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Overpopulation and Ecological Limits: Examining Biocapacity and Carrying Capacity in a Global Context

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Abstract: ***This article investigates the interconnections between overpopulation, biocapacity, and carrying capacity within the context of environmental sustainability. Drawing on data from United Nations reports and ecological indicators, the study highlights how rapid population growth contributes to ecological deficits by intensifying natural resource consumption, deforestation, and carbon emissions. The analysis emphasizes the critical role of biocapacity and ecological footprint in understanding environmental degradation and argues for the adoption of sustainable development strategies that incorporate demographic considerations. The article also explores historical and theoretical insights into carrying capacity, offering a philosophical and ecological critique of population expansion trends.***

Keywords: overpopulation, biocapacity, ecological footprint, carrying capacity, environmental sustainability

1. Introduction

The population of our planet has exceeded 8 billion inhabitants and is constantly growing. This fact has been generating a number of positive and negative effects. However, the negative effects are more numerous and significant because they have serious and permanent consequences regarding vegetation, fauna, and soils, which in turn lead to modifications in the Earth's natural occurring processes. In ecological research, two key concepts that can help us better understand the extent of the negative effects of overpopulation have emerge. These are: biocapacity and carrying capacity.

The theoretical analysis is realized by using deductive and inductive reasoning and by analysing and interpreting the official data. In this way is possible to find out whether there is a cause-and-effect relationship between population growth and the decline in biocapacity per capita, as well as how the concepts of biocapacity and carrying capacity correlate with the phenomenon of overpopulation. The study's significance lies in its timely exploration of ecological sustainability limits amid global population growth, contributing valuable insights into how demographic pressures influence planetary health and environmental policy-making. This article aims to analyse the causal relationships between overpopulation and ecological degradation, particularly through the lenses of biocapacity and carrying capacity.

1) Biocapacity and overpopulation

The first step in the conceptual analysis of the term "biocapacity" is to define it completely. Biocapacity, also known as biological capacity, represents the ability of a given territory (in the narrow sense) or our planet (in the broad sense) to produce the natural resources necessary to sustain biotic factors, while simultaneously naturally eliminating waste (Schaefer et al., 2006). Natural resources come both from the complexity of ecosystems, especially through the existence of forests, pastures, and fish ponds, and from human activity, such as, for example, in the case of land cultivated by humans.

In order to highlight the practical side of the concept of "biocapacity," it was necessary to create a complex system through which we can determine the biological capacity of a given territory or of our planet, with the aim of knowing the numerical expression of all the natural resources at our disposal. Biocapacity is closely linked to the ecological footprint, which measures how fast we consume the natural resources and the biological waste we produce (such as carbon dioxide) (Wackernage & Beyers, 2019).

In this regard, a system similar to accounting is used, in which inputs (assets) represent the biological capacity of the territory/planet, and outputs (liabilities) are represented by the ecological footprint. After an initial stage in which the biocapacity and ecological footprint of a given territory in a given year are determined, a subtraction operation follows. The result of this can be positive, if the biological capacity is greater than the ecological footprint, indicating the existence of a biological reserve, or it can be negative, indicating the existence of an ecological deficit (Wackernage & Beyers, 2019).

Both biocapacity and ecological footprint calculations use a specific conventional unit of measurement, namely the global hectare (gha). It should be noted that each piece of land has its own characteristics, both in terms of the type of biological resource generated (there are notable differences between a forest and arable land) and in terms of climatic differences, geographical characteristics, and, in the case of land cultivated by humans, the cultivation methods used and the efficiency of the equipment used, so that in order to calculate global biocapacity, it was necessary to introduce factors by which to multiply the base value. The equivalence factor (gha/ha) is the same for all countries, with the result being modified annually due to changes in productivity (for example, deforestation will lead to a decrease in biocapacity,

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while the use of improved agricultural methods will lead to an increase) (Schaefer et al., 2006).

