Emergence and Sustainment of Humankind on Earth: The Categorical Imperative

Ulrich Lüttge and Fabio Rubio Scarano

Abstract This essay argues that the "sustainment" of humankind on Earth will require short-term ruptural transformation of rooted individual and societal attitudes and ethics into a new categorical imperative. We establish a difference between "sustainment" of humankind and "sustainability". Sustainment is the process of dynamic state of maintenance of conditions without destruction of prerequisite requirements for well and healthy performance of organisms and systems of life emergent on Earth (i.e. ecological stability). Sustainability is as a moral value related to intergenerational justice, and therefore a societal goal or utopia, backed up by specific science and policy tools. To address sustainment of humankind on Earth, we first provide a brief history on origins and extinction processes, then we discuss existing problems and challenges for sustainment, and we finally provide a reflection on plausible futures with humankind sustained. We aimed to balance out futures perspectives such as those related to the Gaia hypothesis, to the evolution of consciousness, and to trans-humanism, as constrained by the short time left for humankind to halt or reverse the trajectory of planetary degradation it imposed on the planet.

Introduction: Confrontation of Tribal Attitudes by Global Ethics

How optimistic can one be regarding the sustainment of humankind on Earth? The answer to this question depends on understanding the extent to which humankind can replace evolved group and tribal attitudes by global ethics. On the one hand, prospects of self-organization, self-regulation, self-repair and regeneration of nature give reason for some optimism (Lüttge et al. 2013; Scarano and Garbin 2013). On the other hand, the way humankind is currently exploiting the biosphere and Gaia, and

U. Lüttge (✉)
Darmstadt University of Technology, Darmstadt, Germany
e-mail: luettge@bio.tu-darmstadt.de

F. R. Scarano
Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil
e-mail: fscarano@biologia.ufrj.br

L. H. Wegner and U. Lüttge (eds.), *Emergence and Modularity in Life Sciences*,
https://doi.org/10.1007/978-3-030-06128-9_11

the short time span available for behaviour change before an even more acute climate crisis (see also Scarano 2019, in this book), leads to an increasingly pessimistic tone of a majority of scientific authors in environmentalism, ecology, philosophy, social sciences and other fields.

The glaciologist Jean Jouzel believes that in view of the climate problem humankind shall make a giant jump changing attitude and behaviour in its relation to Gaia (Robert and Jouzel 2015). With his book "The Future of Life", Edward O. Wilson presents a fascinating journey through the originally so perfectly functioning ecosystems of the Earth. He describes many examples of the disastrous exploitations performed by man all over the globe and views all the grave problems. He winds up with a sad testament that we leave to the next generations with the statement of how the world will look like at the end of the twenty-first century if the current developments continue. It is a solitary world with artificial landscapes and deserted bush-land instead of rainforests, and it is recurring to genetically engineered organisms for constructing new ecosystems if that is feasible at all (Wilson 2002, 2004, p. 104). Nevertheless, E. O. Wilson remains semi-optimistic in his book. He thinks that there are still many resources on Earth and that the human spirit and inventiveness with the potency of science and technology can manage to sustain our planet undamaged and maintain the wonderful richness of life. If humankind only wishes and is forced to do so, it could make the appropriate decisions (Wilson 2002, 2004, pp. 195, 222).

Others are outright pessimistic about humankind on Earth. Lovelock (2009) assumes that humankind may survive the sixth extinction wave with a greatly reduced population size of a few hundred million people. Many scientists think that life will persist but without man. Alan Weisman is very pessimistic. He develops a series of scenarios of how the planet may develop and look like after an assumed sudden disappearance of man. Even after a few days without pumping, the entire metro of New York shall be flooded. After one year, plants will grow on roads. Within 50–100 years, buildings will break down. In 300 years, cities along coastlines will be washed away, and in 500 years, woods will overgrow everything with remnants of aluminium and stainless steel. Humankind will fade away, while there remains optimism for life as such. Although humankind will take many species away with it, life will continue on Earth with new evolution possibly beginning from bacteria. Life as such in general has a great potential of regeneration power (Weisman 2007a, b). Perhaps elsewhere in the universe, consciousness and empathy may be sustained, but we shall not know.

This chapter aims to balance out optimistic and pessimistic perspectives into a realistic analysis of what it would take to sustain humankind on Earth, while faced by ecological, socio-economic and sociopolitical menaces and practices. Such an analysis required a broad review of literature, across time, geographical space, and disciplines and fields of knowledge. In view of the ongoing interference of humankind with unscrupulous exploitation of the environment, our central argument is that the sustainment of humankind on Earth will require short-term breaking transformation of rooted individual and societal attitude and ethics into a new categorical imperative. We address specifically two types of questions regarding sustainment. First, at which levels must sustainment be achieved? The most critical levels appear to be social levels, as the political and the economic levels, and in a strict biological sense the ecological level (in alignment with the tripod of sustainability—social, economic and environmental). Second, what can be sustained? Will this be specific forms and specific integrated systems of life? Or will this be just life as such with new forms evolving from survivors of extinction? We also speculate on plausible futures depending on whether or not humankind is successful in producing such deep transformations.

Sustainment and Sustainability: Definitions

We establish a difference between "sustainability" and "sustainment". Sustainability is a concept and a moral value, which arguably emerged out of the need for an intergenerational ethics, both human and non-human, in many ways similar to Hans Jonas' (1979) "ethics of responsibility" (Jonas 2003). However, sustainability has become an inflated fashionable term frequently used and often not much reflected for marking demands and challenges in very many respects. The emergence of sustainability in multiple branches—science, politics, technology, moral value—is explored in detail in other chapters of this book, i.e. in relation to the emergence of biomimetic products (Speck and Speck 2019, this book), and by Scarano (2019, this book) who actually argues that sustainability is currently a new utopia. While sustainability is a concept, a value, and possibly a new utopia, we propose "sustainment" as the process whereby humankind might come to realize its own permanence in the planet and that of life as we know it.

Sustainability fits the equation social justice + environmental balance + economic prosperity. Applying it to life of organisms, we must be aware of the fact that all living organisms are open systems through which a steady flow of matter and energy is occurring. Organisms are not in thermodynamic steady-state equilibrium. They are in dynamic pseudo-steady state. Similarly, all systems of life built up from organisms are dynamic open systems. Thus, we can talk about stability where the dynamics of pseudo-steady states are maintained in space and time (Souza and Lüttge 2015; for the debate, see also chapter of Schmidt 2019, this volume). With this thought, here we apply the term "sustainment" meaning the process of dynamic state of maintenance of conditions without destruction of prerequisite requirements for well and healthy performance of organisms and systems of life on Earth.

