INSTITUTE FOR LIFECYCLE ENVIRONMENTAL ASSESSMENT

Human Carrying Capacity of Earth

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Introduction

The carrying capacity of an ecosystem is defined as the "maximum population size of a species that an area can support without reducing its ability to support the same species in the future"[1] . Biological studies of population change typically demonstrate that once the carrying capacity of an ecosystem is exceeded, a severe crash or collapse of the population follows associated with rapid environmental degradation.[2] An example of the "boom-bust" cycle of population growth is found on St. Matthew Island, Alaska, where 29 reindeer were initially introduced in 1944. The reindeer population grew to 6,000, depleted the resource base, and subsequently declined to fewer than 50 deer by 1964.[3]

Though human population growth can demonstrate similar cycles,[4] human population is also affected by more than just resource availability. We, as humans, are unique in our ability to modify the environment and to improve technology for food and energy production. These unique abilities combined with the inherent social nature of humans complicate the estimation of the human carrying capacity of the planet.

According to the United Nations Population Fund's (UNFPA) latest population report,[5] the world population has doubled since 1960 to 6.1 billion people and is projected to increase to 9.3 billion by 2050. Along with the increase in number of people, there is an associated increase in the demand placed on the resources of the Earth. As human population increases at an unprecedented rate combined with the developed world's reliance on non-renewable energy sources it becomes salient to look at how far the human population can continue to escalate while remaining supportable. Ecologists, economists and other scientists and policy makers from all over the world have attempted to estimate the human carrying capacity of the planet. The results vary dramatically depending on the methods used and the assumptions made. The variety of methods employed and assumptions made result in a broad range of estimates varying from as low as fewer than one billion people to as high as 1,000 billion[6]. This paper compiles numerous recent estimates of socially sustainable carrying capacity into a single compendium and investigates the estimates of carrying capacity resulting from methods utilizing energy consumption and production as a metric for estimation.

Biophysical vs. Social Carrying Capacity

The long-term sustainable carrying capacity for the human species on the Earth varies with resource availability as well as culture and level of economic development[7]. Two measures of human carrying capacity arise: the biophysical carrying capacity and the social carrying capacity. The biophysical carrying capacity is a maximum population that can be supported by the resources of the planet at a given level of technology. The social carrying capacity is the sustainable biophysical carrying capacity within a given social organization, including patterns of consumption and trade[8]. The social carrying capacity therefore must be less than the biophysical as it will account for quality of life and estimate the number of humans that can be sustainably supported at a given standard of living.

Currently there exists an extreme dichotomy in the level of energy consumption between the US, other developed countries and undeveloped countries.[9] The amount of energy consumed per person per year is a useful measure of standard of living.[10] Per capita energy consumption is measured in kW/person and includes industrial uses, transportation, home heating and cooling, clothing, electronic entertainment, vacations, food production, etc.. Table 1 summarizes per capita energy consumption from the early 1990's. The U.S. consumed an average of 12 times more energy per capita than developing nations.[11] North American per capita energy use is more than twice that of Europeans, more than 10 times that of Asians and more than 20 times that of Africans.[12]

Region	Energy Use, kW
United States	12
Developed nations average	7.5
Developing nations average	1

Table 1 - Annual per capita energy consumption in the early 1990's.[13]

In order to estimate a sustainable human population, a standard of living or level of consumption must be selected or assumed. At this point, the introduction of social issues becomes important. For instance very high global population could be supported at a very low level of food consumption, perhaps even on the brink of starvation. The result however could be a socially unstable situation. A socially sustainable carrying capacity must be based on a level of consumption that meets basic human needs of food, water and space as well as provides opportunity to enjoy socio-political rights, health, education and well-being.[14] Another important aspect of social sustainability is equitable distribution of resources. Inequitable distribution of wealth can lead to social instability and disruption. As a result, some researchers propose that estimates of carrying capacity should include a downward adjustment for inevitable inequality resulting from human selfishness and short-sightedness.[15]

Estimating Sustainable Carrying Capacity

The basic resources of the planet, such as land, water, energy and biota are inherently limited.[16] Selection of one or several of these limited resources as a metric for measuring the carrying capacity of the planet is a common method of estimating global human carrying capacity. The use of a single resource or combination of limited resources to estimate carrying capacity includes measuring how much of that resource is available globally. For instance, global wheat harvest can be estimated based on land area and water availability, then used to compute the number of humans that those quantities can support.

