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Towards an eco-centric view of human existence: Implications of genomics for the environmental zone

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During the weeks and months preceding the gala televised Human Genome Project press conference on 26 June 2000, the human genome sequencing effort had turned into a massive spurt, involving competing teams who were almost dashing towards completion.[2] The press conference, involving President Bill Clinton as well as the main competitors Francis Collins and Craig Venter as plenary speakers, was the climax of an avalanche of promissory discourse, the tremors of which are still noticeable today. It was proudly announced, for instance, that humankind was about to unveil the core of its identity, and it was even considered conceivable that “our children’s children will know the term cancer only as a constellation of stars”.[3]

Reflecting on the press conference 10 years later, the Human Genome Project (HGP) seems a glaringly self-centred endeavour, not only because it firmly positioned science at the centre of the stage (as the driving force in human history), keeping the natural and the social at a distance as it were, but also in the sense that the project was presented in an overtly anthropocentric vein. While quoting the words of Pope that “the proper study of mankind is man”, genomics seemed to display a basic predilection for human beings as its favourite model organism. The speeches presented at the event were ‘speciesist’ to a high degree in that they focused almost exclusively on human beings and human health, while possible untoward side-effects were solely formulated in terms of risks for humans.

This also goes for the anniversary series of articles published by *Nature* – ’Ten Years After’ as it were - in which several authors (including the two key players, Francis Collins and Craig Venter) reflected in retrospect on the meaning of the human genome sequencing effort and its outcomes, as well as on the train of events it set in motion.[4] Again, the focus is clearly on the human genome. The 4,000 or so other species whose genomes have likewise been sequenced, are mentioned only in passing, by Craig Venter.[5] The “narcissistic insults” of the Copernican, the Darwinian and various other scientific revolutions have passed without leaving much impact.[6] We still seem to regard ourselves as the most important of all species on earth, as the ultimate ‘model species’ of our will to know, as if planet Earth can still be regarded a safe haven of anthropocentricism.

This anthropocentric bias seems as problematic as it is inevitable. Parry and Dupré, for instance, agree that it may appear anthropocentric to foreground the HGP to such an extent, in view of the large sets of viruses, bacteria, fungi, plants and animals whose genomes have likewise been sequenced, while applications in animal husbandry and ecological conservation may eventually eclipse and prove far more weighty than the still pending applications in human healthcare.[7] Nonetheless, they argue that it was the *human* genome project which “galvanized” the genomics revolution and played such a pivotal role in mobilising and channelling resources into

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genomics, thus having ramifications across the wider field of study. This ambivalence concerning the legitimacy of anthropocentrism is omnipresent in genomics discourse. On the one hand, the time has come, so it seems, for decentring of the human once and for all in assessing the implications of genomics for the social, the cultural and the natural. On the other hand, we are undoubtedly the major actors when it comes to implementing and assessing the repercussions of genomics research for life on earth.

Meanwhile, genome sequences continue to proliferate. Sequence information covering thousands of species is collected under the heading of the Genomes OnLine Database (GOLD). From a psychoanalytical perspective, the acronym used here is a highly symptomatic one. These enormous databases can be seen as spates of informational excrement (spat out by sequencing machines with superbly productive intestines) that at the same time represent something of significant value, something 'pure'. It is the symbolisation of life, focused on bioprospecting, on turning messy life into its purified essence, into pure gold, and eventually into financial gain: genome sequencing as a contemporary gold rush, with the genome as our genetic 'metal' to be tested. Like the press conference described above, the sequences on display actually conceal the more muddy and messy aspects of the natural, as well as of laboratory life. Thus, genomics represents a cleansing and dematerialisation (or rather defluidisation) of bodily existence.

The ambivalence continues. In view of the proliferation of genomes, anthropocentrism might seem an uncertain ally. If one pivotal message can be distilled from genomics research during the past decade, it is that we cannot begin to understand its implications as long as we focus solely or even predominantly on human beings and human health. The broader implications of the HGP can only be meaningfully assessed if we are willing to move beyond the dichotomies and bifurcations of traditional metaphysics, in the context of which humankind is time and again singled out from the rest of the living world, the 'non-human'. Indeed, Nietzsche already argued that, when discussing such issues as "man *and* world", the very framing already obscures that we are, in every single molecule of our bodies, part of nature.[8] Yet, the self-centred, anthropocentric view of life is a legacy of long standing and is bound to reassert itself, even in the era of genomics, if only because (unlike, for example, eating vegetables or meat) the sequencing of genomes is an exclusively human endeavour.