Origins and Extinctions

The question of sustainment of humankind is closely related to the question of life itself, because humankind is part of life on our planet. We have no clear knowledge about the origin of our universe. We have no access to physical laws beyond the

Planck time of 5.39×10^{-44} s. We can observe the dynamics of the universe, but regarding its origin, the big bang remains a hypothesis and other alternatives are also discussed. Similarly, we have no knowledge about the origin of life. In his philosophy of biology, Karl Popper notes that life in the universe is a cosmological emergence, and he suspects that even on Earth it must have originated multiple times. The major problem with that is if it is adapted to the environment where it arises; the adaptation of the new organism to its environment is one of the major problems with the question of the origin of life (Niemann 2013; Popper 2013). The theory of evolution explains the uncovering and development of life over the last 4×10^9 years but not its origin. Therefore, we also have no distinct definition of life. Life remains a philosophical and not a scientific category (Nachtigall 2010). We can only scientifically describe life by its relevant properties and listing its most outstanding features that have evolved gradually. Life emerged from the integration of building blocks or modules (Bolker 2000; Lüttge 2012).

The oldest fossils of organisms that we know are calcareous crusts of biofilms of prokaryotic cyanobacteria so-called stromatolites from pre-Cambrian times. Stromatolites found in Australia date back 3.5×10^9 years and in South-Africa 3.4×10^9 years (Allwood and Brown 2004). Fossils of multi-cellular organisms discovered in Africa are 2.1×10^9 years old (El Albani et al. 2010; Donoghue and Antcliffe 2010). However, then later followed an almost instantaneous outburst of complex multi-cellular life as documented by the fossils of the Ediacara fauna $580–540 \times 10^6$ years ago (Grazhdankin 2014), and subsequently metazoan life showed a sudden proliferation in the so-called Cambrian explosion $535–525 \times 10^6$ years ago (Gould 1989). We do not understand why evolution occurred in such outbursts. Perhaps it is an artefact due to the absence of fossilization of earlier forms. On the other hand, possibly sudden self-organization of modules may have really led to the brisk emergence of higher developed metazoan life.

For a reflection on the dynamics of sustainment and extinction of life or of particular forms of life, the Ediacara fauna gives us an early lesson. From the fossils found in the Ediacara hills of the Flinders ranges in Southern Australia which gave the name to this fauna, but also worldwide, e.g. in Newfoundland, Canada, in Russia, in Namibia, Brazil and China, we know about 100–120 species (Grazhdankin 2014). They had tubular structures frequently with a fern-frond like organization and were several centimetres up to almost 2 m large. A lot of them were non-mobile and anchored in the ocean floor; others had creeping mobility. They were feeding by osmotrophically absorbing organic molecules from the ocean water or by foraging mats of micro-organisms like the stromatolites. Most of the investigators of this fauna regard these organisms as the first multi-cellular metazoans. A minority view is that they might have been fungi, lichens or even just giant protists (Retallack 1994; Peterson et al. 2003; Seilacher et al. 2003). On the botanical side, we can assume that certainly also multi-cellular algae were living at the time. After only 40 million years, there was a mass extinction of this fauna. Its species were not surviving into the Cambrian. As one reason, it is assumed that they were outcompeted by the new Cambrian fauna the species of which possibly used the environment to the effect that living conditions of the Ediacaran organisms were destroyed.

Fossils of the Cambrian explosion were specifically found in the Burgess Shale of the Rocky Mountains in British Columbia, Canada. They comprise an enormous diversity of anatomical structures and building principles. We know more than 20 different forms. Among them were the first chorda animals, i.e. chordates, and thus, precursors of the vertebrates. *Pikaia gracilens* was 5 cm large and had a backbone cord. It was the only one of the organisms of the Cambrian explosion which survived their extinction. Without it, vertebrates would not have evolved including humankind which would not have appeared in this form on the planet (Gould 1989).

Thus, we know from the fate of these early faunas that life of individual species is a coming and going. Species are appearing and dying out again. During the entire history of life on Earth of more than 3.5×10^9 years, 4×10^9 species have lived and the survivals of those to date are 1%. Extinction comes in smaller and larger waves. Five major extinction waves (and there are claims for a sixth wave, which we discuss later) of higher organized species occurred at the transitions between geological ages (Courtillot 1995; Butterfield 2007; Alroy 2008; Melott and Bambach 2011; Matyssek and Lüttge 2013):

- 444 million years ago at the transition from the Ordovician to the Silurian not so long after the Cambrian explosion, i.e. less than 100 million years later.
- 364 million years ago at the transition from the Devonian to the Carbonic.
- 251 million years ago at the transition from the Permian to the Triassic 90 when 95% of all existing species were extinct. This included the well-known trilobites.
- 206 million years ago at the transition from the Triassic to the Jurassic. This extinction was associated with the appearance of the dinosaurs.
- 65 million years ago at the transition from the Cretaceous to the Tertiary when 75% of all existing species were extinct. This extinction included the ammonites, but remarkably also the dinosaurs after their geologically short time of 140 million years which were so dominant at their times. This led to the tremendous proliferation of the mammals on Earth.

Extinction waves were due to changes of environmental conditions caused by volcanism and meteorites. They were always followed by very rapid evolution. They created room for the selection of new forms of life such as in the above enumeration the dinosaurs and after extinction of the dinosaurs the mammals, which then included man. The extinction waves were global events.

As a consequence of the exploitation of the biosphere by man (with all the problems discussed next), some argue that we are presently experiencing a sixth extinction wave which is now anthropogenic, self-made by humankind, and therefore substantially different from the previous five waves. Habitats are altered or destroyed so that they become uninhabitable for many species which are dying out at an accelerated rate. Will humankind vanish with it?

As we have seen above, 99% of all species that have occurred on our planet have been subject again to extinction. All species are threatened by dying out. This also applies to man. The evolutionary history of hominides is more than 7 million years long. However, our own genus *Homo* with *Homo rudolfensis* did not appear earlier than 2×10^6 years ago and species of *Homo* lived on Earth at times as follows (see Matyssek and Lüttge 2013):

- *Homo rudolfensis* 1.9 million years back,
- *Homo habilis* 1.9–1.44 million years back,
- *Homo erectus* 1.9–0.5 million years back,
- *Homo heidelbergensis* 0.8–0.3 million years back,
- *Homo neanderthalensis* 0.2–0.03 million years ago,
- *Homo sapiens* 0.2 million years back to present.

All of them except us, *Homo sapiens*, are extinct. Species of *Homo* clearly were not exempt from the destiny of extinction. Our own species is the only survivor to date, more than 60 million years after the disappearance of the dinosaurs on Earth. The question is if humankind is not taking itself along with the current anthropogenic sixth wave of major extinctions while only once again life as such and with other forms is sustained?

Problems

The pressures behind what is possibly a sixth wave of extinction largely derive from a process known as "The Great Acceleration", which takes place since the 1950s and means that Earth System indicators show shifts beyond the range of variability of the Holocene, all driven by human activities. Thus, humanity has transgressed planetary boundaries especially as regards climate change and biosphere integrity (Steffen et al. 2015; see also Scarano 2019, in this book). In this section, we examine some key problems, such as overpopulation, pollution, land-use change, invasive species, sea-level rise and food insecurity.