By adding up the biocapacity of all the world's land and water areas, we obtain the biocapacity of our planet. The most recent data is provided by the 2023 edition of the NFBA (National Footprint and Biocapacity Accounts), with most of the data processed being obtained by the United Nations (UN). This data shows us what our planet's biocapacity was up to 2022, as well as estimated data for 2017-2022 for most of the world's territories. According to the statistics presented, in 2022 our planet's biocapacity was 1.51 global hectares per capita (gha/capita), totalling 12,044,118,590 global hectares (gha).

The data provided for 2022 can be considered extremely alarming if analysed in terms of their evolution over time. Thus, we can see that although 50 years ago, we had a planetary biocapacity of 9,804,650,067 global hectares (gha), with an increase of approximately 2.2 billion global hectares, in terms of the number reported per capita, which was 3.14 gha/capita in 1962, meaning that it has at least halved over the same period.

This is indisputable statistical evidence that population growth, from approximately 3. 12 billion inhabitants in 1962 to approximately 7.95 billion inhabitants in 2022, is one of the factors that has led to a negligible increase in the planet's biocapacity, along with a halving of its biocapacity per capita.

To get the full picture, we need to check out the stats on measuring the ecological footprint. This was done by adding up the ecological footprint of consumption with the ecological footprint of production, and the total of these two is the total ecological footprint. In 2022, the total ecological footprint of our planet was 2.58 global hectares per capita (gha/capita) and 20,588,847,129 global hectares (gha).

Performing a mathematical operation of subtracting the total biocapacity of our planet from its ecological footprint results in the global ecological reserve or deficit. In this case, in 2022 we obtain the following results: 9,804,650,067 global hectares - 20, 588,847,129 global hectares, the result of the calculation being -10,784,197,062 global hectares, or 3.14 global hectares per capita - 2.58 global hectares per capita = -0.56 global hectares per capita. These results indicate that our planet is in a significant ecological deficit.

Although it is true that there are several specific causes that have led to this significant ecological deficit, the most influential factor appears to be the exponential growth of the population. When the population grows, the ecological footprint will inevitably increase, as people consume more natural resources and produce more ecological waste, which must be eliminated by the environment. The most important ecological waste is carbon dioxide, which is why the carbon footprint of a person, a territory, or a human action is measured separately. The ecological footprint is calculated in the same way as biocapacity, so each territory must be analysed separately, as people use resources and pollute the environment differently.

The lifestyles of human communities have a direct impact on the ecological footprint. Modernization, the use of an increasing amount of fuel, the growing need for production in agriculture, the textile industry, and services require increasingly higher consumption of natural resources, while also causing a depletion of existing resources and an increase in the carbon footprint. Some of these, such as oil, natural gas, coal, and uranium, are non-renewable natural resources that can be depleted. In some regions of the world, even water is considered a resource that can be depleted. The depletion of resources is also a frequent cause of international conflicts. Furthermore, the implementation of natural resource extraction systems has required changes to the existing natural landscape, thus affecting the natural habitat of local animal and plant species. This has profoundly affected the ecological balance of the area, leading to environmental degradation.

In addition to these, there is also the need for territorial expansion, as each person has specific territorial needs. This has led to actions to occupy, modify, and destroy fauna, vegetation, and soils in order to expand the areas needed for human settlements. A significant 55% of the ecological footprint is represented by ensuring the food needs of the planet's population are met, along with the production and processing of the food necessary to feed it (Hannah et al., 2022). For this reason, population growth directly causes an increase in the ecological footprint, with each person having an ecological footprint that adds to the total result, while in very few cases can there be an increase in the planet's biocapacity achieved individually by humans, which leads to an increase in the ecological deficit.

Among these destructive actions, deforestation is the most dangerous and damaging operation within our theme. Trees and plants are one of the most effective methods of eliminating ecological waste, because their specific operation of producing food through photosynthesis has effects within the specific natural environment, producing oxygen and eliminating carbon dioxide. This effect accumulates and amplifies as the number of specimens increases, leading to an increase in the biocapacity of the territory and, implicitly, of the planet.

According to existing data, massive deforestation over large areas continued to occur and intensify, reaching alarming figures and percentages from the mid-19th century onwards. Some studies show that in 1947, there were between 15 and 16 million km2 of mature tropical forests on our planet, while in 2015, their existence had been reduced to about half, with the percentage of tropical forests on the globe falling from 14% to 6% (Tucker & Richards, 1983; Marilon, 2015). As all the studies conducted are relatively recent, we can assume that the original forest areas, before the emergence and development of the human species, were immeasurably larger.

