially little more than a matter of careful chemistry.[7]

Part of the reason why Lee's objection seems overstated is a doubt about whether simply the scale of the manipulation of nature can make any morally relevant difference. Rearranging naturally occurring materials, whether these materials be carbon atoms or tree limbs, is something humans have been doing for millennia. Even if nanotechnology aims to change nature by working at the level of the atom or molecule rather than at larger, more familiar scales, it is not obvious why this should have any particular moral import.

In the case of biotechnology, the creation of new biotic kinds may also not be the problem Lee thinks it is. One reason for questioning the moral significance of manipulating a genome is the known fluidity of the concept of a species. Since the beginning of Darwinian theory it has been clear that species are not fixed kinds but transient assemblages composing and shifting over time as the

individuals that make them up die out, change habitat, mutate and adjust incrementally – and sometimes relatively rapidly – in response to environmental stressors. Darwin himself warned 'I look at the term species, as one arbitrarily given for the sake of convenience to a set of individuals closely resembling each other' (Darwin, 1898: 66). If, as Ernst Mayr claims, species are only 'groups of actively or potentially interbreeding natural populations that are reproductively isolated from other such groups' (Mayr, 1942: 120) then it is not clear why there would be anything particularly morally significant about such contingently assembled populations.

A second common argument for why the creation of new biotic kinds may not be a moral problem is that humans have been creating biotic artefacts for thousands of years. The hybridisation of crops and the domestication of animals is a perennial thorn in the side of those wishing to make deontological arguments against biotechnology.[8] Deontologists have to show how modern genetic manipulation is different in kind from traditional selective breeding. Lee thinks the distinction can be made because of the difference in the degree of manipulative control in modern biotechnology compared to traditional hybridisation. She suggests there is 'a quantum leap in the level of artefacticity' between projects relying on a breeding program steered by the principles of Mendelian genetics and the laboratory techniques used in modern molecular DNA technologies (Lee, 2003: 148). The rate, scope and degree of transformation are all enhanced by molecular genetics. Transgenic organisms illustrate this degree of transformation. Without molecular biotechnology there certainly would be no tobacco plants that glow in the dark due to the presence in their cell nuclei of genes from fireflies.

But a deontological argument that relies on rate, scope and degree of transformation has its limitations. The argument rests on the significance of differences in degree and not differences in kind. Since naturally occurring genomes have been artificially changed throughout human history, it is not clear how these differences in degree can be definitive. Why is there a marked difference between today's changes occurring in a laboratory and yesterday's occurring in a farmer's field or barn? In both cases what takes place is the intentional manipulation of the inherited genetic material of an organism. As in the case of molecular nanotechnology, the only difference appears to be the scale and the method of the manipulation. If it all boils down to scale, then it is hard to see how to sustain an adequate deontological objection.

In addition to the questionable quality of the deontological argument against molecular biotechnology there is a practical consideration growing in significance with each passing year. Just as it is almost impossible to object to traditional selective breeding today on the basis of its having been around and accepted for millennia, so is it becoming increasingly hard to draw a line in the sand against genetically modified organisms. In 2003, 167 million acres of genetically modified crops were planted world wide, with 65 per cent of those being

planted in the US. US farmers in particular produce an increasingly wide range of genetically modified crops including corn, cotton, soybeans, canola, squash and papaya for domestic and export purposes. Over 85 per cent of soybeans and 76 per cent of cotton grown in America is already genetically modified.[9] The genie appears to be already well out of the bottle. The deontological objection against genetically modified organisms is already sounding rather passé.

Reflecting the shakiness of the deontological arguments, most of the opposition to late-twentieth century genetic biotechnology tends to be made on prudential rather than deontological grounds. Much is made of the potential harm of bio-engineered crops and species on native ecosystems as a result of the replacement of historical biodiversity with modified organisms. In addition, the potentially devastating effects of biotechnology on indigenous knowledge and on local economies have been well highlighted by Vandana Shiva (1993, 1999) and others.