Overpopulation

Overpopulation of the planet by the dominating mammal *Homo sapiens* is a primary problem. All the other problems are secondary consequences of the activities of life of humankind that has been and continues growing too much. Human population sizes can be listed as follows:

- in the year 1700 6×10^8,
- in the year 2014 7×10^9, of which 1×10^9 are suffering from hunger, in Sub-Saharan Africa 30% of the population,
- extrapolation for the year 2050:
  - at current fecundity and propagation 12.8×10^9,
  - prognosis by the UN in 2014 9.6×10^9, provided that family planning continues and is successful, then stagnation or slight reduction.

How can the phase of stagnation be reached? In a humane way by family planning? Or with dreadful horrifying humane tragedies some of which the globe is already experiencing to a certain extent, i.e. epidemics, hunger, wars and natural catastrophes, where in critical regions natural evil is multiplied by local overpopulation. If stagnation is not reached, would it still be possible to reduce socio-economic inequalities and their consequences such as hunger?

Pollution

Pollutants are deteriorating all major parts of the biosphere's environments: air and the atmosphere, soils and the lithosphere, water and the hydrosphere. Major pollutants are gaseous ones (Matyssek et al. 2013a) because they all are the so-called greenhouse gas molecules contributing to global warming which even a wide public is now recognizing to be one of the foremost menaces:

- Carbon dioxide (CO_2) predominantly comes from fossil sources of energy.
- Methane (CH_4) comes from cattle farming but is also liberated from wet fields of rice; it develops with new energy sources, such as fracking for gas and harvesting marine methane clathrates.
- Nitrogen oxide (N_2O) develops in nitrogen-fertilized crops and is part of one of the vicious cycles of intensive agriculture needed to feed a growing human population of the globe.
- Ozone (O_3) in the troposphere is a secondary pollutant formed in atmospheric chemistry from emissions of traffic (Matyssek et al. 2013a, b), industry and agriculture, besides acting as a greenhouse gas it exerts oxidative stress.

Pollutants of water and soil are heavy metals and all kinds of drugs and chemicals in human waste. Among the major ones increasingly polluting the oceans is plastic not only in its macroscopic form but broken down to the small millimetre-sized building blocks of plastic and found as pellets and also further to microscopic particles (Weisman 2007a, b) which via food chains also accumulate in fish, one of the prominent sources of food of humankind. Agrochemicals include pesticides, fertilizers, plant-growth regulators, repellents and attractants, which are added to the environment to boost agricultural productivity. They are the most common pollutants in 20% of the Earth's land surface (Sanchez-Bayo and Tennekes 2015).

Land-Use Change

The recent special report on Land Degradation of the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES 2018) informs that by 2014, more than 1.5 billion hectares of natural ecosystems had been converted to croplands. Although agricultural expansion is the main driver of conversion of natural habitats, cities cover

2% of the planet surface use 75% of its natural resources (Puppim de Oliveira et al. 2011). Less than 25% of the Earth's land surface has escaped substantial impacts of human activity—and by 2050, the IPBES experts estimate this will have fallen to less than 10% (IPBES 2018). This has created 35 biodiversity hot spots in the planet, i.e. areas with high species diversity, high levels of endemisms, but highly threatened (Myers et al. 2000; Zachos and Habel 2011). Such degradation impacts the well-being of at least 3.2 billion people and has immediate links with climate change (IPBES 2018).

Invasive Species

Invasive species develop into destructive pests. Before the times of man's interference migration of organisms across oceans was difficult and very limited. Rare arrivals could evolve, and a characteristic endemic flora and fauna could develop, for example, on young marine volcanic islands such as Galapagos and Hawaii. However, under anthropogenic influence, wittingly for agriculture and husbandry and unwittingly as carried on passengers, plants and animals were and are increasingly rapidly distributed traverse the oceans. Where they arrive, the foreign species can propagate rapidly with numerous adverse effects, for example:

- destruction of native habitats,
- destruction of native flora and fauna by replacement of native species,
- interference by a growing human population as consequence of agriculture and husbandry with pollution, land use and overexploitation (Wilson 2002, 2004, p. 74).

In Tahiti, the tree species *Miconia calvescens* DC. (Melastomataceae), primarily introduced for its ornamental appeal and originally native to tropical areas of South America, is now called "green cancer". It forms dense woods up to 15 m high and covers two-thirds of the entire vegetation of the island. It also threatens the tropical forests of Hawaii (Wilson 2002, 2004, p. 100). Thus, similarly to having talked about "stem species" for renewal and repair (Scarano and Garbin 2013; see also section on *Gaia*, next), we can here also speak of "cancer-species" for destruction.

Sea-Level Rise

By heating up and by dilution of the ocean waters but particularly by melting of glaciers of mountains, of Greenland and of the West Antarctic, the level of the oceans is continuously rising, i.e. currently about 3 mm per year. However, with different global warming scenarios, more dramatic increases are predicted, i.e. 3 m up to 2300 or even 7 m if Greenland and the West Antarctic are melting completely (Robert and

Jouzel 2015; Hansen et al. 2016). This will take away extended areas of land now inhabited by large human populations.

Food Insecurity

Food insecurity results from the primary problem of overpopulation, particularly considering the persistence of inequality and inefficiency in resource distribution. For instance, 30% or more of the food produced every year is lost or wasted (FAO 2011).

Regarding the size of the human population predicted by 2050, we would need to double the productivity of highly developed agriculture. This is one of the major current challenges of humankind (Lüttge 2013). Anthropogenic management of nature in agriculture and forestry also needs to become sustainable to stop loss of arable land (Lüttge 2016). On the one side, there are promising advances of research; on the other side, limitations are building up. One of them is increasing pollution. This causes tremendous reductions of productivity. Considering ozone alone, for example, which in India reduces productivity of wheat by 2–59% and of rice by 7–55% (Pandey et al. 2013), we can see that stopping just this one pollution we could well advance towards reaching the aim of necessary increased food supply. Another limitation is vanishing resources exemplified as follows.

Arable land and soil: At present 1.4×10^9 ha or 17% is irrigated and provides 30–40% of global food production. Losses are advancing due to salinization by 200,000 ha/year, erosion, degradation, sealing and urbanization by 1,000,000 ha/year.

Water: Water is one of the most critical resources for agriculture. It is already an issue of international conflicts, and it is predicted that wars may arise over it. According to the global education project (www.theglobaleducationproject.org/earth/fresh-water.php), the total global water amounts to $1\,400 \times 10^6$ km^3. Most of it is saline, largely in the oceans. Freshwater is 35×10^6 km^3. Much of it is in glaciers, snow and ice. The major reserve for human use including agriculture is fresh ground water with 10.5×10^6 km^3. It is threatened by overexploitation locally. Other sources are comparatively minimal: rain 0.1, lakes 0.09, soil 0.02 and rivers 0.002×10^6 km^3.

