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Commentary

Let the Transformative Anthropocene Be Positive!

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Species influenced by humans will be critical to the evolution of life. This will happen through various processes and mechanisms that can alter the evolutionary pathways of all living and non-living things by creating new interactions. Human dominance and the transformation of the biosphere are major drivers of these enormous changes. These factors are critical and are linked to the scale and intensity of our actions on the planet, often exceeding what our biomass would naturally allow. In this way, our extraordinary powers of abstraction and creativity can significantly transform the planet, creating new flows of materials and energy. In the Anthropocene, therefore, our actions and imagination will function as powerful forces of nature. The risk of our extinction through the misuse of this power shows the need for a cultural, ethical, and technological revolution that includes new perspectives in the way we live. Here, we show a "positive" perspective through the lens of the bio-evolutionary Anthropocene.

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A living Planet

The Earth can be viewed as a living organism where many processes and patterns determine its existence. The most important energy source is sunlight, which is taken by living organisms through photosynthesis and transferred to all other trophic levels. The processes that maintain life depend on these beings and their interactions with the environment and other living as well as non-living things. In this way, organisms, materials, and energy flows broadly characterize the Biosphere. We can say that interaction is the main rule of life, and humans and all other living beings only exist because they are part of the web of interactions in the Biosphere. Even our bodies, which are composed of cells, harbor a variety of microorganisms, such as bacteria and fungi. Besides interacting with the microorganisms inside our bodies, we also need to interact with other elements in the Biosphere and numerous other beings outside our bodies. This is the case with most species we use as food or inputs to our activities and, on a broader scale, with those that make the atmosphere oxygen-rich. In agriculture, in particular, these species have historically been extensively modified by humans.

The biodiversity we currently know is at risk at the beginning of the Anthropocene due not only to extinction but also to the alterations we have caused in environments and living as well as non-living things. The current

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mass extinction is primarily caused by human activities, such as anthropogenic climate change, habitat loss, and degradation. Human actions have a significant transformative power that can affect vast space and time scales[1][2]. The immediate harmful effects of pollution are relatively easy to observe. However, the long-term impacts are still unknown and unpredictable. These transformative factors in environments, and their impact on ourselves and other beings in the Biosphere, change the properties of systems and often lead to irreversible alterations[3]. Additionally, these transformations might lead to significant changes in current living conditions[4], potentially endangering humankind[5].

There are many examples of human-induced transformation. One of the most notable is the case of invasive alien species dominating invaded environments and competing with, eliminating, or displacing native species. Alien species inevitably transform environments. On the other hand, humans can also be considered the primarily invasive species, and our actions often lead to complete environmental change. The areas where we live are generally completely different from natural habitats, as the flows of materials and energy are manipulated to support our survival and increase our population. The complex production systems for food, housing, industry, and other human activities almost always pose risks to biodiversity and the Biosphere's balance. The reason is that they result in the extinction of original and natural habitats and the elimination or transformation of various species for human benefit. Throughout history, the enslavement of both other beings and humans has been a recurring pattern.

In light of these changes, new evolutionary scenarios are emerging in the biosphere. Urban and agricultural areas are prime examples of new sites for this evolutionary process, and the impact of human transformation in many respects goes well beyond biomass. Consequently, the artificial environments we create also act as sites for biological evolution[6], sometimes actively forming novel ecosystems[7]. Agriculture currently covers more than 40% of the Earth, and we have colonised about 50% of the Earth's surface. With a world population of nearly 8 billion people, each with their own expectations, dreams, and inventions, predicting the future of the planet in the face of human dominance is challenging. We need to rethink the trajectory of destruction, as we are essentially creating a 'new world'. The "positive" perspective, therefore, lies in recognising transformation and reinventing our trajectory on Earth.