If Keekok Lee's arguments fall short, it appears we are no further along in retaining a problem-free use of the nature/artefact distinction by environmentalists. There seem to be problems both with its use to condemn traditional modifications of nature (such as using saws and chisels to shape wood) and with attempts to use it to condemn modifications made by what Lee calls 'deep technologies'. At this point, recalling Vogel, it is worth asking again whether there is any remaining good use that environmentalists can make of the distinction between nature and artefact for their normative agenda. I have suggested that philosophers will need to keep the distinction at the very least for the purposes of having a signifier for the 3.598 billion years of evolutionary history before the arrival of *Homo habilis*. And though I have not dared enter the morass here, it seems likely that some account of 'degrees of naturalness' will be useful from distinguishing Rift Valley mud huts from Walmart parking lots. But is there any technological arena in which environmentalists can still safely use Aristotle's distinction in its unmitigated form to raise deontological objections against manipulations of biological nature?

The answer is 'yes' and the arena is synthetic biology.

## 5. THE LAST STAND FOR ARISTOTLE'S DISTINCTION

Synthetic biologists assemble short DNA sequences with known properties to create synthetic organisms that perform desirable functions. The self-appointed task of a synthetic biologist is to 'create living systems from the scratch and then endow these systems with new and novel functions' (Chopra and Kamma, 2006). The products of the technology potentially include drugs for medical applications, vehicles for targeted drug delivery, biosensors to detect and neutralise contamination in the environment, biotic components for information technology applications, new biodegradable materials, and the environmentally

sensitive generation of methane or ethanol for energy projects. Due to the scale at which this work is carried out, some synthetic biologists call the technique 'natural nanotechnology'.

These are still relatively early days for the research. Nevertheless, Israeli scientists have engineered DNA to carry out basic mathematical functions that could theoretically be integrated into functioning computers. A Princeton University team has made an artificial organism within an *E. coli* bacterium that blinked predictably. Both teams in effect designed a biological machine to perform a chosen function, with the product of their efforts located entirely within a living cell. This form of engineering seems to successfully blur the line between a living biological organism and a purpose-built machine.

One of the major preliminary tasks for synthetic biologists is to isolate the properties of particular DNA sequences so that those sequences might be used as 'bio-bricks' to build future synthetic organisms. MIT has set up a Registry of Standard Biological Parts in order to catalogue these bio-bricks.[10] This element of synthetic biology is sometimes characterised in terms of the bioscientific project of 'understanding life'. But the project of gaining more knowledge about living systems takes on a different hue when bio-bricks are used to engineer functional synthetic bio-systems. In these endeavours, synthetic biology is more appropriately characterised as the engineering of life (Endy 2005). The goal of redesigning life using engineering principles is the true framework under which synthetic biology operates.

Environmental ethicists have long recognised that not all biological organisms are created equal. Most agree that there is a significant moral difference between wild genomes and genomes influenced by conscious human intention. Nineteenth century environmental advocate John Muir was one of the first to take up this point when he decried the artificially created stupidity of domestic sheep, famously calling them the 'hooved locusts' of the High Sierra. Contemporary environmental philosopher J. Baird Callicott, thinking along similar lines, categorises domestic animals as 'living artefacts' constituting 'yet another mode of extension of the works of man into the ecosystem' (Callicott, 1980: 330). Callicott's attack against biological organisms that are not 'wild, natural, and free' is even more vitriolic than Muir's. 'From the perspective of the land ethic', Callicott has insisted, 'a herd of cattle, sheep, or pigs is as much or more a ruinous blight on the landscape as a fleet of four-wheel drive off-road vehicles' (Callicott, 1980: 330). But however much both these theorists condemn domestic animals as 'biotic artefacts', the products of future synthetic biology will reach a whole new level of artificity.