Nutrients: The major mineral nutrients for agriculture are nitrogen and phosphorus. Nitrogen is abundant as di-nitrogen, N_2, which makes up 80% of the planet's atmosphere. It can be reduced technically to ammonia to become available as fertilizer in the Haber–Bosch process

$$N_2 + 3H_2 \rightarrow 2NH_3.$$

It has a very high demand of energy, i.e. currently 1.4% of the world's energy consumption, as it needs high pressure (250–350 bar) and temperature (500–600 °C) and uses hydrogen, H_2, which is an important energy carrier. Currently, 95% of the phosphorus mined is for agriculture. It is estimated that the more readily exploitable reserves are depleted in 100–130 years. Exploration of new reserves will have a high energy demand. Efficient techniques of phosphorus recycling from life stock and human faces need to be developed.

Vanishing agricultural yield potential: During agricultural history yield increased considerably. For one grain of wheat, for example in antiquity 3 grains could be harvested, in the middle ages 6 grains and currently 50 grains. At the end of the twentieth century, in the decade 1987–1997, the development of yield still advanced. The global per-area production of wheat and rice increased by 20% and 17%, respectively. This has come to an end. In the following decade 1997–2007 wheat declined by 1% and rice only grew by 2%. The reasons are manifold, but pollution is a major cause as seen by the example of ozone above.

Gaia, Biosphere and the Holobiont

Regarding the problems listed and the pressures on the biosphere, it is relevant to take a brief but closer look at the Gaia hypothesis as originally posed by Lovelock (1979). Actually, viewing the entirety of life on the planet, we can look at three conceptions: Gaia, biosphere and holobiont. Named after Gaia, the goddess of Earth of the ancient Greek mythology, Lovelock (1979) has defined his scientific concept of Gaia as "complex entity involving the Earth's biosphere, atmosphere, oceans and soil". We would rather comprise with biosphere all the life on our planet, i.e. all life harboured by lithosphere, hydrosphere and atmosphere at the surface of the Earth. In this way, Gaia and biosphere can be considered synonyms (Matyssek and Lüttge 2013).

A holobiont is *a host organism (plant or animal) in interaction with all associated micro-organisms as an entity for selection in evolution*. These interactions may be symbiotic or parasitic of organisms closely living together. In this way, man is also a holobiont with carrying a good kilogram of innumerable bacteria with him with 100–150 folds the number of genes than in his own genome. When we extend this definition to organisms in general and if we stress interaction, we arrive at a definition of *organism in interaction with all associated organisms as an entity for selection in evolution*. This opens the application of the concept of holobiont to an enormous range of scaling levels. Habitats, biotopes, ecosystems and biomes are all highly integrated holobionts (Lüttge 2012; Matyssek and Lüttge 2013). For a higher scaling level, this may be illustrated by looking at forests which are entirely integrated by interconnecting the trees with the fungal hyphae of their mycorrhizae in the soil (Mathesius and Watt 2010). Man is not only biologically part of and dependent on Gaia/biosphere, but from his cultural position, he also influences it. With the extension to man's cultural means of interaction and globalization, the entire humankind as an abstraction may be considered as a holobiont.

The entire biosphere is a holobiont, and Gaia is a supra-organism, the ultimate case of a holobiont (Matyssek and Lüttge 2013; zu Castell et al. 2019, in this book). The global extinction waves described above reflect instabilities (Schmidt 2019, in this book) during geological times. Considering life as such, however, these instabilities mean dynamical stability with pseudo-steady states. Life as such remained stable after extensive disturbances of the biosphere. It was maintained, with new evolution leading to emergence of new forms. When the pressure of selection in a wider sense of evolution is not only the fight for resources but the struggle for fitness under varying ambient conditions in general, we can see that with this a system like Gaia as a holobiont is also subject to evolution even when there is no direct akin competitor.

The sustainability of Gaia is of primary relevance for the sustainment of humankind. In his initial approach to the concept of Gaia, Lovelock (1979) was very optimistic considering Gaia as "a short-hand for the hypothesis [……] that the biosphere is a self-regulating entity with the capacity to keep our planet healthy by controlling the chemical and physical environment". Knowing about the massive extinctions, this has been early criticized. However, we need to understand that as keeping the planet healthy for sustaining life as such and not particular specific forms of life. Then, Lovelock's optimistic view of 1979 is appreciated even on the background of the five waves of massive extinction.

Indeed up to date we observe pioneer species of plants establishing themselves on extreme sites, starting successions and creating new habitats for living holobionts. We have called such pioneer species stem species in analogy to the stem cells of the self-assembly processes of development of individual organisms (Lüttge et al. 2013; Scarano and Garbin 2013). They are involved in self-organization and self-management of Gaia. They play the central role in regeneration of devastated land (Scarano et al. 1998; Lüttge et al. 2013; Scarano and Garbin 2013; Lüttge 2016). Is this sufficient, however, for sustaining humankind as part of the Earth, of Gaia?

Tribal and national egoisms appear to prevent the appropriate actions of humankind. Moreover, there are also many ideologies about things that appear desirable, but for sociopolitical action, it needs to be questioned if we can afford them under the threat of the apocalypse of not being able to feed 10 billion of people. Questionable among others are (1) sexual-moral ethics where they limit family planning, (2) resource demanding meat consumption although evolved as an omnivore man cannot completely abandon meat, (3) banning particular forms of energy, (4) growing so-called energy plants, (5) bio-agriculture although ecologically sustained practices of agroforestry management need to be developed, (6) hostility against genetically modified organisms (GMOs), which provide the most promising products of rapid enough breeding for meeting the world food challenge.

Thus, in his later book (Lovelock 2009), 30 years after the first proposal of the concept of self-stabilizing Gaia (Lovelock 1979), James Lovelock abandons his original optimistic view and speaks of "a final warning". His pessimistic prognosis is that if under the influence of humankind at the current pace the self-regulating potency of Gaia declines and is extinguished, the planet may be able to support only a few hundred million people, i.e. a population of the size as around the year 1700 in the culturally so productive and creative renaissance. The selection of these survivors from a much more than one order of magnitude larger population will be an apocalypse.

Idea of Humankind on Earth

Hans Jonas calls the existence of humankind on Earth the categorical imperative (Jonas 2003). He meant this particularly in relation to responsibility and Kantian ethics, which has enormous practical demands and consequences we will refer to later. The idea of humankind on Earth may be a categorical command: a matter of life and death. Therefore, it seems appropriate to discuss briefly at least the self-conceptions of man on Earth. Self-reflections of man are imbedded in mythology, in religions, in philosophy and in the arts with painting, sculpture, literature and music. Sustaining humankind, what is it that could be preserved?