The current Anthropocene

The Anthropocene is just beginning, and it is a period in which human actions significantly impact the planet. The concept was first developed by scientist Antonio Stoppani in 1873, when he proposed the idea of the "Anthropozoic Era." He predicted that humans would leave a mark on the planet that could be seen even after our extinction. Much later, in the 1980s, biologist Eugene Stoermer coined the term Anthropocene, which gained widespread recognition in 2000 through his work in collaboration with Paul Crutzen[8]. Today, the concept serves as a wake-up call for humanity since "Culture and Technology" accelerate extinctions and uncontrolled habitat changes. One of the many branches of the Anthropocene's idea is the "Technosphere" concept, which encompasses all the materials we produce technologically, such as concrete and metal, widely used in our homes and constructions. Concrete is currently one of the most abundant

materials on Earth's surface. Estimates suggest that the weight of this "Technosphere" is around 30 trillion tons[9]. Much of this material comprises products that are difficult to decompose and will remain for centuries. One such product is nuclear waste, which poses a significant risk to humanity as it is highly hazardous and will remain on the planet for thousands of years. In addition to natural environmental changes, urban and other anthropogenic environments constantly evolve as cities and technologies progress.

There is still a debate about the Holocene's end and the Anthropocene's beginning, mainly because scientists argue about the need to establish a precise and unequivocal time reference. In this regard, Lake Crawford in Canada was chosen as the "golden spike" for comparisons of pollutant emissions[10]. Nevertheless, there is little doubt that the Anthropocene has already begun, and among the hallmarks of this onset are the "Industrial Revolution," the "Nuclear Explosions," and the "Great Acceleration." The Industrial Revolution brought about massive changes in energy flows on Earth. Industrialization drove profound alterations in the planet's surface, particularly in producing new substances that affected the Biosphere. For example, it increased the proportion of carbon dioxide (CO2) in the atmosphere, which is the primary driver of the greenhouse effect. Nuclear explosions leave visible marks of their impact on living and non-living entities. Another well-known phenomenon is the "Great Acceleration," which began around 1950 and was characterized by an exponential increase in many processes linked to human population growth. This acceleration is interpreted in many ways, primarily by analyzing trends, socio-economic indicators, and other parameters of Earth's systems, all of which have been significantly altered, suggesting risks for the planet's Biosphere.

Some trends stand out, such as the exponential growth of the human population, the elevation of the urban population, increased energy and fertilizer usage, greater water consumption, and heightened transportation needs. In summary, these aspects are all connected to the exacerbated human population growth. Concerning changes in trends in the Earth's systems, the most striking of these is the emission of CO_2 into the atmosphere, which is largely leading to global warming and climate change. Furthermore, there is an increase in methane, the acidification of the oceans, overfishing, the destruction of forests, and the soil used for agriculture. In other words, various aspects indicate changes in the Earth system due to human activities. Therefore, these signs are quite evident, and although there may be some uncertainty about when they began, the reality is that we are in an initial, destructive stage of the Anthropocene. We do not know the specific consequences for the planet if this pattern persists.

Biosphere's future

The Bio-Evolutionary Anthropocene concept (hereafter BioEA) suggests that if human impact continues or intensifies its current level, several species will become extinct, while others will be favored or transformed by human influence. The great change in the planetary system has also led to the emergence of anthropogenic landscapes, such as agricultural fields, cities, industries, and much more. Therefore, human-driven changes have marked natural systems. As previously mentioned, approximately 50% of the planet's surface has been modified by human activities (see http://www.anthroponumbers.org). Given the significant impacts of mining, industrial activities, pollutant emissions, and other factors on global climate change, it is evident that human influence extends across the entire planet. This influence is particularly noticeable in Polar

Regions[11], where human population density is minimal but the environmental impact of human activity is substantial. Consequently, the effects of our actions are widespread throughout the Biosphere.

The Visible and the Invisible

The impact of human activity on the Earth's surface is evident in many "visible" ways. However, there are many other changes that are less obvious - the "invisible" ones. Several human activities, such as agriculture, extraction, hunting, and industry, can lead to various outcomes including pollution, biotic homogenization, urban expansion, the introduction of exotic, hybrid, and transgenic species, pandemics, fragmentation, edge effects, and habitat loss. Our culture and technology influence these changes, which have a significant impact on Earth's systems and biological evolution. While the scenarios are complex with direct and indirect consequences, it is widely agreed that human actions are altering evolutionary processes[12]. For example, species living in urban environments, which did not exist before humans, may have different traits compared to those living in natural environments, indicating that their biological evolution is therefore being influenced by human activities.