Thus, genomics has reinforced a basic uneasiness that scientists, philosophers, novelists and many others have been facing since the first narcissistic insults mentioned above have 'decentralised' the human by indicating that we should stop seeing ourselves as something ontologically privileged and unique. Through scientific discoveries we realise that (from an astronomical, anatomical, physiological, neurological, evolutionary and genetic perspective) we are quite similar to other life forms when it comes to the basic constituents and processes of life. We are not only subject to the same physical laws as other entities on earth, but also to the same evolutionary laws and biomolecular mechanisms. Yet, at the same time, these very insights seem to underscore our uniqueness. As far as we can tell, we are the only

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entities on earth (or, for that matter, in the universe) involved in questioning and exploring the origins and functioning of life in general and of our own existence in particular. Only human beings seem able to explicitly address issues of descent, as well as questions of identity. Besides living our life, we have been producing a discourse of astonishing magnitude on what it *means* to live a life, a performance without precedent in nature, and this prolific discourse has had a tangible impact on human existence, has 'materialised' in countless efforts towards regulation and reform of life. Our self-consciousness has become a major factor affecting life on earth. The very fact that we are able to *talk* about endangered species as 'endangered species', for instance, has consequences for their prospects of survival.

What is the basis for this openness towards ourselves and the world around us? What is it that makes our self-consciousness possible? The human genome sequence in itself fails to provide answers to such questions. As a genome sequence, it underscores continuity between humankind and 'the rest of nature', but as a chapter in the history of knowledge, HGP stresses science as a uniquely human endeavour, also from an evolutionary perspective, significantly transcending the type of information provided by our sense organs. Through research, we have tremendously expanded our temporal and spatial horizons, whereas other (closely related) species persistently focus on the local here and now.

Yet, when it comes to understanding the societal impact and cultural significance of genomics, it would be a fatal mistake to focus our attention on the *human* genome only. If one philosophical lesson can be drawn from genomics at all, it is that we can only come to terms with our own identity and history (as human beings) if we see our existence and our history as part and parcel of a much broader narrative: the history of life on earth and of living nature. In order to make sense of our genome, we need these 4,000 or more other genome sequences as well. The HGP incites us to embark on the paradoxical task of developing an *eco-centric anthropology*, a decentralised narrative of humankind, redefining our self-understanding in eco-centric terms, in terms of multiple-species narratives. First of all because the currently known genomes of other animals are a testimony to our basic affinity with them, notably on the molecular and biochemical level. Comparative genomics tends to stress the marginality of differences between species, and this includes differences between human and 'non-human' genomes. Second, because the genomes of cultivated plants such as rice, grain and potato on the one hand, and of domesticated animals such as cow, horse, pig, camel, dog, on the other, may serve as source books or archives containing valuable information about *human* history, not as a single-species narrative, but as a story-line that is embedded in a much broader multiple-species narrative frame: the history of domestication as a multiple species history.[9] Notably, these genomes contain informative archives concerning the vicissitudes and histories of the - to a certain extent - man-made, but nonetheless multiple species agricultural ecosystems called villages that began to emerge 10,000 or so years ago: the agricultural village as an evolving multiple-species ecosystem.

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And finally, genomics not only points to the importance of including plants and animals into our history, but also indicates the necessity to include microbes more explicitly in our view of nature and of ourselves. Genomics research underscores the cardinal insight that Earth is basically a microbial planet and that the guts and cavities of our own bodies may be regarded as environments for the plethora of life forms by which we are inhabited. Genomics has made it much more explicit than ever before that we are not 'individuals' in the sense of insulated, self-sufficient entities. On the contrary, our bodies can be seen as environments in their own right, hosting floating swarms of micro-organisms responsible for a broad range of biochemical processes that are usually listed under the heading of 'metabolism' – processes moreover that as a rule are attributed to the activities of our own bodies and organs, rather than to the silent, invisible and unacknowledged labour of the billions of guest organisms that dwell within us as a symbiotic workforce.

From the very outset, it has been an important objective of the HGP to deepen our understanding of ourselves. More than 25 centuries ago, a famous admonition was inscribed in the forecourt of the temple of Apollo at Delphi in ancient Greece by one of the seven Sages, namely "Know thyself". Self-knowledge was regarded as the ultimate goal in human life, the basic objective of all knowledge-directed activities - from pilgrimages to holy sites in ancient Greece up to genome sequencing efforts in present-day genomics facilities.[10] The ancient admonition was taken up by the neo-classicist poet Alexander Pope, in his *Essay on Man*: "Know then thyself, presume not God to scan / The proper study of mankind is man".[11] As mentioned above, these lines were subsequently quoted by Francis Collins during the 26 June 2000 press conference.[12] After a long journey of exploration, we were finally expected to be able to know and explore ourselves. Thus, Collins described the human genome as "our own instruction book" and as "the draft of the human book of life". Moreover, he expected that this tremendous leap in self-knowledge would provide us with effective tools, enabling us significantly to improve the human condition.