Questioning the prospects of a sustainment of humankind for an extended future, it may be pertinent when for a start we just pick up two philosophical views on the higher advance of humankind and its progress. Both are views from two fundamentally different horizons and philosophical positions arriving at different outlooks and beliefs how humankind could advance. However, both share and exemplify the profound thinking of about how humankind could evolve freeing itself from the bonds of its current existence: (1) "Übermensch" (superman) of Friedrich Nietzsche (philosopher and writer; 1844–1900), and (2) the point omega or "noosphere", jointly elaborated in 1926 by Marie-Joseph Pierre Teilhard de Chardin (anthropological palaeontologist, philosopher and Jesuit theologian; 1881–1955), Vladimir Vernadsky (Ucranian geochemist; 1863–1945) and Edouard Le Roy (French philosopher and mathematician; 1870–1954).

In his philosophy, Nietzsche focuses on the dictum "god is dead" and man has to search himself for the sense of life. In his novel "Also sprach Zarathustra" (Nietzsche 1883–1885, 1891; "Thus spoke Zarathustra") and right at the beginning of it, he introduces the "Übermensch" striving for higher advance of humankind. Superman with exaltation of the will to dominate, the will for power, is unscrupulous and pitiless, and the present man can thus be overcome and renewed.

The biologist Konrad Lorenz thinks that with the evolution of culture, humankind has the potency of unforeseen higher development (Lorenz 1977, p. 304). By great contrast to Nietzsche, Teilhard de Chardin aims at a synthesis of Christian creation theology and science of evolution. He proposed an evolution of humankind to supreme consciousness (Teilhard de Chardin 1956, 1966). From the point of the "primordial atom" of George Henri Lemaître (1894–1966), which led to the big-bang hypothesis of the origin of our universe, Teilhard de Chardin imagines us to evolve in a spiritual unification from the individual egos towards an overego. This is the "point omega" of Teilhard de Chardin, the maximum state of complexity and consciousness. In other words of Teilhard de Chardin, this is an evolution of the biosphere to a noosphere, the sphere of thinking and the domain of consciousness.

It is not possible here to go at any depth, but the two extreme positions on a putative development and longevity of humankind may exemplify the wide scope of mythology, religion and philosophy evaluating the idea of man. Humankind is destructively exploiting the environment of the planet and covers areas of the globe with gruesome devilish wars of self-destruction. Yet man is also wonderfully creative generating divine productions in the arts, literature and music. In his book "A history of the world in 100 objects" Neil MacGregor has illustrated this. He has chosen 100 objects from the British Museum and used them to narrate the entire history of humankind (MacGregor 2010).

Plausible Futures?

Harari (2017) distinguishes three central programmes on the agenda of future humankind: immortality, bliss and divinity. Divinity, upgrading man to god, is somehow related to Nietzsche's superman, discussed above. Next, we will examine the evolution of consciousness and trans-humanism in the realms of bliss and immortality.

Consciousness

There are many drafts of definitions trying to help grasping and understanding consciousness. Consciousness means sense of individuality, personal identity and reflection of the ego on interior and exterior subjects. Consciousness may not have a material basis. It can be considered as an emergent phenomenon of the human brain with its 86×10^6 neurons and their ten to one hundred thousand times more numerous connections (Jaeger 2017, pp. 328–329). Thus, consciousness is a property of highly developed brains. Therefore, we often consider consciousness as a specific attribute of man. Exploring the sustainment of humankind, it appears interesting to ask for the existence of conscious life beyond humankind.

Evolution of consciousness was gradual (Heschl 2009). There are different degrees of consciousness developed by animals with complex brains, such as primates, dolphins and birds. Dolphins and elephants have been observed to show empathy, an attribute of consciousness, in the face of death of congeners (Heschl 2009, p. 225). The presence of man on Earth may have inhibited further evolution of consciousness in such lineages, but prospects of evolution may arise if man perishes (Morris 2003, 2008; Heschl 2009).

Simon Conway Morris relies very heavily on the phenomenon of convergence when he argues that evolution of man-like conscious beings is inevitable and will occur again if humankind disappears (Morris 2003, 2008). Biology is full of examples for convergence where under the pressure of environmental conditions selection has frequently led to independent evolution of particular structures and functions in phylogenetically remote lineages of life. A prominent example among animals is the eye with lens and retina that has evolved leading to an almost identical structure among worms (Alcipodia), mollusks and mammals including man (Morris 2003, 2008). In the plant kingdom convergence of stem succulence is often depicted, the evolution of which occurred independently in several plant families including the Cactaceae and the Euphorbiaceae. It is hard to distinguish stem succulents of the two families if it were not for the flowers and the presence of latex in the Euphorbiaceae, which is lacking in the Cactaceae. Convergence not only occurred in the two phylogenetically far separated families but also on remote continents with the Euphorbiaceae in the old world and the Cactaceae in the Americas. Even cognitive abilities related to culture show convergence. The songs of birds and humpback whales have remarkable similarities to human music, with respect to both the output of songs and the underlying neurology (Noad et al. 2000; Gray et al. 2001; Morris 2003, 2008). These few examples may be sufficient to illustrate the principle of convergence. There are numerous examples, and convergence is rather the rule than exception.

When the sixth extinction takes away higher forms of life, evolution may start again on Earth beginning with bacteria and produce convergence towards formation of complex brains. In the early stages of evolution on our planet 4×10^9 years ago, bacteria have overcome extreme conditions. They were under pressures of selection of a strength and severity far beyond the environmental problems of our days. This included UV radiation and radioactivity. There are still many extant so-called extremophilic bacteria and archaea which can endure extreme conditions of stress particularly of temperature, desiccation, ionizing and UV radiation. Polyextremophilic bacteria species are resistant to several of these stresses. Among them is *Deinococcus radiodurans* Brooks and Murray which can endure extremely high rates of radioactive radiation. It possesses very effective mechanisms of DNA repair and molecular tools for protecting proteins (Anderson et al. 1956; Mattimore and Battista 1996; Battista 1997; Cox and Battista 2005).

Extant extremophilic micro-organisms, bacteria and fungi, also live deep under the surface of the Earth's crust in the so-called SLiMEs, the acronym meaning **s**ubsurface **li**tho-autotrophic **m**icrobial **e**cosystems. The thermophilic organisms can reach depths as low as 4.2 km where temperatures of 110 °C prevail. In the deep biosphere far from the Earth's surface, they have an extremely hard existence in isolation and with scarcity of energy and nutrients. They obtain their energy from inorganic chemical reactions weathering the rocks and survive with very slow rates of reproduction (Frederikson and Onstott 1996; Fyfe 1996; Kerr 1997; Wilson 2002, 2004, pp. 28–29). Where ever there is some fluid and room, such life appears possible. With these organisms a new evolution could possibly start. The observations of SLiMEs on Earth also nourish expectations that life may even exist extraterrestrially on Mars or on Jupiter's moon Europa.