One of Keekok Lee's main objections to molecular nanotechnology was its ability to 'construct *de novo* synthetic, abiotic kinds, from the design board' (Lee, 1999: 118). Synthetic biologists do exactly this but with biotic, rather than abiotic, kinds. The rhetoric used by synthetic biologists reveals just how ambitious are their construction projects. 'Think of it as Life, version 2.0' sug-

gested the author of an article in *Scientific American* in 2004. The side-stepping manoeuvre synthetic biology makes around the historical evolutionary process is unique. Craig Venter, a synthetic biologist who earlier headed the consortium that mapped the human genome, is described as desiring to 'short-circuit millions of years of evolution and create his own version of a second genesis'. Other researchers share the goal of replacing evolution with something better. 'It will be a marvelous challenge to see if we can outdesign evolution' offered George Whitesides (2001).[11]

Statements such as these bring out the difference between synthetic biology and traditional biotechnology. The relevant difference is that traditional biotechnology has always started with the genome of an existing organism and modified it by deleting or adding genes. The biologist has always taken a viable organism and made a selective change, hoping in the process not to modify the existing organism to such a degree that it is no longer able to survive. In every case of traditional biotechnology – even in the case of transgenic organisms – the genome on which the modification takes place is either the product of natural evolutionary processes or is the descendent of such a product. In every case in traditional biotechnology, there exists prior to the modification a viable organism on which the manipulation takes place.

This is not the case in synthetic biology. Synthetic biology does not start with a viable genome and modify it. It starts afresh with bio-bricks possessing known properties. There is no existing genome that undergoes modification. In the current state of the technology, the synthetically engineered DNA sequences have all been inserted into existing single-celled organisms. The idea, however, is not to preserve properties of the existing bacteria with modified behaviour. It is to create an entirely new organism with DNA constructed in its entirety according to human plan. The products of synthetic biology do not borrow any genetic function from genomes produced by the historical evolutionary process. To the contrary, synthetic biology is guided by the idea of leaving evolution and existing genomes behind in order to do a better job of creation with human goals in mind.

There are a number of familiar prudential worries that immediately arise with synthetic biology. Environmentalists might be concerned about risks that range from bioterrorism to the havoc such synthetic organisms might potentially wreak on the natural world. Synthetic biologists themselves already recognise this latter worry. The Venter Institute in California states on its website that '[T]he group has long been committed to fully exploring and educating the public about the ethical issues surrounding synthetic life. As such the team is dedicated to developing only synthetic organisms that completely lack the ability to survive outside the lab.'[12] Steve Benner, a synthetic biology pioneer at the University of Florida, tries to create similar reassurance with his claim that the more different an artificial system is from a natural biological system, the less likely it is to survive in the wild. But in addition to the important prudential

arguments, it seems there is also a clear basis for a deontological argument against synthetic biology.

In a famous article against the coupling of nanotechnology with biotechnology in *Wired Magazine* in 2000, Bill Joy, founder of Sun Microsystems, came close to articulating the problem. Joy claimed that future bio-nano technologies will cross a fundamental line when they allow the 'replicating and evolving processes that have been confined to the natural world … to become realms of human endeavor' (Joy, 2000). Joy's worry can be refined to apply to synthetic biology. Arteficity is again the problem. But the reason that the arteficity in synthetic biology is particularly worrisome is that it is a kind of arteficity that departs from the fundamental principle of Darwinian evolution, namely, descent through modification.

Charles Darwin himself, when searching for clues as to how the transmutation of species occurred in nature, spent many hours amongst dog and pigeon breeders admiring what these breeders had created using selective breeding techniques. His comfort level in this company is revealing. Darwin appreciated that when an experimenter modifies an existing genome through selective breeding he or she is doing much the same thing as natural selection has been doing continuously for over 3 billion years. In fact, it was because these breeders were doing something so similar to natural selection that Darwin was able to gain important insights he incorporated into his emerging theory.

Since natural selection works by taking an existing viable genome and modifying it incrementally, it seems plausible to characterise many previous types of biotechnology the same way. We might accept selective breeding, hybridisation and genetic technologies on the basis that they, like natural selection, work with the fundamental principle of descent through modification. They take existing genomes and modify them, even though they do it intentionally rather than randomly. All late twentieth century molecular biotechnology, including (perhaps rather surprisingly) the creation of transgenic organisms, follows this basic pattern. Viable genomes are modified with humans in laboratories now playing an integral role in making it happen. Clearly the modifications are not as incremental as they were in the case of pigeon breeding. Many of today's modifications would likely never have happened through natural selection or selective breeding. Nevertheless the biotechnology of the late twentieth century might charitably be recognised to retain the essence of Darwinian descent through modification.