This dramatic decline in forest resources was deeply influenced by population growth, the main determining factor being the development of agriculture, which required the expansion of processes into increasingly larger areas. From this point of view, it is considered that within the processes analysed, the direct causes of deforestation are: subsistence agriculture, accounting for 48%, commercial agriculture accounting for 32%, logging accounting for 14%, and the use of wood as fuel (most commonly for heating and cooking) accounting for 5% (United Nations Framework Convention on Climate Change, 2007). In addition to deforestation caused by agricultural development, there is also the need to provide living space for an increasing number of people, which has led to the need to cut down trees around homes and eliminate dangerous animals.

However, it is necessary to point out some possible factors that lead to inaccurate calculations of the biocapacity of a given territory. Specialized studies reveal that the biocapacity of a territory has been underestimated, as it has been calculated using methods that did not take into account the particularities of the respective territories. The most significant case in this regard is the conclusions of a modern specialized study, in which the authors demonstrated that the biocapacity of the Jing and Shiyang river basins had been miscalculated. By recalculating the biocapacity taking into account multidimensional spatial, geographical, and economic factors, the authors of the study concluded that the aforementioned territories are in fact sustainable, contrary to the results obtained using the classic method officially used. (Since the presentation of technical information on the methodology for calculating biocapacity is beyond the scope of this article, for further information the entire article "Scale dependency of biocapacity and the fallacy of unsustainable development" D. Yuea, et al., 2013) represents an excellent choice.
From another point of view, both the calculation of biocapacity and that of the ecological footprint are inaccurate due to the fact that each forest is different and absorbs carbon dioxide from the atmosphere in different ways, which is not revealed by the existing calculation factors. For this reason, a global hectare of forest may absorb more or less than the calculated annual average, which leads to automatic changes in data and results. Another problem could be that, when measuring the ecological footprint, fossil fuel is assumed to be inexhaustible in the future, which is not factually valid. For this reason, only the emissions produced by burning it are measured and calculated, and not its calculation as a non-renewable resource (Goldfinger, et al., 2014). For these reasons, the use of the global hectare unit of measurement, along with the entire calculation process, should be viewed as part of the broader field of sustainability and not as its entirety, because sustainability is a vast and complex process that cannot be reduced to a simple mathematical calculation.

For this reason, official results are important, even if the figures only show part of the truth in terms of sustainability. In this sense, the fact that our planet is in ecological deficit should first and foremost be seen as a wake-up call regarding its future and, implicitly, that of humanity. The purpose of creating this imperfect system is to try to quantify as realistically as possible the amount of resources available now and in the future and to understand that our actions have consequences. It is estimated that we would need 1.7 Earths for our planet to be sustainable for future generations. It has also been calculated that, starting in August 2024, the renewable resources virtually available for the current year will already have been consumed, so that everything we consume thereafter will produce an ecological deficit relative to this year.

One of the few European countries with a low ecological deficit is Romania. This European country has amazing biodiversity, due both to its geographical position and to the fact that all the main types of terrain can be found within its borders: plains, plains, hills and hills, mountains, as well as river basins, rivers, the Danube River, the Danube Delta, and also has access to the Black Sea. These characteristics lead to the conclusion that there is significant biological capacity, along with the existence of multiple ecosystems and important natural landscapes. For this reason, analysing the evolution of the ecological footprint, biodiversity, and transport capacity is an undeniable practical necessity.

Romania's biocapacity has varied throughout history from 2.5 global hectares per capita in 1961 to 2 global hectares per capita in 1991, reaching 2.9 in 2019 and 2.5 in 2022. The main sources of biological capacity in Romania are agricultural land, 26,871,045 global hectares in 2019, and forest land, 21,203,042 global hectares in 2019. The total number of hectares for both types of land increased by approximately 2 million hectares for forest land and 18.5 million hectares for agricultural land.