In various ways, these expectations proved overstated. Rather than a series of answers and solutions, from which humankind in general, but notably patients suffering from cancer, were expected to benefit, the HGP produced a "deluge" of data and a "labyrinth" of new questions.[13] Yet, perhaps the real significance of the HGP must be sought first and foremost in its *cultural* relevance. By this I mean the impact the HGP has had on our understanding of ourselves and our history, in close relationship and interaction with "the rest of nature". On 26 June 2000, the implications of the HGP were still defined in humanistic and anthropocentric terms. Now, genomics is increasingly shifting its attention towards areas such as environmental genomics, microbial genomics and metagenomics. This raises the question (somewhat neglected in current ELSI genomics discourse, I think) of how genomics in general and the HGP project in particular have affected our views on our position within the living world. I will argue that genomics has deepened our understanding of the embeddedness of human existence in the web of life, and that this might make new forms of relationship, more sustainable "covenants", as it were, with our natural environment possible.

In order to address this rather broad range of topics, I will focus on a number of specific issues. First of all, I will outline how genomics has enriched our understanding of human history, notably the history of agriculture and domestication ('The Genesis of man-made, multiple-species ecosystems'). This broadens a self-centred view on human existence into a more eco-centric view. Subsequently, the scope will once again be broadened by shifting the focus from domesticated plants and animals (as our companion species) towards microbial life forms and their importance, both in our external environment ('Microbial planet') and in our internal environment ('The microbial unconscious'). Finally, I will outline how genomics is redefining our policies towards the natural world, especially when it comes to "genome management" of endangered species (notably mammals). A new genomics-based covenant with nature appears to be emerging (The return of the Ark).

The Genesis of man-made multiple-species ecosystems: towards a genomics-based genealogy of village life

The Bible book *Genesis* contains a fascinating legend: the story of the Ark. Against the backdrop of an ecological disaster - a sudden dramatic climate change unleashed by chronic and massive human (mis-)behaviour - a protective contrivance is built, a kind of lifeboat for supporting and ensuring the survival of a limited number of favoured and carefully selected human beings and animals. They are, so it seems, set on the trail towards domestication and self-domestication. After the Flood, they are allowed to repopulate the land. In various ways, the story of the Ark can be seen as a model narrative for framing important events, such as periods of climate change and mass extinction in the recent or distant past (as studied and uncovered by geology and palaeontology), where the Ark symbolises what is nowadays called a survival bottleneck (a genetic window into the future in times of mass extermination). But it may also serve as a narrative scheme that allows us to frame and assess what is happening in the present (the genomics era) in terms of conservation policies to ensure survival of favoured and yet endangered species, allowing them to accompany us in our journey towards the landscapes and environments of the future. Thus, the Ark provides an archetype for framing the narrative of the interaction between humans, animals and other organisms. The Ark has proliferated into a world-wide network of regulatory lifeboats and survival sites in order to counteract the massive killing fields that endanger biodiversity on earth.

Archaeological research has made it abundantly clear that the Ark really existed, namely in the form of the primordial agricultural village, an ecological lifeboat in a challenging, threatening and rapidly changing environment when the Pleistocene era gave way to the current Holocene period. Perhaps the most decisive event in human history, the so-called Neolithic, or agricultural, revolution, began some 10,000 years ago in various parts of the world more or less isolated from one another, such as Mesopotamia and Egypt, North and South China (along the Yellow and the Yangtze Rivers), the Indus valley, West Africa, Mexico and the Andes highlands.[14] From there it gradually spread to other areas, such as Europe. The face of the earth began to change as humankind began systematically to modify its natural environments through wilderness clearing and reclamation. It was a moment of awakening, as it were, of mankind as a whole.

The simultaneity and common pattern of these worldwide changes suggest a common external factor in terms of global climate change.[15] As humans and animals found themselves united in their effort to circumvent post-glacial draught, former hunters became cultivators and domesticators in their retreating oases.[16] Thus, emerging villages provided a lifeline for endangered species (including Homo sapiens) under the leadership of humankind. We as a species had firmly taken the lead in the drama of evolution and survival. The village represented a protective environment or Ark amidst environmental perturbation and flux. Every region involved produced its own typical domesticated plant form - a plant that gave the area in question an identity, a face, so to speak - making use of the wild types available: wheat in the Middle East, millet in the northern parts of China, rice in South China, maize in Mexico. The civilisations concerned became wholly dependent upon a small number of key species.[17] Eventually, around 5,000 years ago, extended parts of the world including China and Europe became real *agri*-cultures, that is areas where agriculture flourished and constituted the basis of societal existence[18].

As a consequence of the agricultural or Neolithic revolution, a number of other transformations of pivotal importance took place as well, such as the emergence of states, of cities and of written language. Until recently, scholars relied on linguistic, archaeological and other "traditional" sources to reconstruct these largely pre-historical transformations. Now, however, genomics has redefined the field. Jones, for instance, describes how DNA information has transformed archaeology in a very profound way, - has transformed it into bioarchaeology.[19] The focus of attention has shifted from analysing artefacts such as pottery or ornaments and tools, to analysing DNA fragments in organic remains (seeds, animal bones, human bones, etc.) as sources of information concerning the life, health status and nutritional habits of ancient rural communities. The focus of interest for bioarchaeologists is on the plants these rural communities cultivated, on the animals they domesticated, on the "biotechnologies"[20] they relied on and on the man-made ecosystems they created. Due to this shift, archaeologists became "DNA hunters", and archaeology evolved into a merger of humanities and hard core technoscience. Eventually, genome sequencing is bound to become an important branch within archaeology as a field