As a result of retaining this Darwinian essence, genetically modified organisms possess a continuous causal chain between the genome currently being manipulated and the historical evolutionary process. At every point in this chain, there has existed a viable organism. This is true even if the organism being modified is itself the product or selective breeding or is transgenic. No product of twentieth century biotechnology has ever lacked this causal connection to

the historical evolutionary past. Before synthetic biology, every organism had ancestors connecting it to the historical processes environmentalists value.

When a synthetic biologist creates a genome from scratch, by contrast, building organisms *de novo* from bio-bricks, causal continuity with the historical evolutionary past has been severed. With synthetic biology, all trace of descent from naturally selected ancestors has been eliminated. Though they still contain the nucleic acids, the biotic artefacts created by synthetic biology borrow none of their genetic sequencing from viable products of the historical evolutionary process. A genome built from bio-bricks is as complete an artefact as any biological organism can be. This makes it possible to offer an argument that accepts hybridisation, selective breeding and late twentieth century genetic biotechnology but rejects synthetic biology. The argument hinges on the fact that synthetic biology creates a more fundamental type of biotic artefact.

The heart of this argument against synthetic biology is consistent with the worries articulated by Keekok Lee but finds them realised in a different place. Lee argued, correctly it seems, that 'the supercession of natural evolution' (Lee, 2003: 190-3) is a serious worry for environmentalists. But the supercession of natural evolution does not occur, as Lee had suggested, when humans take a genome created through natural processes and modify it. Nor does it occur when humans take a modified genome and modify *that*. It occurs when humans create new genomes from scratch. In the former cases, there remains in place a chain of viable organisms connecting the latest modification to the 3.6 billion years of the natural evolutionary process. This causal connection remains even when the last few steps in the chain have involved the active manipulation of the genome by humans. Lee was right about unnaturalness being the problem, but she drew the line in the wrong place. Contra Lee, humans do not usurp the historical evolutionary process when they simply modify an existing genome. In certain senses, by doing this humans are doing to biological organisms exactly what evolution has 'done' to them over natural history, namely, descent through modification.[13]

But in the case of a bacterium with its DNA created through synthetic biology, there is no causal chain of viable organisms connecting the synthetic organism with the historical evolutionary process. As Lee suggested was the problem with molecular nanotechnology, synthetic biologists create biotic kinds *de novo*. It is this creation of organisms *de novo* that makes synthetic biology different from previous biotechnologies.

## 6. AN OBJECTION BRIEFLY CONSIDERED

Proponents of synthetic biology will likely be unimpressed with this line of argument. They might offer the counter-argument that it is part of human nature to build and create things, many of them from scratch. Why would building

and creating biological organisms be any different from building and creating synthetic abiotic objects? Why is it morally significant that the products of synthetic biology depart from the historical evolutionary process even if, allegedly, the products of molecular biotechnology do not? After all, when discussing molecular nanotechnology earlier, it was suggested that there is no particular reason to think that creating new kinds of abiotic materials is morally problematic, especially since chemists have been doing so for hundreds of years. Why are things any different with synthetic biology? And what is the moral significance of rupturing the causal chain that connects an organism to the historical evolutionary process?

If this objection is to be successfully answered it probably needs to be answered from within the normative commitments of environmental philosophy itself. As argued in Section 2 above, the historical evolutionary process has implicit or explicit moral significance for many environmentalists. Aldo Leopold, often considered to be the first modern environmental ethicist, thought hard about what lay behind the symbolism of ancient cranes returning to a crane marsh to nest:

> Their annual return is the ticking of the geologic clock. Upon the place of their return they confer a peculiar distinction. Amid the endless mediocrity of the commonplace, a crane marsh holds a paleontological patent of nobility, won in the march of aeons ... (Leopold, 1949: 97)

If, like Leopold, you are an environmentalist who puts normative stock in the idea of the historical evolutionary process then synthetic biology should be opposed on deontological grounds due to the way it disconnects the biological artefact from this evolutionary history. This departs from the natural evolutionary process in the way that is different from any previous supercession in biotechnology. If that natural evolutionary process has substantial normative significance then these biotic artefacts are morally different from all previous ones. The biotic artefacts produced by synthetic biology depart from nature in a more radical way than anything that has come before.