Romania has an ecological deficit of 0.4 global hectares per capita, and if the entire planet consumed resources and polluted like our country, 2.3 Earths would be needed. However, Romania is one of the European Union countries with a small ecological deficit. The same official data reveals that in the hypothetical situation presented, three planets would be needed to maintain the standard of living in Germany, 2.8 in France, and eight in Luxembourg.

Globally, the data is alarming: in 2022, we will need 1.75 Earths for resource use to be sustainable and greenhouse gases to be naturally eliminated. For this reason, we can see that our entire planet is in ecological deficit. This year, the day on which we will have consumed the planet's resources for one year will be August 1, and it is noteworthy that this day, called "Overshoot Day," has been getting closer and closer to the beginning of the year (from September to August) over the last century. Earth Overshoot Day in Romania in 2024 will be on July 20.

These results are of significant importance, despite the inaccuracies present in the calculation methodologies. It is an indisputable fact that humans have altered and destroyed ecosystems and habitats, and their activities have led to the extermination of animal and plant species, natural landscapes, and the systematic degradation of the environment. For this reason, increased attention to this issue, together with the methodological improvements necessary for calculating biocapacity and ecological footprints, will lead to the alleviation of environmental problems and the improvement of human life, and will contribute to prolonging the life of our planet.

A growing population will exacerbate all existing global problems and stand in the way of achieving many humanitarian goals that require a decrease in the use of certain resources and an increase in the quality of life for the entire human population. If we cannot now provide basic needs such as healthcare and clean water to the world's population, how can we expect to do so with a growing population? The current human population will not only rapidly consume the resources of planet Earth, but also contributes enormously to global catastrophes such as climate change, with greenhouse gas emissions being the primary driver and continuing to exacerbate this problem (Miller & Spoolman, 2012).

As economic systems continue to evolve and developing nations continue to transition to developed ones, the population will consume and pollute more than it does today. This means that although we want people to have a better quality of life and more resources, the transition of countries can have a significant negative impact on the environment. Although this ongoing modernization and development is beneficial to the human population, it can be noted that it has catastrophic consequences for the environment. The values borrowed from developed countries tend to emphasize that for all human beings to have a better quality of life and adopt a lifestyle similar to that of those living in developed countries, it is necessary to use even more natural resources, as a result of the population adapting to a more comfortable lifestyle, which highlights the nature of the ever-expanding consumer market.

From this point of view, a concrete example of the appreciation of the values of developed countries can be considered the United States of America. This country is extremely important in the context of globalization, as it represents the model of a good and desirable life. However, according to statistics, this country currently uses the second highest amount of energy per capita globally (2,182 million tons of oil equivalent). In 2024, the United States of America will require the equivalent of 5.1 Earths. From this point of view, using an exercise of imagination, we can imagine that if all people on Earth lived a lifestyle comparable to that of Americans, we would need a huge amount of resources to sustain this standard of living, and if the population continues to grow, this number will increase proportionally. Since natural resources are limited, some of them being non-renewable, in the process of being consumed or depleted, it is not difficult to imagine that in order to bring the standard of living to a level close to that desired by the population, copied from the model of developed countries, it is necessary to reduce population growth.

Furthermore, consuming resources until they are exhausted will lead to new internal and international conflicts due to the impossibility of maintaining a constant standard of living for citizens. The possibility of conflicts arising will contribute to the reallocation of economic resources to ensure military protection, to the detriment of other areas necessary for increasing the well-being of citizens. A direct effect of this can be considered the imbalance in socio-economic life, as some people will have access to certain resources, while others will not, increasing the gap between the rich and the poor, along with the associated social fragmentation. If we want to prosper and improve the quality of life for as many citizens as possible, we need to understand the limits we can afford in the exploitation of natural resources and adapt our consumption and lifestyle behaviour accordingly.