Indeed, the DNA revolution in archaeology has only just started and is bound to continue well into the future. Besides analysis of DNA samples recovered on archaeological sites, another source of information has presented itself, namely the DNA of *contemporary* organisms (plants, animals and humans that are currently alive) as "archives". Genomes are the Rosetta Stones of (the history of) life. This first of all applies to humans. Luca Cavalli-Sforza and Allan Wilson's Human Genome Diversity Project (also known as the "second" Human Genome Project) as well as the HapMap project and the Genographic Project[21] of National Geographic and IBM are shedding new light on early human history and have re-opened a number of debates in archaeology, palaeontology, language studies and cultural anthropology. In this manner, genomics is affecting our understanding of early human existence - which is basically the history of early human migration - as well as the origins of human society and culture.

But again, it would be wrong to solely focus on *human* genomes in this respect. Indeed, it is impossible to come to grips with the dynamics of early human history as long as we disregard the evolutionary pathways of our fellow-travellers and accompanying species, in whose genomes we find our common histories reflected. These genomes contain the records and footprints of our own activities. Thus, bioarchives may be consulted as mnemonic devices and recordings of multiple-species trials and tribulations reaching far into the distant past. We have been evolving, not as a single “species” in competition with others, as Darwin and his followers thought and think, but rather as members of multiple-species networks and symbiotic constellations, in environments such as villages and cities. The story of agriculture is a multi-species narrative that has greatly affected the history and evolution of other species besides humans.

Moreover, the agricultural revolution is a story to which a substantial number of species have contributed besides Homo sapiens. Early agriculture consisted of the creation of artificial environments or ecosystems in an era of climate change and environmental stress, initially in the form of small man-made “islands” surrounded by natural wilderness. A select number of plants were cultivated and a select number of wild animals were domesticated, a process that greatly influenced their conditions of existence and (eventually) their genomes. Micro-organisms were used for processes of fermentation and food conservation. As a result of agriculture, human beings created their own life-world. Rather than being dependent on the food that was provided by natural surroundings, humankind began to produce its own food products and thus increasingly to control its own food policies and food intake. Yet, in doing so, we significantly relied on a wide range of “biotechnologies” developed by tiny organisms such as yeast in the course of evolution.

The agricultural village was designed to function as a protective shell and relatively safe haven, allowing its inhabitants to flourish more exuberantly compared to populations (of humans, animals and plants) that remained “outside”. Although moments of catastrophe and crisis (in the form of famine and the spread of infectious disease) did occur, eventually this new way of life became a success story. Whereas humans, plants and animals involved in the domestication program tended to flourish, their wild type cousins or ancestors declined and often became extinct. Indeed, domestication is neither a history nor a story, but rather a programme that still continues to unfold. Generations of human farmers have left their fingerprints on genomes they selected and eventually altered. Therefore, we have come to realise that, in order to understand our own history, the genomes of other domesticated species - together with the genomes of animals such as the mammoth or the indigenous American horse, whose extinction coincided with the transformation of our own history from a merely biological evolutionary pathway into a success-story of our own making - should be consulted as well as a kind of source book for early human history.

The systematic sequencing of the genomes of species that were involved in this grand narrative, in this ongoing programme, adds a whole new dimension to our understanding of it. A promising new source of complementary information becomes available, often allowing us to fill in some of the gaps and lapses in the various archaeological, anthropological and linguistic records that had survived. Recently, for instance, the draft sequence of the cow genome became available.[22] This sequence is not only bound to provide important information concerning health, nutrition and disease that can be put to use in the context of animal husbandry, but it may also allow us to reconstruct more accurately the various domestication events over the past millennia by studying the impact of selection and husbandry on the cow genome.[23] Although this type of research is still in its infancy, the idea is that the imprints of domestication and breed development on the genomes of livestock will help us to improve our understanding of the common history of cows and humans during past millennia, notably by studying the bottleneck signatures associated with domestication and selection.

When the human genome 'map' was announced in 2000, the hype was predominantly about the new medicines and cures for human diseases that would emerge as a result. Yet it has been argued that genomic findings have had a much greater impact on for instance animal husbandry. They have "revolutionized" dairy farming,[24] through tailoring diets to genomes (animal nutrigenomics) and through targeted selection procedures (producing "farmyard supermodels"[25]), as well as through boosting resistance against disease. Yet, besides these utilitarian outcomes and economic benefits, valuable cultural and historical insights are provided by the sequenced genomes of cows and other domesticated animals.