Biological evolution can also be affected by the anthropogenic extinction of species, as the relationships between species change when one is removed from the environment. We are currently experiencing the sixth mass extinction[13], leading to significant changes in living beings and the emergence of species favored by humankind. One notable example is the *Biston betularia* moth, which adapted its appearance (phenotype frequency change) during the Industrial Revolution in England. The moth camouflaged itself on tree trunks, which had become darker due to factory soot. As a result, the gray moths became predominant[14] in this anthropogenic environment. Additionally, literature suggests that many animals have evolved in cities[15] with patterns that are only possible in this novel environment.

Biological evolution is a dynamic process. The networks of interactions between living beings can be affected directly or indirectly on a variety of time and space scales. Adaptive changes occur through interactions between organisms and the environment, shaping phenotypic traits that will influence new interactions in a dynamic loop[16]. These loops and interactions are driving forces of the Bio-EA, where organisms favored by humanity and/or new organisms, such as aliens, hybrids, and GMOs, will interact with other beings and the environment, creating new evolutionary pathways[17].

Anthropocenic Landscapes

Currently, we have transformed landscapes, which we refer to as "Anthropocenic," and affected the living and non-living beings inhabiting these places and their biotic and abiotic interactions. The occurrence and abundance of novel organisms are linked to human cultural practices and technology that vary according to location and time. The made and seen changes happening on our planet are causing irreversible and unpredictable alterations to the environment and living organisms, forcing them to adapt in order to survive. These processes are incredibly significant for the Biosphere and are occurring at a rapid pace in today's world.

Living beings adapt to their environment at an accelerated rate due to the constant changes on our planet driven by survival needs. Adaptations arise from biotic and abiotic interactions and the inherent variability in living organisms. These adaptations occur randomly but are influenced by human habits and activities. Even planned actions can lead to unforeseen consequences, such as ecosystem restoration efforts, which may affect species richness and abundance[18]. Human-mediated ecological restoration activities directly influence the outcomes, reflecting human actions and decisions. Therefore, behavioral and cultural actions influence the outcomes in restoration, management, landscaping, agriculture, food, and many other areas. Thus, every environment on the planet inhabited by humans is part of the "human niche," where organisms must adapt quickly, potentially leading to the survival of organisms favored by humanity in a changing environment. These changes can even lead to new evolutionary pathways, fed by the loop of interactions between the species and the environment.

In addition to biotic and abiotic interactions, we must also consider human intervention and the changes in population distributions and densities of living beings. Population changes directly or indirectly caused by humanity and the environmental changes can lead to significant disruptions in interaction loops. For example, shifts in plant pollination, global warming, and the appearance of new diseases such as Covid-19.

New Beings

There are numerous indications of accelerated evolution as a result of human activity. Human behaviors constantly lead to changes, degradations, improvements, and shifts in both the environment and living and non-living beings. For instance, genetic engineering has opened up numerous possibilities for modifying and creating organisms that can bring about desired effects. Similarly, many species in their natural environment have experienced significant ecological changes that impact their survival. These changes can also generate unpredictable outcomes influenced by unknown deterministic processes or chance. In addition to the creation of new organisms, we are also witnessing the emergence of new environments, where exotic, enhanced, or hybrid species are introduced, either directly or indirectly. These new or altered ecosystems bring about new biological interactions. Additionally, changes in abiotic conditions over time present new challenges for the survival of organisms in their natural or modified environment.

The combined effects of these changes may lead to the sixth mass extinction and the Bio-EA. This could create new opportunities by reducing competition and increasing the availability of resources, thus favoring the establishment of other species favored by the Anthropocene. These may include economically and agronomically significant species, invasive species with favorable reproductive and growth characteristics for colonizing new environments, and species well-adapted to cities, which are more suitable to survive in these anthropogenic ecosystems.

In the Bio-EA, exotic, hybrid, and genetically modified organisms will shift biological evolution. This is the result of human activities. This cultural and technological evolution has accelerated the speciation process[19]. For instance, the use of antibiotics has not only helped control diseases and extend life expectancy but has also led to the emergence of resistant bacteria due to artificial selection. Throughout history, human influence has modified the evolution of

pests, organisms, diseases, and species, causing imbalances in natural systems. The spread and evolution of the coronavirus causing Covid-19 is also attributed to human influence. Many other species are expected to thrive on the planet due to human preference.