However, the remaining time on Earth is short for a second evolution of conscious life. The lifetime of our solar system is limited. Cosmic processes will lead to a development of the solar system where the solar radiation in about $500–1\,000 \times 10^6$ years will heat up the Earth so much that life becomes impossible. In 5×10^9 years, the sun will then develop to a red giant before it dies and it will definitely destroy Gaia. Our universe is 13.7×10^9 years old. The age of life on Earth is 4×10^9 years. That means if the remaining time for life is 1×10^9 years, 80% of its time have elapsed already and man is with it for 0.05% of the time.

There are billions of planets elsewhere in the universe which could carry life, and the probability that life evolved in space appears to be very large (Pajot and Mayor 2015). In the view of Morris' convergence (Morris 2003, 2008), this must include conscious life. Views like those of Morris that evolution towards highest degrees of complexity with consciousness is inevitable are already expressed by Teilhard de Chardin (1956, 1966, p. 35) with the idea of encephalization laying ground to evolution towards the fullness of the noosphere. With the huge distances and travel times of information involved, it appears just as improbable, however, that we ever learn about the life in remote space as it is probable that it may exist. With remarkable fantasy Gerhard Börner develops visions of the future of humankind in the universe. He argues that the cosmic times of 5×10^9 or at least $0.5–1 \times 10^9$ years available before the Earth is burnt out will be sufficient for an inventive and creative humankind to acquire approaches for escaping and settling elsewhere (Börner 2012). Despite apparent political advances in the dialogue between nations to foster sustainability (see historical description in Scarano 2019, this book), such far-reaching projections along cosmic dimensions of space and time contrast with the fact that the time available for actions is rather short for assuring sustainment of humankind. Allowance of delay is much shorter than the cosmic times of Börner by six to seven orders of magnitude, but this very short time is decisive.

Trans-humanism or Voluntary Human Extinction?

Immortality is a fundamental desire of man, a dream, a promise of religions. Scientifically, medicine is working on man's longevity. The number of centenarians is increasing. Trans-humanism goes far beyond that. It is a doctrine that originated in the 1980s in Los Angeles, USA, and currently develops to a new movement. Longevity of man could be 140 years up to 500 years and even infinitely (Weisman 2007a, b, p. 330; Thivent 2015; Alexandre 2015). For its realization medicine techniques are envisaged to be used. This would include artificial intelligence and implanting nano-robots onto the neurons in the human brain creating technically modified people at the interface of brain/machine (Alexandre 2015). Enormous ethical problems are related to this. Trans-humanism develops ideas for sustainment of the longevity of individuals. Will this, however, not destroy the integrity of humankind (Berger et al. 2015)? Will the dominance of robots really support the quality of individual life and associated social relations of communities? On the contrary, it is even well possible that learning machines and a reign of machines with trans-human intelligence will finish the era of humankind even more effectively than the sixth extinction wave (Jaeger 2017).

The death of death will not sustain humankind as we know it. Death is part of humanism. Life and death are intimately interwoven. The death of individuals and even of entire species is necessary for development and innovation. It is the basis of evolution. Selection is correlated with death. Decease and birth are dialectical contrasts where the synthesis is fresh advance. In death is life—life is in death. Inevitable death, is it sacrifice or reconciliation?

The movement of Voluntary Human Extinction (VHEMT) founded in 1991 by Les U. Knight goes in the opposite direction, i.e. rather for an immediate termination of humankind after the currently living generations than for an infinite extension (Weisman 2007a, b, p. 328; Omrod 2011). This could be achieved by renouncing on reproduction, e.g. by developing a virus which renders all human sperm cells ineffective. The idea of VHEMT is that such Voluntary Human Extinction would avoid terrifying painful mass dying of people and would make the remaining time for the present generations rather pleasant until their end. We find it contra-positive to all evolved innate driving forces of humankind, it is certainly not on agendas such as that noted by Harari (2017), and also it would violate the categorical imperative.

Conclusions

Sustainment of Gaia and with it of the existence of humankind on Earth demands that we develop ethics of responsibility for the future (Jonas 2003). Remarkably the book on the philosophy of the principle of responsibility with an ethics for the technological civilization by Hans Jonas and the book on the scientific concept of Gaia by Jim Lovelock first appeared in the same year 1979 (Jonas 2003; Lovelock 1979). It does not appear that they knew of each other. In 1979, Lovelock still looked at Gaia in a rather optimistic way. Jonas with remarkable clarity as early as 1979 already realized all the problems that have now become grave existential concerns for humankind.

Much of the traditional ethics are built on the categorical imperative expressed by Immanuel Kant in his practical philosophy ("Die Kritik der praktischen Vernunft", 1788) according to which one should always perform in a way that the maxim of one's will could equally serve as the principle for a general jurisdiction.[1] As explained by Jonas (2003), these ethics are addressed with directness towards individual persons at present time and specific location. This chapter describes our actual situation. Due to man's interactions with Gaia, completely new ethical challenges arise. Lovelock (1979) writes that "… if Gaia does exist, then we may find ourselves and all other living things to be parts and partners of a vast being …" (p. 1), but that man assumes he "… is the possessor of this planet; if not the owner …" while in contrast "… The Gaia hypothesis implies that the stable steady state of our planet includes man as a part of, or partner in, a very democratic entity" (p. 145). Jonas (2003) speaks of the imperative of the existence of humankind on Earth and that this is the only imperative which in his view really justifies the Kantian contention of "categorical" (pp. 91–92). The new ethics must not remain restricted to persons, time and location. We need global ethics directed towards groups and populations of people, to nations and the entire humankind including present and future generations, which are our descendants. We are responsible for people who are not living yet, whom we do not know yet and of whom we are not aware of how they shall live. Edward O. Wilson picks up the distinction between short-term and long-term values and that ethically

[1] "Handle so, dass die Maxime deines Willens zugleich als Prinzip einer allgemeinen Gesetzgebung gelten könnte".

we have the difficulty of not only having to look at the presence and the immediate short-term future but that with universal environmental ethics we need to incorporate the long-term future (Wilson 2002, 2004, pp. 65, 160). Some writers argue in a very Gaian vein that such responsibility must be extended for also embracing morally relevant interests of animals and even organisms like plants and fungi (Varner 1998; James 2015). When the existence of man on Earth is the very categorical imperative, this creates categorical responsibility.