Likewise, the sheep genome is claimed to provide valuable insights into the history of sheep domestication, one of the first animals to be invited into the man-made rural enclaves of the Neolithic revolution. Marginalised descendants of early waves of domestication are like relics of the past. By unravelling their genomes and by comparing the genomes of various sheep varieties, new insights can be acquired into the history of pastoral societies whose economy depended on sheep husbandry.[26]

What goes for the genomes of domesticated animals also applies to the genomes of cultivated plants such as rice, potato, grapes and wheat. The importance of the sequence of the rice genome, for instance, does not reside only in the fact that rice as a crop is a staple for more than half the world's population - hundreds of millions of people depend on it for their daily living. It is also important because the rice genome is the outcome of a long and winding history of cultivation. Traces of this history can be found throughout its genome.[27] Thus, genomes contain the annals, written in the "alphabet" of DNA, of the Neolithic revolution and the introduction of agriculture, spreading throughout the world like a biotechnological epidemic, with humans as carriers, significantly affecting the earth's flora and fauna. The genomics of cultivated

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plants such as rice, potato or cereals and of domesticated animals such as cows can be read and put to use as complementary archives whose histories, recorded in their DNA, mirror our own.

Microbial planet

Besides allowing us to reconstruct the outlines of the primordial agricultural Ark, genomics also incites us to look upon our own bodies as vessels, floating through a microbial web of life and providing a hospitable environment for the species that inhabit us.

Contrary to the (outdated) idea that we inhabit a predominantly *human* planet, whose human and mammalian inhabitants (as dominant species) are threatened by micro-organisms as infectious agents – germs that in a future, utopian world are bound to become exterminated, as H.G. Wells wrongly anticipated in his novel *The Time Machine*[28] - we now realise the predominance of microbial life forms, not only from a temporal perspective (microbial evolution covers the lager part of the process of evolution as such), but also from the perspective of biodiversity and sheer biomass.

Microbes have been the only forms of life on Earth for something like 80 percent of its history and remain even today by far the commonest living things. Even their biomass still exceeds that of multicellular organisms if structural plant material is excluded.[29] We ourselves are like tiny entities or floating islands temporarily nestling themselves in these dynamical microbial mires of Gargantuan proportions. Genomics entails a narcissistic offence, not only because the human genome contains only 22,500 or so protein-coding genes, and is almost indistinguishably similar to the genomes of the chimpanzee or the laboratory mouse, but also because it is difficult to uphold that in the grand narrative of life on earth we should be regarded as the principal character or key player, and the emergence of human beings as the principal focus event. As Lynn Margulis and others have argued, during the first two billion years or so of evolution, microorganisms have developed the “biotechnological toolboxes” of life we are only beginning to unravel.

In her book *Microcosmos* as well as in a number of subsequent publications, Margulis and her co-author Dorion Sagan describe how our own life as human beings is nourished by and dependent upon the presence of a worldwide microbial “superorganism”, providing and maintaining the conditions that support and sustain life on earth, a microbial *web of life*.[30] The earth’s microbial biosphere emerges as a “communicating and cooperating worldwide community of interdependent entities”.[31] For Margulis, the key idea of the life sciences is the idea of a global microbial communicating and cooperating *network* that constitutes our indispensible bio-environment and that also lives *in us* and *through us*. It has been able to survive all cataclysms of the past and can be regarded as virtually immortal. In similar terms, Nobel Prize winner Christian De Duve speaks about the Earth being enveloped in a colourful “web” of throbbing life.[32]

Margulis also subscribes to the idea that our own bodies (like the bodies of other organisms) can be “read” as archives containing annals and reminiscences of lost worlds and decisive geographical and evolutionary events. Indeed, our bodies contain “a veritable history of life on earth”. Our cells, to begin with, maintain an environment like that of the earth when life began, similar to the environment of the early seas. Our bodies preserve the atmosphere of an earlier earth.[33] This converges of course with the idea, already outlined above, of our body as an archive in which the genomes of humans and other species are regarded as records of primordial events.

Besides redefining the Earth as a microbial planet, the history of the human body is likewise reframed in microbial terms, giving rise to a genomics-based view of world history in which the role and functioning of micro-organisms is duly acknowledged. An important contribution in this direction is the best-seller *Guns, Germs and Steel: The fate of human societies* by Jared Diamond, in which the decisive contribution of microbes to major events on the world historical stage is brought to the fore.[34]

Diamond sets out to develop a new perspective on world history based on the avalanche of novel forms of information coming from scientific disciplines that were traditionally seen as somewhat remote from the analysis of human history, such as genetics, molecular biology, and biogeography. First of all, his “tour of human history on all continents” reveals that during the beginning of village life and the early days of plant and animal domestication, the availability of suitable species provided some areas with a head start over others, a fact of life which Diamond subsequently uses to explain the differences between various cultures on various continents. But the real key players of his book are germs. Their history is closely associated with the history of domestication, since the major killers of humanity have been infectious diseases that evolved from diseases of domesticated animals with which humans co-existed, often even under the same roof. Notably, the ships used by invaders sailing to the New World were like Arks carrying not only humans and animals but also microbes across “the tumbling billows of the main” towards promising shores.