Resource use must also be differentiated between renewable and nonrenewable resources (Table 2) for estimation of global carrying capacity. Renewable resources are driven primarily by solar energy and are regenerated through natural processes. Non-renewable resources are those with limited quantities and very low or no renewal rates. Long-term use of non-renewable resources is generally not sustainable. A socially sustainable global carrying capacity must be based on use of renewable resources, possibly supplemented by very low consumption of non-renewable resources.[17]

Renewable Resources	Non-renewable Resources
Solar energy (drives wind & hydropwer)	Energy sources (e.g., oil, coal, natual gas, nuclear)
Freshwater	Stratospheric ozone
Some soil used for agriculture	Tropical forests
Wood for construction	Biodiversity
Some animal species (e.g., animals for transport, insulin and vaccines)	Minerals (e.g., diamonds, gold, iron)

Table 2 - Examples of resources that are renewable at reasonable rates of consumption.

Recent estimates by the World Energy Council[18] suggests that one-third of the world's oil reserves have been used and that the remainder will be significantly depleted by the end of the 21st century if current rates of consumption continue. Other studies[19] suggest that declines in oil production will occur as early as 2010. Other non-renewable energy sources, such as coal and natural gas, will supplement as oil production potentially declines; however, these sources are also not sustainable over the long-term. Changes in available technology for energy and food production and distribution, and waste disposal also impact the resulting carrying capacity estimate. Sir Thomas Malthus, in his famous 1798 treatise on population growth, did not account for the advancements in fertilizing agricultural land leading to increased food production, which in turn allowed for greater population growth than he estimated. Some estimates of carrying capacity account for future improvement in technology, and other estimates presume that the level of technological development remains the same.

Energy inputs

Energy availability is a useful metric that can be used to estimate carrying capacity because it can account for many different resources. Energy from the sun is the driving force of the Earth's ecosystems. Solar energy generates atmospheric processes that provide wind energy and freshwater. Plants, trees, food crops, and animals all require energy from the sun. The balance of energy consumption and production can be used to estimate the number of humans that the planet is capable of sustainably supporting. The total amount of energy input by the sun to the earth is finite and can be estimated. When that energy is divided up among the entire earth ecosystem, it is possible to estimate at a given level of consumption, how many humans can be supported on the earth. The resulting estimate is a sustainable number because it does not rely on non-renewable energy sources. Currently, about 50% of all solar energy captured by photosynthesis is used by humans. On its own, solar energy cannot support the present human population without supplementation by non-renewable energy sources, such as fossil fuels.[20]

Land area

Land area can be used in different ways to estimate carrying capacity, either as a metric for other resource uses or as a measure itself. The simplest way of using land area to compute carrying capacity is to presume a population density for a given area and compute the total number of people that the region can support. Another method, the ecological footprint concept, uses land area as a metric for a combination of other factors. Ecological footprint takes many different resource uses and measures them by the equivalent amount of land area required for their production. The ecological footprint describes how much land is necessary to support a given population in terms of energy, food, and other resources at a certain level of consumption. The result is that developed/rich countries with high levels of resource consumption have much larger footprints than they actually occupy.[21]

Food production

Estimates of carrying capacity using food as a metric determine the total amount of food that can be produced globally and divide by a standard level of food consumption per person. The result is a global population that can be supported at a given level of subsistence assuming that food is equitably distributed around the globe. More complex methods consider changes in crop yield with increased technology, food distribution, varied world diets, and other resource supply, such as fossil fuels.

Recent carrying capacity estimates

When one considers the array of factors that must be estimated and the conditions that must be assumed, it is unrealistic to expect a unique figure defining the Earth's human carrying capacity. Professor Joel Cohen in his 1995 book, How Many People can the Earth Support?,[22] summarized estimates of human carrying capacity of the Earth beginning with estimates made as early as the 1600's. His summary is not limited to estimates that are considered socially sustainable as he includes estimates that only consider biophysical parameters. Many studies cited by Cohen give a range of population carrying capacities with a low estimate and a high estimate. In his 1995 Science paper,[23] Cohen computed the median of the high estimates and the median of the low estimates. The result was a range of medians from 7.7 to 12 billion people.

Table 3 summarizes the estimates from Cohen's book that do consider social sustainability as well as estimates from other sources. The estimates vary from 0.5 to 14 billion depending on the metric used and the standard of living and technological improvements that are assumed. The medians of the low and high estimates provide a range from 2.1 to 5.0 billion people. With the current Earth population estimated to be 6.1 billion people,[24] the median range of sustainable carrying capacity estimates suggests that the Earth's population be reduced in order to be sustainable.

Summary & Conclusions

A sustainable population of humans on the Earth implies reliance on renewable energy sources combined with socially sustainable standards of living. Standard of living and carrying capacity are inversely related, such that as standard of living decreases, the number of people that can be supported on Earth increases.[25] The current global population of 6.1 billion people exceeds the median range of socially and biophysically sustainable carrying capacity estimates shown in Table 3. Exceedance of the Earth's carrying capacity is made possible by consumption of nonrenewable energy sources, such as fossil fuels as well as inequities in global distribution of food and energy consumption.