2) Carrying capacity and overpopulation

Carrying capacity is a term that refers to an abstract estimate of the maximum number of animals that can sustainably inhabit a given territory for an indefinite period of time. This concept was expressed by a constant designated as "K constant." Pierre Verhulst, and later Raymond Pearl and Lowell Reed, created and improved the formula for calculating carrying capacity in the case of the human population. However, in the case of these authors, carrying capacity was used in a managerial logistics sense and not in the sense used in contemporary ecology. Gradually, the term was adopted in ecological sciences by H. L. Bentley and Kaibab Plateau, who used it to increase the productivity of domestic animal populations, and was later applied to the study of fauna by Aldo Leopold and Paul Errington, being used, together with the K constant in the case of human populations, by Eugene Odum in his work entitled "Fundamentals of Ecology" (Hixon, 2008).

The practical utility of the concept of carrying capacity is extremely important, and four general directions of its operation can be outlined. By synthesising and combining these four general directions, we obtain the maximum relative number of members of a species that can populate a given territory without degrading its substance and without irreversibly consuming its renewable resources, to which, in the case of domestic animals, the difference between profit and the cost of exploitation is added (Young, 1998).

Although this concept was initially used to calculate the possibilities for expanding the number of animals on farms, in livestock breeding, and in fish farms, and was to be used by ecological sciences in wildlife control and protection programs, it began to be used in relation to the human species as well. The carrying capacity of the human population is analysed mainly on the basis of two different lines of research: the main line analyses the Earth's maximum capacity to sustain population growth, while the secondary line refers to the management of migration flows (Subach, et al., 2023).

Although many philosophers have put forward theories about the possibility of reaching a maximum limit for the human population, the most important philosopher and theorist to analyse this issue in depth is Thomas Malthus, who published the first edition of his work, An Essay on the Principle of Population, in 1798. "An Essay on the Principle of Population," which became famous with the publication of subsequent editions, due both to its novelty and the extremely bleak predictions that the author made in it.

In this work, Thomas Malthus establishes a principle that later became established in subsequent debates. This is the principle that "population, when unhindered, doubles every 25 years, or grows in geometric progression," while "the means of subsistence can only grow in arithmetic progression" (Malthus, 1992, pp. 19-20). In other words, human population growth can occur at a rate far higher than the growth of means of subsistence, which can lead over time to famine and a decline in quality of life.

In the first part of the work, Malthus provides several examples of obstacles that may arise and modify, halt, or reverse this doubling, or geometric growth of the population, including wars, pandemics, and famine caused by the destruction of crops due to natural causes. The thesis of his theory is summarized in three statements: "1. Population is limited by the means of subsistence; 2. Population invariably increases when the means of subsistence increase and if it is not prevented by some very powerful and obvious obstacles; and 3. These obstacles, which restrain the preponderant force of population growth and keep its effects at the same level as the means of subsistence, all reduce to moral abstinence, vice, and misery" (Malthus, 1992, pp. 21-23).

Although Malthus sought to create a demographic theory to determine how the population would grow, using parameters such as means of subsistence and obstacles presented, the author's research results were often seen as a significant warning sign for the future of the population, which led to the creation of the phrase "Malthusian disaster."

The population problem, as noted by neo-Malthusian ecologist Paul Ehrlich, author of The Population Bomb, is "a numbers game." As the human population has surpassed seven billion and will soon reach eight billion in a few years, it is fair to ask what possibilities there will be for societies to live in harmony with the natural world. This is while technological answers—from fusion power to agriculture, super-bioengineering, and space colonization- are either impossible to achieve or "solutions" that are worse than the problem itself.

Despite Malthusian numerology, this is not self-evident. Consequently, overpopulation may be a source of the current world hunger crisis, but further reasoning is needed to automatically conclude that hunger is simply the result of "natural laws" when it occurs in a class society with a market economy and private land ownership.

These premises find their fullest expression in William Catton's book, Overshoot. The Malthusian premises it shares with deep ecology and the way it has been used in the proliferation of deep ecology ideas make it an important text for this subject. Based on the concept of "carrying capacity," Catton's thesis is that "the human population has long since entered a dangerous phase of the cycle of population growth and decline." He explains: "Carrying capacity, though variable and not easily, or always, measurable, must be taken into account in order to understand the human situation" (Catton, 1982, p. 42).