There is a strong historical connection between colonialism, violent collisions and germs. Soldiers and voyagers have always been notorious for their role as carriers of deadly germs. Until World War II, more victims of conflicts died of the illnesses caused by war-borne microbes than from battle-wounds. Diamond underscores the decisive role of microbes during transcontinental collisions, such as between the Old and the New World. Although the numbers of Native American victims of European colonisation were substantial, they were dramatically outnumbered by victims of European microbes. Diamond calls this Europe’s “sinister gift” to other continents: the germs evolving from Europe’s long intimacy with domestic animals. The exchange of germs was almost exclusively one-way. Microbes paved the way for European expansion, but not always: malaria, yellow fever and other diseases of tropical Africa, South East Asia and New Guinea furnished the most important obstacle to European colonisation in those tropical areas.

Yet, microbes do not only flourish in our external environment. Genomics research also sheds new light on the role and importance of microbes dwelling and flourishing in our internal environment. Genomics invites us to look upon ourselves as incubators, as it were, for symbiotic and cooperative microbes, rather than as vehicles for "selfish" genes.

Love is a microbe... **The microbial unconscious**

"Microbes thrive on us: we provide wonderfully rich and varied habitats, from our UV-exposed, oxic and desiccating skin to our dark, wet, anoxic and energy rich gut that serves as a home to the vast majority of our 100 trillion microbial (bacterial and archaeal) partners." (Ley et al).[35]

Love is a microbe… At times I have attacks of melancholy and of atrocious remorse; but you know, the fact is, that when all this discourages me and gives me spleen, I am not ashamed to tell myself that the remorse and all the other things that are wrong with me might possibly be caused by microbes too, like love… (Vincent van Gogh)[36]

The HGP was not exclusively devoted to sequencing the genome of humankind. Contextualising this large-scale endeavour, and as a preparatory exercise as it were, the genomes of other species such as C. Elegans and Drosophila were sequenced and published before taking on the human code. Moreover, as outlined above, in the wake of the HGP an exponential number of genomes has been added to the list. Some of them have a close relationship with agriculture and anthropogenesis, as we have seen. Their histories, recorded in their genomes, are an integrated part of the collective multi-species narratives that constitute our common eco-centric biography.

But domesticated plants and animals are not our only "companions". Our bodies constitute a rich environment, an often forgotten realm of life. Genomics research has given due attention to this hidden world. An important role is played by the Human Microbiome Project (HMP), a metagenomic initiative to sequence the genomes of all the microbiological flora collected from a variety of body sites. Through such research initiatives, we are becoming more aware of the vital role played by the indigenous microbial metagenome in human physiology.[37] From this perspective, the human body is seen as an ecosystem in its own right, containing multiple ecological niches and habitats in which a variety of cellular species collaborate and compete. Human beings are redefined as superorganisms that incorporate symbiotic multiple-species colonies.[38]

One way of framing it might be to say that this web of microbial life existing within our internal environment is our "unconscious", first of all in the sense that we tend to be unaware of its existence. We tend to believe that digestion, for instance, is carried out by our own internal equipment, our own biotechnological toolbox, and fail to realise our dependence on this vast army of labouring companions. Microbial life usually becomes visible and noticeable only through symptoms or pathologies whenever something is ill-functioning or wrong with “us”. Then, all of a sudden, we become aware of the fact that we are pervaded by microbial life forms.

Yet our internal microbial world may also be regarded as our “unconscious” in a more psychoanalytical sense of the term, namely in the sense that, even though we are apparently aware of its existence, we are hesitant or even resistant when it comes to really acknowledging its presence and importance. As soon as these embedded biota are uncovered, the awareness of their existence is bound to become obscured or repressed once again. From the very moment that Anthony van Leeuwenhoek for the first time opened up the microbial realms of life to human perception, using self-built microscopes as windows into this miniature world, humankind subsequently tended to forget about this biosphere again and to lose sight of it once more, pushing the microbes beneath the surface, so to speak. Time and again, microbes had to be rediscovered. After the days of Van Leeuwenhoek and Robert Hooke the interest in microbiology declined and for many decades only a few people studied bacteria.[39] Until Louis Pasteur and Robert Koch ushered in the ‘golden era’ of microbiology (the second half of the 19th century), interest in and awareness of the importance of microbes had more or less come to a standstill. Microbes were virtually forgotten, even by the scientists themselves, until Pasteur and Koch rediscovered their existence. It took the “crusading spirit of Pasteur, his zeal and skill as a polemicist, to drag the microbes out of the obscurity into which they had passed once more”.[40] He brought them back to life again. The era of Pasteur and Koch was a moment of Renaissance and rediscovery. Microbes are recovered and subsequently forgotten, time and again.

Yet, Pasteur and Koch allowed microbes to emerge *in a certain manner,* namely predominantly as a threat looming from the outside. Microbes were seen as entities that indicated their invading presence notably through symptoms of disease. Likewise, for Freud, their psychic counterpart, in the form of the unconscious, was a kind of looming Id, a hidden entity that engulfed people’s minds and hampered their effectiveness.