The German theologian Hans Küng around 1990 initiated the project "world ethos" (Küng 1990; Küng and Kuschel 2001). It aims for peace by coordinating the common ethical commands expressed in the great world religions with various formulations all eventually coming close to Kant's categorical imperative. A huge meeting, the "world parliament of religions", took place in 1993 in Chicago. Foundations were established in Tübingen, Germany, and in other countries. Sustainment and protection of ecosystems were explicitly articulated with the request of an "ecological world ethos" (von Weizsäcker 2001). The recent re-emergence of millenary beliefs of indigenous peoples in the global south and the incorporation of some of their principles of living well with other people and with nature into national policies is another symptom of this ongoing trend (see Scarano 2019, in this book). Like Kantian ethics determining personal performance, world ethics is asking for political action. There needs to be intergenerational justice, and increasingly intragenerational justice seems a prerequisite for that. Can humankind abandon tribal egoisms inherited in evolution and still so much practiced in nationalisms (Diamond 1991)? Can it be " … that the destiny of humankind is to become tamed, so that fierce, destructive, and greedy forces of tribalism and nationalism are fused into a compulsive urge to belong to the commonwealth of all creatures which constitute Gaia" (Lovelock 1979, p. 148)? Could humankind, under a demand of ethical integrity, give up the exclusiveness of self-interest or will it remain intellectually and ethically overwhelmed (Jaeger 2017)?

References

Alexandre L (2015) Les transhumanistes ont gagné sans livrer bataille. La Recherche 504:89–90

Allwood A, Brown A (2004) Seeking the oldest evidence of life on Earth. Microbiol Aust 25:26–27

Alroy J (2008) Dynamics of organization and extinction in the marine fossil record. Proc Natl Acad Sci USA 105(Suppl. 1):11536–11542

Anderson AW, Nordan HC, Cain RF, Parrish G, Duggan D (1956) Studies on a radio-resistant micrococcus. I. Isolation, morphology, cultural characteristics, and resistance to gamma irradiation. Food Technol 10:575–577

Battista JR (1997) Against all odds: the survival strategies of *Deinococcus radiodurans*. Ann Rev Microbiol 51:203–224

Berger F, Lethimonnier F, Sigaux F (2015) Tuer la mort est un crime contre l'humanité. La Recherche 504:84–86

Bolker JA (2000) Modularity in development and why it matters to evo-devo. Am Zool 4:770–776

Börner G (2012) Die Entwicklung des Kosmos: Vom Urknall zum komplexen Universum. In: Hacker J, Hecker M (eds) Was ist Leben? Nova Acta Leopoldina 116/394:41–68. Halle

Butterfield NJ (2007) Macroevolution and macroecology through deep time. Paleontology 50:41–55
Courtillot V (1995) La vie en catastrophes – Du hasard dans l'évolution des espèces. Arthème Fayard, Pairs
Cox MM, Battista JR (2005) *Deinococcus radiodurans*—the consummate survivor. Nat Rev Microbiol 3:882–892
Diamond J (1991) The rise and fall of the third chimpanzee. Vintage, London
Donoghue PCJ, Antcliffe JB (2010) Early life: origins of multi-cellularity. Nature 466:41–42
El Albani A, Bengtson S, Canfield DE, Bekker A, Macchiarelli R, Mazurier A, Hammarlund E, Boulvais P, Dupuy J-J, Fontaine C, Fuersich FT, Gauthier-Lafaye F, Janvier P, Javaux E, Ossa F, Pierson-Wickmann A-C, Riboulleau A, Sardini P, Vachard D, Whitehouse M, Meunier A (2010) Large colonial organisms with coordinated growth in oxygenated environments 2.1 Gyr ago. Nature 466:100–104
FAO (2011) Global food losses and food waste—extent, causes and prevention. Food and Agriculture Organization, Rome
Frederikson JK, Onstott TC (1996) Leben im Tiefengestein. Spektrum der Wissenschaft 12(1996):66–71
Fyfe WS (1996) The biosphere is going deep. Science 273:448
Gould SJ (1989) Wonderful life: the Burgess shale and the nature of history. W. W. Norton, New York
Gray PM, Krause B, Atema J, Payne R, Krumhansl C, Baptista L (2001) The music of nature and the nature of music. Science 291:52–54
Grazhdankin D (2014) Patterns of evolution of the Ediacaran soft-bodied biota. J Palaeontol 88:269–283
Hansen J, Sato M, Hearty P, Ruedy R, Kelley M, Masson-Delmotte V, Russell G, Tselioudis G, Cao J, Rignot E, Velicogna I, Tormey B, Donovan B, Kandiano E, von Schuckmann K, Kharecha P, Legrande AN, Bauer M, Lo K-W (2016) Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2° global warming could be dangerous. Atmos Chem Phys 16:3761–3812
Harari YN (2017) Homo Deus. A brief history of tomorrow. Vintage, London
Heschl A (2009) Darwins Traum. Die Entstehung des menschlichen Bewusstseins. Wiley-VCH, Weinheim
IPBES (2018) Summary for policymakers of the thematic assessment report on land degradation and restoration of the intergovernmental science-policy platform on biodiversity and ecosystem services. In: Scholes R, Montanarella L, Brainich A, Barger N, ten Brink B, Cantele M, Erasmus B, Fisher J, Gardner T, Holland TG, Kohler F, Kotiaho JS, von Maltitz G, Nangendo G, Pandit R, Parrotta J, Potts MD, Prince S, Sankaran M, Willemen L (eds) IPBES Secretariat, Bonn, Germany
Jaeger L (2017) Wissenschaft und Spiritualität. Universum, Leben, Geist –Zwei Wege zu den großen Geheimnissen. Springer, Berlin, Heidelberg
James SP (2015) Environmental philosophy. An introduction. Polity Press, Cambridge
Jonas H (2003) Das Prinzip Verantwortung. Versuch einer Ethik für die technologische Zivilisation. Suhrkamp Taschenbuch, Frankfurt a. M.
Kerr RA (1997) Geomicrobiology: life goes to extremes in the deep Earth—and elsewhere? Science 276:703–704
Küng H (1990) Projekt Weltethos. Piper Verlag, München
Küng H, Kuschel K-J (2001) (eds) Wissenschaft und Weltethos. Piper-Verlag, München
Lorenz K (1977) Die Rückseite des Spiegels. Versuch einer Naturgeschichte menschlichen Erkennens. Deutscher Taschenbuch Verlag, München
Lovelock JE (1979) Gaia. A new look at life on Earth. Oxford University Press, Oxford
Lovelock JE (2009) The vanishing face of Gaia—a final warning. Basic Books, New York
Lüttge U (2012) Modularity and emergence: biology's challenge in understanding life. Plant Biol 14:865–871