Energy is a useful metric for estimating carrying capacity because it can be used to estimate available renewable energy from the sun as well as standard of living based on energy consumption. Solar energy is the primary source of renewable energy on Earth as it generates atmospheric processes as well as food and forest resources. Per capita energy consumption can be used to estimate resource use that defines human standards of living, including food, transportation, manufacturing, heating and cooling, housing, etc. Using standards of living lower than the current North American average, estimates of carrying capacity using energy as a metric range from 1 to 3 billion people. This is less than half of the current global population.

Estimating the carrying capacity of the Earth is a difficult task involving value-based decisions and assumptions. Whether the future of the Earth includes a dense population of humans with reduced biodiversity and degraded environmental qualities or a smaller human population living sustainably on a diverse resource base remains to be seen. However, current levels of energy consumption and the impending depletion of non-renewable energy sources point toward the necessity for a change in either population growth or consumption trends if the human race is to survive at anything close to its current level of subsistence.

Source	Low estimate (billions)	High estimate (billions)	Basis of Estimation	Assumptions
Palmer 1999	9	9	Ecological footprint	Standard of living lower than US current (1 hectare per person) and improvements in energy efficiency, food production, pollution contr valign=topol and preservation of biodiversity.
Rees 1996	4.3	6	Ecological footprint	4.3 billion computed using 13 billion ha of land and 3 ha/person, which is current Eurpoean standard of living. 6 billion using ecological footprint of current N. American standards.

Pimentel et al. 1994[†]	1	3	Energy	Based on use of renewable solar energy. 1-2 billion in relative prosperity - based on use of renewable solar energy. 3 billion - Adequate food supply.
Daily et al. 1994	1.5	2	Energy	"Optimum" population estimate with consumption siginifantly less than current US standard.
Pimentel et al. 1999	2	2	Energy	Optimal human population enjoying a relatively high standard of living.
Ferguson 2001	2.1	2.1	Energy	Based on energy consumption and CO_2emissions.
Smil 1994[†]	10	11	Food	Eliminate disparity in energy consumption and food production technology between developed and un-developed world. A shift in the Western consumptive mindset toward a sustainable diet and pattern of life would be necessary.
Brown & Kane 1994	2.5	10	Food	Estimate depends on level of consumption. The lower estimate corresponds to US level of consumption and the highest estimate to the level of people in India. Based on an estimated world grain harvest of 2.1 billion tons in 2030.
Hulett 1970[†]	1	1	Multiple factors	Based on food, wood products and nonrenewable resources. At US standard of living with current (1970) technology and production.
Westing 1981[†]	2	3.9	Multiple factors	Based on total land area, cultivated land area, forest land area, cereals (grain) and wood assuming technology and politics of 1975 and at affluent (average of world's 27 richest nations) to austere (average of 43 nations of average wealth based on GNP) standards of living.
Heilig 1993[†]	12	14	NPP*	Based on NPP for biophysical capacity, accounting for increased technology and "with ecological care and in the framework of an economically sound and socially-just development policy"
Whittaker & Likens 1975[†]	2	7	NPP*	2-3 billion could be supported at a "more frugal European standard" if "steady-state systems of resource use and cycling were established". 5-7 billion with most human beings living as peasants.
Meadows et al. 1992[†]	7.7	7.7	Systems model**	Systems model results for supporting global population sustainably with enough food, consumer goods and services. Includes increased technology, pollution reduction and efficient use of nonrenewable resources.
Ehrlich 1971[†]	0.5	1.2	Unknown	Best estimate of what the planet can maintain over long period of time
Medians of estimates	2.1	5.0		

Table 3 - Estimates of socially sustainable carrying capacity

[†]From Cohen (1995a)

*Net Primary Productivity (NPP) is defined as "that part of the total or gross primary productivity of photosynthetic plants that remains after some of this material is used in the respiration of those plants."[26] NPP provides the energy and material for life on earth. The world's total NPP is 172×10^{9} tons/year.

** World 3.0 is a system dynamics computer model that can vary global policy assumptions and models five variables: population, food, industrialization, nonrenewable resources and pollution. The results of Scenario 10 suggested that the world could sustainably support 7.7 billion people. The conditions of this scenario include: improved technology to protect land, reduce pollution, and use non-renewable resources with high efficiency, as well as controls on land erosion and increased land yields of food per capita.

*** Rees (1996) includes energy in his footprint analysis. Palmer (1999) claims that energy is a different sustainability problem and should be decoupled from the food, wood and degraded land footprint.

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