Contemporary genomics-based microbiology, however, allows microbes to emerge in a completely different and much more positive light, namely as a symbiotic source of energy. Thus, insofar as our microbiome can be regarded as our “hidden realm”, as our “unconscious”, we now discern that we should not think of it in terms of the 19th century “threatening” unconscious, as framed in the writings of Freud, but rather in terms of a “productive” unconscious, as is done in the writings of authors such as Gilles Deleuze and Felix Guattari who reframed psychoanalysis during the final decades of the 20th century. Although Freud can be credited with discovering the unconscious, just as Pasteur and Koch can be credited with (re)discovering microbial life, he more or less lost touch with it again, these authors argue. For them, the unconscious is not something which is blocking or hindering us, interfering with our societal or erotic performance. Rather, they reframe it in terms of productivity. “It (the unconscious) functions, it is basically productive, and on an molecular level.”[41]

Our bodies are pervaded by the molecular productivity of desire. We are biochemical factories and assemblies of organic machines. Whereas according to Freud our unconscious activities and desires must be restrained by the prohibitions of society, preventing us from satisfying our desire and resulting in a sense of guilt and chronic malaise, Deleuze and Guattari rather argue that this scheme basically reflects the 19th century Victorian objective of domesticating one's desire, the anxious striving towards taming nature, notably the unconscious sides of it. Human life thus became a kind of anthropocentric stage where triangular (oedipal) relationships between humans as *individuals* were played out. What tended to be forgotten, left out of the picture, was the world of labour and productivity, the transformation and circulation of matter, both on the societal level and on the level of bodily existence. According to Deleuze and Guattari, the unconscious must now be seen as a biochemical factory rather than as a stage setting and should be spoken of in terms of productivity and biochemistry rather than in terms of (neurotic and suffocating) triangular relationships. There is continuity, rather than discontinuity, between libido as a molecular and biochemical phenomenon on the one hand and the world of labour, art and scientific research on the other. Instead of a domesticating approach of unconscious desire, Deleuze and Guattari stress the productive and dynamic nature of bodies, organs, cells, amino acids, genes and – last but not least - of microbes, the silent labourers in the factory of human life.

Their understanding of the unconscious was explicitly inspired by the new life sciences emerging in the latter half of the 20th century, exemplified by authors such as Jacques Monod. When Vesalius opened up the fabric of human anatomy, microbes were still subliminal entities. In the course of the 20th century, however, we became aware of the plethora of processes in which they are intimately involved. They are the "masses", the millions of anonymous workers who are operating our molecular machines. Microbes are the unconscious at work, as a part of nature in the sense of *natura naturans*, producing human activity and human desire. Modern genetics and biochemistry, rather than Freudian reinterpretations of ancient Greek myths, allow us to come to terms with it.

The quotation taken from the letters of Vincent van Gogh, cited at the beginning of this section, may be seen as an articulation of this view. Van Gogh was pondering over his brain and wanted to find out what was wrong with it. Conversations with psychiatrists served as an important source of inspiration. Whereas nowadays psychic phenomena are explained in terms of the functioning or misfunctioning of neurotransmitters such as dopamine, in those days pathological moods were attributed to the presence of microbes in human brains. In the era of Pasteur and Koch, diffuse ideas concerning the microbial unconscious were beginning to spread. At a certain point they reached the letter-writing artist in his secluded psychiatric ward. For him, the insight that various phenomena of human life are the outcome of microbial processes, and that microbes are involved in our basic physiology and psychology, was, it seems, a liberating one. Apparently, his aberrant moods involved the work of microbes. What for Van Gogh was something of an artistic intuition can nowadays in the microbial genomics era be articulated and explored much more explicitly in biochemical language. How do these new views of life allow us to reformulate our position in the living world, notably in terms of our responsibilities towards other living beings?

New covenant with nature?

With just 1,600 giant pandas estimated to remain in the wild, Chinese scientists have led the task of immortalizing the charismatic critter's 2.25 billion base pairs of DNA… Although it is unlikely to have any significant effect on conservation, the work is a proof-of-principle for next-generation sequencing technologies… Indeed, one tactic for researchers hoping to win funding may be to sequence similarly patriotic symbols."[42]

As genomics reveals and underscores our chronic and fundamental dependence on other living beings, it may have a significant impact on our relationship with the rest of nature. We could call this the "cultural" impact of genomics. The "genomics world view" may give rise to a more humble vision of ourselves, fostering a more sustainable attitude towards life on earth. But of course the very opposite may also be the case, in the sense that genomics provides us with novel opportunities to adjust our natural environment to our benefits and interests. The moral message of this paper is *not* that human existence submerges into the grand mire of life, but rather provides us – *in principle*, that is - with a broader understanding of the often detrimental impact we are having on the ecosystems that surround us. Whereas genomics entails a decentring of the human in genetic and biomolecular terms, our uniqueness as moral agents who are explicitly challenged to consider the consequences of our way of life is basically reaffirmed. On the basis of genomics information, we may develop an even more detailed view of our history and place in the world and this could strengthen the awareness of our responsibilities vis-à-vis other life forms.