Lüttge U (2013) The planet Earth: can it feed nine billion people? In: Matyssek R, Lüttge U, Rennenberg H (eds) The alternatives growth and defense: resource allocation at multiple scales in plants. Nova Acta Leopoldina 114/391:345–364
Lüttge U (2016) Plants shape the terrestrial environment on Earth: challenges of management for sustainability. Prog Botany 77:187–217
Lüttge U, Garbin ML, Scarano FR (2013) Evo-Devo-Eco and ecological stem species: potential repair systems in the planetary biosphere crisis. Prog Botany 74:191–212
MacGregor N (2010) A history of the world in 100 objects. Penguin Books
Mathesius U, Watt M (2010) Rhizosphere signals for plant-microbe interactions: implications for field-grown plants. Prog Botany 72:125–161
Mattimore V, Battista JR (1996) Radioresistance of *Deinococcus radiodurans*: functions necessary to survive ionizing radiation are also necessary to survive prolonged desiccation. J Bacteriol 178:633–637
Matyssek R, Lüttge U (2013) Gaia: the planet holobiont. Nova Acta Leopoldina NF 114(391):325–344
Matyssek R, Clarke N, Cudlin P, Mikkelsen TN, Tuovinen J-P, Wieser G, Paoletti E (eds) (2013a) Climate change, air pollution and global challenges. Developments in environmental sciences, vol 13. Elsevier, Amsterdam
Matyssek R, Wieser G, Fleischmann F, Grünhage L (2013b) Ozone research, *quo vadis*? Lessons from the free-air canopy fumigation experiment at Kranzberg Forest, pp 103–129. In: Matyssek R, Clarke N, Cudlin P, Mikkelsen TN, Tuovinen J-P, Wieser G, Paoletti E (eds) Climate change, air pollution and global challenges. Developments in environmental sciences, vol 13. Elsevier, Amsterdam
Melott AL, Bambach RK (2011) A ubiquitous ≈62-Myr periodic fluctuation superimposed on general trends in fossil biodiversity I. Documentation. Palaeobiology 7:92–112
Morris SC (2003) Life's solution. Inevitable humans in a lonely universe. Cambridge University Press, New York
Morris SC (2008) Jenseits des Zufalls. Wir Menschen im einsamen Universum. Berlin University Press, Berlin
Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB, Kent J (2000) Biodiversity hotspots for conservation priorities. Nature 403:853–858
Nachtigall W (2010) Bionik als Wissenschaft. Erkennen – Abstrahieren – Umsetzen. Springer, Heidelberg
Niemann H-J (2013) Karl Popper, die Mühle bei Hunstanton und die Anfänge der Molekularbiolgie. Bemerkungen zu Karl Poppers Medawar-Vorlesung, Teil II. Aufklärung und Kritik 2:7–34
Nietzsche F (1883–1885, 1891) Also sprach Zarathustra. Chemnitz & Leipzig
Noad MJ, Cato DH, Bryden MM, Jenner M-N, Jenner KCS (2000) Cultural revolution in whale songs. Nature 408:537. https://doi.org/10.1038/35046199
Omrod JS (2011) Making room for the tigers and the polar bears: biography, phantasy and ideology in the voluntary human extinction movement. Psychoanal Cult Soc 16:142–161
Pajot P, Mayor M (2015) La quête d'exoplanètes est devenue un pan majeur de l'astrophysique. La Recherche 504:34–37
Pandey V, Oksanen E, Singh N, Sharma C (2013) Impacts of air pollution and climate change on plants: implications for India. In: Matyssek R, Clarke N, Cudlin P, Mikkelsen TN, Tuovinen J-P, Wieser G, Paoletti E (eds) Climate change, air pollution and global challenges. Developments in environmental sciences, vol 13. Elsevier, Amsterdam, pp 391–409
Peterson KJ, Waggoner B, Hagadorn JW (2003) A fungal analog for newfoundland ediacaran fossils? Integr Comp Biol 43:127–136
Popper KR (2013) Eine Neuinterpretation des Darwinismus. Die erste Medawar-Vorlesung 1986. Aufklärung und Kritik 1:7–20
Puppim de Oliveira JÁ, Balaban O, Doll CNH, Moreno-Peñaranda R, Gasparatos A, Iossifova D, Suwa A (2011) Cities and biodiversity: perspectives and governance challenges for implementing the convention on biological diversity (CBD) at the city level. Biol Cons 144:1302–1313

Retallack GJ (1994) Where the Ediacaran fossils lichens? Paleobiology 20:523–544
Robert B, Jouzel J (2015) Je crois en un sursaut de ce monde face au problème climatique. La Recherche 506:5–8
Sánchez-Bayo F, Tennekes HA (2015) Environmental risk assessment of agrochemicals—a critical appraisal of current approaches. In: Larramendy ML, Soloneski S (eds) Toxicity and hazard of agrochemicals, Intech open science. https://doi.org/10.5772/59450
Scarano FR (2019) The emergence of sustainability. In: Wegner LH, Lüttge U (eds) Emergence and modularity in life science. Springer, Cham, pp 51–74
Scarano FR, Garbin ML (2013) Stem species: plant species that function as regenerating cells of Gaia. Nova Acta Leopoldina NF 114(391):317–324
Scarano FR, Rios RI, Esteves FA (1998) Tree species richness, diversity and flooding regime: case studies of recuperation after anthropic impact in Brazilian flood-prone forests. Int J Ecol Environ Sci 24:223–225
Schmidt JC (2019) Is there anything new under the sun? Instability as the core of emergence. In: Wegner LH, Lüttge U (eds) Emergence and modularity in life science. Springer, Cham, pp 3–36
Seilacher A, Grazhdankin D, Legouta A (2003) Ediacaran biota: the dawn of animal life in the shadow of giant protists. Paleontol Res 27:43–54
Souza GM, Lüttge U (2015) Stability as a phenomenon emergent from plasticity—complexity—-diversity in eco-physiology. Prog Botany 76:211–239
Speck T, Speck O (2019) Emergence in biomimetic materials systems. In: Wegner LH, Lüttge U (eds) Emergence and modularity in life science. Springer, Cham, pp 97–115
Steffen W, Richardson K, Röckstrom J et al (2015) Planetary boundaries: guiding human development on a changing planet. Science 347 https://doi.org/10.1126/science.1259855
Teilhard de Chardin P (1956) Le groupe zoologique humain. Éditions Albin Michel, Paris
Teilhard de Chardin P (1966) Die Entstehung des Menschen, 4th ed. C. H. Beck, München
Thivent V (2015) La nouvelle condition humaine. La Recherche 504:80–82
Varner GE (1998) In nature's interests? Interests, animal rights, and environmental ethics. Oxford University Press, New York
Weisman A (2007a) The world without us. Thomas Dunne Books, St. Martin's Press, New York
Weisman A (2007b) Die Welt ohne uns. Piper, München–Zürich
von Weizsäcker EU (2001) Ökologisches Weltethos. In: Küng H, Kuschel K-J (eds) Wissenschaft und Weltethos. Piper-Verlag, München, pp 337–355
Wilson EO (2002) The future of life. Alfred A. Knopf, New York
Wilson EO (2004) Die Zukunft des Lebens. Wilhelm Goldmann Verlag, München
Zachos FE, Habel JC (eds) (2011) Biodiversity hotspots. Springer, Heidelberg
zu Castell W, Lüttge U, Matyssek R (2019) Gaia—a holobiont like system emerging from interaction. In: Wegner LH, Lüttge U (eds) Emergence and modularity in life science. Springer, Cham, pp 255–279