At first this looks like a fairly substantial deflation of the argument since it limits the 'unnaturalness objection' to those who hold a particular view in environmental philosophy. The deflation is deliberate since the author recognises that synthetic biology is already seen by many as an acceptable and promising development in biotechnology. Nevertheless, two brief closing thoughts come to mind. First, the intuition that the natural evolutionary process has some role to play in establishing the moral significance of the natural world is, I suspect, a more widely held premise amongst environmental thinkers than might be first appreciated. Both anthropocentrists and non-anthropocentrists make some use of this idea. It is nearly impossible to put Earth's biota into any ecological or biological perspective without acknowledging the significance of the long history from which it emerged. The idea that the 4.598 billion years of Earth's

history before the arrival of *Homo sapiens* must play some role in supporting an ethic of nature is widely shared, having traction beyond simply those that are objectivists about natural value. Because of the widely held nature of this premise, the creation of biological organisms with no continuous causal connection to this process is a dramatic technological development.

Second, even if this line of thinking limits the argument in terms of those who are likely to use it, it does manage to retain what has always been a pivotal distinction for environmentalists. One of the claims made earlier in this paper was that Aristotle's relatively simple distinction between nature and artefact, though considerably undermined, is not yet redundant. Environmentalists simply need to find the appropriate context in which to use it. As the effects of human activities on the biosphere become more widespread, the 3.598 billion years of evolutionary history before the creation of the first artefact becomes a better and better referent for the term 'the natural'. The line of objection to synthetic biology developed here relies on the moral significance of retaining a connection to this history. If the significance of the connection is denied, many – perhaps the majority – of positions in environmental ethics may need to be rethought.

## NOTES

[1] Clearly one needs to argue for *why* nature unmodified by human activity has moral significance. That is not my task here. Environmental ethicists over the last thirty-five years have put considerable energy into making this case. For the purposes of the current paper, I will simply assume that this intuition is widely held both by environmental ethicists in particular and by environmentalist activists more generally.

[2] The 'paradox' here seems to be caused by an equivocation on the word 'natural'.

[3] The question of whether humans and their activities should be thought of as inside or outside of nature remains one of the most vexing issues in environmental philosophy. As much as is possible given the topic, I sidestep it here.

[4] Unfortunately, the problems don't stop with the issue of crudity. In North America and beyond, it has been well documented how environmentalists' hasty use of Aristotle's distinction has led to frightful kinds of ethnocentrism and racism. 'Natural' landscapes, apparently unmodified by human activity, are now widely recognised to be an immigrant American's fantasy, an error that has led to the denial of indigenous histories written across numerous ecologies. This connection with ethnocentrism seriously undermines the utility of Aristotle's nature/artefact distinction for environmentalists.

[5] The threat of pollution posed by different nanomaterials and, conversely, the potential of nanotechnology to mitigate pollution remains relatively unknown. But there are certainly reasons to be concerned about the possible ecological effects of artefactual nanoparticles on the environment. See Colvin 2003.

[6] It is not entirely clear why Lee sees this as 'ontological impoverishment.' With the creation of new, artificial kinds alongside natural ones there would actually be more categories of being in the world not less. Some might see this as a desirable form of 'ontological enrichment.'

[7] The 'Drexler-Smalley Debates' in nanotechnology are about whether nanotechnology is fundamentally a matter of engineering or chemistry. Smalley's argument against Drexler is that the mechanical manipulation of atoms is impossible due to the so-called 'fat' and 'sticky' fingers problems.

[8] What I am calling deontological objections, Gary Comstock calls 'intrinsic' objections. He characterises an intrinsic objection as one that does not rely on an account of potential future harms. He lists a number of intrinsic arguments against molecular biotechnology including i) playing God, ii) illegitimately crossing species boundaries, and iii) commodifying life (Comstock, 2002: 93). Comstock notes that each of these intrinsic objections relates in some way to the claim of unnaturalness. I characterise the unnaturalness argument as deontological because it suggests we have a duty not to proceed in a certain way.