Genomics libraries may help us to deepen our understanding of processes of extinction and to improve our programmes directed towards ecosystem management and population management of endangered species. At the same time, this may strengthen a rather "bureaucratic" view of nature, governing nature on the basis of assembled genomes rather than on the basis of real-life interactions and first-hand knowledge. Knowledge is power. This was already true for the practical knowledge of the first domesticators, but it is also true for contemporary genomics-based conservation programmes. Thus, although we cannot meaningfully think about the implications of genomics for humans without taking the environment into account, the mapping through genomics research of the environmental zone brings to the fore the impacts of our disturbances as well. Genomics challenges us to think about *ourselves* from the perspective of an ecocentric anthropology, and about our *environment* from the perspective of an anthropocentric ecology.

On top of the archetypal village, new types of high tech Arks have emerged more recently, such as DNA banks as informational Arks: storehouses of genomes, DNA collections and barcodes, complemented by tissue samples, cell lines, seeds and various other bio-objects. Thus, not life as such, but rather its genetic 'quintessence' is stored and preserved. Assembling the genomes of more than 4,000 species into our digital Ark, some of which are on the verge of extinction, does little to change the fact that concrete contributions to sustainability and biodiversity are limited as yet. As exemplified by the quote at the beginning of this section, for a species such as the panda to have its genome sequenced does not significantly enhance its prospects for survival. This rather depends on a complex constellation of practices, including deforestation. Also, the focus on a single species would be at odds with the ecocentric perspective engendered by genomics. Survival is a multiple-species phenomenon. Basically, it is an ecosystem that survives.

Most concrete examples of the contribution of genomics to biodiversity and sustainability come from bioremediation. Armies of microbes with optimal genomes for performing certain ecosystem services are injected into soil or water for ecosystem restoration and ecosystem management. Microorganisms can aid environmental restoration by oxidising, binding, immobilising, volatilising or otherwise transforming contaminants.[43] Microbial remediation is generally regarded as more nature-friendly than non-biological options. Yet once again, an ecocentric perspective is pivotal. What may work in particular environments may not work at other sites. Moreover, new possibilities for bioremediation may have detrimental side-effects as well. It may encourage new projects and experiments in the realm of geo-engineering and hazardous extractions of resources, hoping our new microbial allies will restore the damage afterwards. But what will inserted microbial invaders do to existing ecosystems? In other words, the genomics of particular microbial biota has to be combined with ecogenomics: the development of a broader, more comprehensive view of the functionings and vulnerabilities of real-life ecosystems instead of purely utilitarian uses of genomics. Most advances in genomics-based bioremediation are still experimental studies in vitro. Given the astounding complexities of ecosystems – and there is a tendency to underestimate the complexities and vulnerabilities of the ecosystems involved - genomics-based bioremediation is still in its experimental or trial-and-error stage. Here again, the promise of genomic technology remains something of the future rather than a present-day reality.

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[1] Radboud University Nijmegen – Faculty of Science; Institute for Science, Innovation & Society; Department of Philosophy & Science Studies - Centre for Society & Genomics. h.zwart@science.ru.nl

[2] "The race to complete the first human genome sequence had everything a story needs to keep its audience enthralled – right down to a neck-and-neck sprint for the finish by two fierce rivals. In the end, the result was basically a tie". Editorial: The Human Genome at Ten. *Nature* 1 April 2010; 464 (7289): 649-650; Cf. H. Zwart. The Adoration of a Map. Reflections on a Genome Metaphor. *Genomics, Society & Policy* 2009*;* 5 (3): 29-43.

[3] http://www.genome.gov/10001356

[4] The Human Genome at Ten, *Nature* special issue; notably: F. Collins. Has the revolution arrived? *Nature* 1 April 2010; 464 (7289): 674-675

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[7] S. Parry and J. Dupré. 2010. Introducing Nature After the Genome. In Parry and Dupré ibid: 3-14.

[8] "Wir lachen schon, wenn wir 'Mensch und Welt' nebeneinandergestellt finden, getrennt durch die sublime Anmaßung des Wörtchens 'und'!" Nietzsche, *Die Fröhliche Wissenschaft* V, 346. [We laugh as soon as we encounter the juxtaposition of 'man *and* world', separated by the sublime presumption of the little word 'and'." F. Nietzsche. 1887/1974 *The Gay Science [Die fröhliche Wissenschaft]*. Transl. W. Kaufmann. New York: Vintage Books.

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[12] http://www.genome.gov/10001356. This phrase has subsequently been cited in a series of strategic documents, such as the Position Papers of the Standing committee for the Humanities and of the Standing Committee for the Social Sciences, entitled *Vital Questions.*

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