Aliens

Alien species are those that do not occur naturally in a given environment. Many of these species colonize new environments naturally, through immigration. However, most of the exotic species seen today in invaded terrestrial or aquatic environments have been introduced or favored by humans. This is a notable feature of the Anthropocene, during which favored organisms may drive changes in living beings. There are thousands of exotic species colonizing new environments around the world, with humans themselves being the primary example, as they inhabit a variety of sites. Alien species are almost always responsible for environmental imbalances that lead ecosystems into unusual and often ecologically unsustainable conditions[20]. Their establishment affects natural processes and patterns, leading to the local extinction of native species.

Alien species are considered an environmental problem because they can disrupt ecosystems. However, it is also possible that these new species in natural or anthropogenic ecosystems could contribute to biodiversity, reshaping biological evolution due to their capacity to survive human-caused impacts. Therefore, the true consequences or effects of exotic species on environments are not fully understood.

Genetically Modified Organisms

Genetically modified organisms (hereafter GMOs) are those whose genetic makeup has been altered by humans. Among these, a transgenic organism is one that carries genes from another species. However, modern genetic modification techniques can also cause changes such as the insertion or deletion of parts of the organism's own genome, which are not considered transgenic. This occurs through gene editing and similar processes. However, within the context of the Bio-EA, all organisms modified by humans are considered GMOs.

There are many aspects to consider regarding the impact of GMOs on natural and anthropogenic environments. These organisms are likely to play a significant role in biological evolution. Initially, it was believed that the development of GMOs would not affect natural environments as it was expected to be conducted in controlled environments. However, we now know that GMOs are widespread in many ecosystems, as major crops like soybeans, corn, cotton, alfalfa, and canola are genetically modified and cultivated as monocultures in numerous places.

While these crops provide food for humans and livestock, they also have a significant impact on ecosystems. This includes the direct destruction of habitats, the elimination of species due to pesticide use, and the release of fertilizers and pollutants into the soil and water. This demonstrates once again that "interaction" is a crucial factor, and even seemingly closed production systems are open. Additionally, it contributes to the spread and incorporation of GMOs into the interaction webs, leading to planetary changes.

Hybrids

Hybrids are organisms that result from the mixing of two species, and they are highly favored by humankind. They exist today in various places and are closely linked to many human activities. For example, many food items are hybrids, some of which lead to environmental imbalances. One of these organisms in nature is the "boar–pig hybrid," which has been spreading in worldwide areas and often has higher fitness than its parental species, adapting well to regions where species similar to the wild boar occur. In the Brazilian Atlantic Forest, there are also hybrid monkeys resulting from crossbreeding local species with alien ones, and these hybrids seem better able to survive in forests in the early stages of succession and in forest fragments impacted by humans. The issues linked to hybridization are complex, and some scientists consider hybridization to be a real invasion of the genome[21]. Genome evidence of hybridization has recently been found in blue whales, an endangered species. This may indicate the challenges this species faces in surviving in a modified environment with anthropogenic influences. While hybridization occurs naturally, human interference has enhanced this phenomenon, causing more hybrids to appear than would be expected naturally.

Choices in the modern Anthropocene

Nowadays, our actions have a significant impact on the environment and can transform the Biosphere. Understanding the depth of these changes is the first step in addressing the destructive trajectory that is disrupting planetary systems at the beginning of the Anthropocene. We need to recognize that we are part of a complex network of living and non-living beings and that our survival depends on other organisms and the environment. Our predominantly "Anthropocentric" viewpoint must expand to consider new ethical perspectives that enable us to live in a more sustainable manner. Reflecting on "what kind of humans we want to be" can help us tackle the issues we are currently causing. Urgently recognizing that planet Earth is home to numerous other living and non-living beings is crucial. Ultimately, how we choose to inhabit the Anthropocene is the primary challenge facing humanity today and could determine our long-term survival on this planet.

Statements and Declarations

Author Contributions

Conceptualization and Writing, P.J.F.P.R. and C.d.F.L.; Review & Editing, P.J.F.P.R.

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