In short, Catton's vision stems from a Darwinian perspective of a competitive struggle for survival between species. Human beings have historically followed a process of "taking over" the carrying capacity ("diverting" resources from other species to themselves), "essentially to the detriment of other inhabitants of the earth." But human expansion inevitably had to face the limits of scarcity, of the earth's carrying capacity. Only the discovery of new territories and new forms of extraction could prevent a dramatic decline in population (Catton, 1992, 44-45).

However, we must take into account modern criticisms regarding transport capacity. These are varied, the most well-founded referring to the mismatch between actual results and those calculated by Malthus, particularly with regard to the possibility of securing the means of subsistence. Malthus' theory was based from the outset on well-defined parameters. While the population grew steadily, the possibility of securing basic foodstuffs increased thanks to technological advances. At the time Malthus developed his theory, the means of production were adequate for that period, with basic agriculture. Over time, the means of production have been modernized, raw material processing techniques have been greatly improved, and new models of agriculture have allowed the population to gain access to the means of subsistence at a global rate of approximately 90%. However, malnutrition remains a problem today, particularly in overpopulated countries and territories such as India, China, and Pakistan.

Another interesting argument is that put forward by Romanian-born economist Nicholas Georgescu-Roegen (Nicolae Georgescu), who points out that Malthus was optimistic in his theories and failed to take into account two possible truths: geometric population growth can be infinite, while our planet's capacity to produce the resources necessary for life is finite, even in the context of the ongoing modernization of the production and processing of raw materials necessary for subsistence (Gerogescu-Roegen, 1975). Taking these two statements into account, continued population growth will make it impossible to ensure the subsistence level of an increasing number of people.

For this reason, it is necessary to analyse in particular the carrying capacity of the human species. This can be examined through the lens of three different, interconnected components. Firstly, there is physical and biological carrying capacity, Kb, which expresses the maximum physical limit of people who can populate a given territory. Secondly, there is social carrying capacity, KS, which assumes that there is a maximum socio-cultural capacity for people to coexist in a given territory. The third component refers to the carrying capacity that shows the impact on the environment (ecosystem) (Seidl & Tisdell, 1999). This represents the possibility of coexistence without irreparably destroying the environment, falling within the nominative sphere of the term sustainability. Authors Daily and Ehrlich argue that "sustainability is a necessary and sufficient condition for the population to be either at the maximum limit of its carrying capacity or below it" (Daily & Ehrlich, 1996, p.992).

Transport capacity, analysed primarily in the field of ecology, indicates, within general limits, the resilience of the environment. The main issues today are finding and establishing moderate public policies that take into account studies on calculating carrying capacity and those on the difference between biocapacity and ecological footprint, so that we can reduce environmental degradation.

2. Results and Discussions

As we have shown, population growth is one of the most important factors in terms of biocapacity, ecological footprint, and transport capacity. As we have shown, overpopulation leads to the restriction of wildlife territory, an increase in the carbon footprint, along with massive pollution, the destruction of natural habitats, the degradation of ecosystems, and a decline in the quality of human life. These findings provide strong evidence of the existence of causal links between the concepts analysed. Although there are valid criticisms of the methodologies used to calculate biocapacity and carrying capacity, The planet's resources and territories are not infinite. Continued population growth is not only unsustainable at a certain point, but could also be impossible from a practical standpoint, as there would be insufficient space to continue populating territories, further destroying ecosystems and simultaneously decreasing the quality of human life.

Thus, we can observe that population growth is the most important variable in the concept of ecosystem carrying capacity, thus establishing a link between this concept and the dual system represented by biocapacity and ecological footprint. For this reason, controlling overpopulation can lead to the resolution of all the problems outlined above. For this reason, finding effective solutions to halt population growth would lead to a halt in the growth of the ecological footprint, which, combined with improvements in agricultural and fishing techniques and the planting or replanting of forests, would lead to an increase in biocapacity and the creation of an ecological surplus. Furthermore, by controlling population growth, we will prevent the population from reaching its peak, as determined and analysed in the concept of carrying capacity, thus avoiding the negative consequences of this scenario. A multidisciplinary approach integrating environmental science, policy reform, and demographic planning will be essential in mitigating future ecological crises driven by overpopulation.

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