[9] These statistics are drawn from a report completed as part of the Pew Initiative on Food and Biotechnology, available at: http://pewagbiotech.org/resources/factsheets/display.php3?FactsheetID=2. (date accessed 30 Aug 2007)

[10] This registry can be found at: http://parts.mit.edu/. (date accessed 30 Aug 2007).

[11] Quotes from 'Biology's Bad Boy is Back', (http://money.cnn.com/magazines/fortune/fortune_archive/2004/03/08/363705/index.htm) (date accessed 30 Aug 2007) and 'Synthetic Life', *Scientific American*, May 2004.

[12] See the research page of the Venter Institute's web page: http://www.venterinstitute.org/research. (date accessed 8/30/07).

[13] Clearly there remain marked differences. For example, in 'Terminator technology' engineered organisms are modified expressly so that they cannot reproduce. This could never be the norm in natural evolution.

## REFERENCES

Aristotle. [1941]. *Physics*, trans. R.P. Hardie and R.K. Gaye. New York: Random House.

Callicott, J. Baird. 1980. 'Animal liberation: A triangular affair'. *Environmental Ethics* **2**: 311–338.

Chopra, Paras and Akhil Kamma. 2006. 'Engineering life through Synthetic Biology'. *In Silico Biology* **6**, 0038.

Colvin, Vicky. 2003. 'The potential environmental implications of engineered nanomaterials', *Nature Biotechnology* **21**: 1166–1170, doi: 10.1038/nbt875.

Comstock, Gary. 2002. 'Ethics and genetically modified foods', in M. Ruse and D. Castle (eds.), *Genetically Modified Foods* (Amherst: Prometheus), pp. 88–105.

Darwin, Charles, 1898. *The Origin of Species, By Means of Natural Selection*, Vol. 1. New York: Appleton and Company.

Elliot, Robert. 1982. 'Faking Nature'. *Inquiry* **25**(1): 81–93.

Endy, D. 2005. 'Foundations of engineering biology'. *Nature* **438**: 449–453, doi: 10.1038/nature04342.

Hargrove, Eugene. 1989. *The Foundations of Environmental Ethics*. Englewood Cliffs, NJ: Prentice Hall.

Hettinger, Ned and Bill Throop. 1999. 'Refocusing ecocentrism: De-emphasizing Stability and defending wildness'. *Environmental Ethics* **21**: 3–21.

Joy, Bill. 2000. 'Why the future does not need us'. *Wired Magazine* **8**(4), http://www.wired.com/wired/archive/8.04/joy.html (accessed 30 Aug 2007).

Katz, Eric. 1992. 'The call of the wild'. *Environmental Ethics* **14**: 265–73.

Lee, Keekok. 1999. *The Natural and the Artifactual: The Implications of Deep Science and Deep Technology for Environmental Philosophy*. New York: Lexington Books.

Lee, Keekok. 2003. *Philosophy and Revolutions in Genetics: Deep Science and Deep Technology*. Basingstoke: Palgrave MacMillan.

Leopold, Aldo. 1949. *A Sand County Almanac*. New York: Oxford University Press.

Mayr, Ernst. 1942. *Systematics and the Origin of Species*. New York: Columbia University Press.

McKibben, Bill. 1989. *The End of Nature*. New York: Random House.

Rolston, Holmes, III. 1986. 'Can we and ought we to follow nature?' in Holmes Rolston, III, *Philosophy Gone Wild* (Buffalo, NY: Prometheus), pp. 30-52.

Rolston, Holmes, III. 1988. *Environmental Ethics: Duties To and Values in the Natural World*. Philadelphia, PA: Temple University Press.

Schummer, Joachim. 2001. 'Ethics of chemical synthesis'. *Hyle*, **7**: 103–124.

Shiva, Vandana. 1993. *Monocultures of the Mind: Biodiversity, Biotechnology and Agriculture*. New Delhi: Zed Press.

Shiva, Vandana. 1999. *Stolen Harvest: The Hijacking of the Global Food Supply*. Cambridge: South End Press.

Vogel, Steven. 2002. 'Environmental philosophy after the End of Nature'. *Environmental Ethics* **24**: 23–39.

Whitesides, George. 2001. 'The once and future nanomachine'. *Scientific American* (Sept).