**No world cup 2100: imminent decline in the population of humans on Earth predicted by model**

Time lag of 70 years, less than 2 billion humans on the planet by mid 22nd century

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**Abstract**

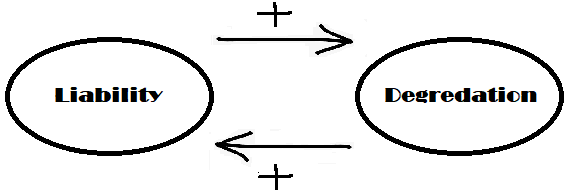
Population growth in any species is always limited by the amount of available resources. As populations approach their carrying capacity, growth rates are adjusted to accompany the limitations of the environment. However, these adjustments are not instantaneous. Recent human population growth has been projected to stabilize somewhere between 9.4 and 12.7 billion people. Such projections don’t account for the inevitable delay in response to environmental changes. In this article it is shown that population data can be modeled accurately by introducing time delay. The consequence of this is a lower carrying capacity than was previously thought. The delay is found to be a remarkable 70 years. An analytic equation relating carrying capacity to resource consumption and environmental degradation is also derived. Thorough analyses of carrying capacity can be carried out using this equation. The results of this paper call for the urgent need to reduce human footprint worldwide and prepare for societal collapse.

**Introduction**

We live in a finite universe. Certain physical laws impose limits on what can be achieved. It is not possible to surpass the speed of light. The laws of thermodynamics prohibit perpetual motion machines. Pathogens live among us. A broken glass will not reassemble itself. Furthermore, at any given time there are restrictions arising from lack of knowledge or inadequate technology that serve as limiting laws until breakthrough is achieved. Apart from population growth, there is no endeavor in science or technology where optimization procedures aren’t implemented. These considerations suggest the need for introducing prior planning and optimization into human population studies.

Consider a field containing a limited number of productive hens and fruitful trees- metaphors for nature’s providers or capital. Each provider represents a certain yield, leading to an overall productivity rate for the field. This productivity rate sets an upper limit to the overall consumption rate that can be attained solely from renewable resources, which brings us to the concept of carrying capacity. The carrying capacity of an environment for a particular species is the maximum number of individuals of that species the environment can sustain indefinitely, or for a very long time. A corollary to this definition is that the use of resources must be such that the environment does not degrade over time. This implies that there should be no accumulation of wastes and overall consumption rates must not surpass productivity rates for any tangible amount of time.

Now let us consider the consequences of allowing consumption rates to surpass regeneration rates. Since the environment can no longer provide for all the needs of its inhabitants, the surplus of consumption must come at the expense of natural capital. In our example, this implies the destruction of trees and killing of hens (nature’s providers or capital). The result is environmental degradation, implying a population that has exceeded its carrying capacity. Moreover, less providers means lower regeneration and productivity rates, which amplifies subsequent liability and accelerates the reduction in size or number of providers. Thus a vicious cycle involving positive feedback loop is initiated. The size of the environment shrinks, and with it so do regeneration rates.



**Fig. 1: Depiction of the effects of surpassing environment regeneration rates.** A positive feedback loop implies progressively greater deviation from stability.

The trees in our example provide more than just apples. Degradation brings about secondary and tertiary complications- albeit with time delay. Such are antibiotic resistance, reduced capacity for providing clean air and capturing atmospheric CO2 and so on. These subsequent effects will in turn increase the consumption levels required to meet the same needs (such as clean air, water and food), thus further exacerbating liability. Unlucky individuals and those who can no longer meet the increased requirements will suffer and eventually die off..

Surpassing the carrying capacity does not imply instant collapse, and just because the environment continues to provide does not mean overshoot hasn’t occurred. It is possible for a population to survive overshoot for some time by relying on natural capital, a phenomenon that is not allowed for in the ideal logistic curve. This can be seen in other physical systems as well. An elevator that can normally sustain 10 people will still manage overload for some time, showing signs of wear before the cable finally breaks.

Symptoms of overshoot include waste accumulation, increased frequency of conflicts and anxiety, increased disease outbreak, depletion of resources, increased occurrence of accidents, etc, etc. This is what is meant by exceeding the carrying capacity.

Currently all signs of overshoot are present: Nutrient depletion (*1*, *2*), topsoil erosion (3*-* 5), ocean acidification (*6*, *7*), air pollution, loss of biodiversity(*8*, *9*), antibiotic resistance… , these are not the signs of optimal or near optimal pace.

Usual population projections do not take into account time delay in response to the environment. Using age-structure models that lead to the Verhulst ideal logistic growth curve, the UN population division projects human population to stabilize between 9.4 and 12.7 billion in the next century (*10*).

However, in reality time delay is always present, as there is no instantaneous transfer of information in the limited universe. Without prior planning, anticipation of threats and optimized growth rates, it is not possible to avoid delay. Previous work by Haberl and Aubauer shows the necessity for including time delay in mathematical models (*11*). In this paper, population data is analyzed by introducing time delay into the ideal logistic growth curve while accounting for a variable carrying capacity. Using UN population data from 1950 to 2020 (*12*), and introducing time lag and a variable carrying capacity into the ideal logistic equation, human population growth is satisfactorily modeled.

**Results**

Carrying capacity must be considerably lower than previously thought to offset the effects of time delay. A remarkable time delay of over 70 years is found..

The findings are displayed in figures 1 through 4. The resulting parameter estimates for the model are as follows:

Lag = 72.48 years, Population rate of growth = 0.03 billion per year, Carrying capacity rate of growth = 0.02 billion per year, Final carrying capacity = 5.53 billion, Initial carrying capacity (at year 1500) = 0.00032 billion.



Fig. 2: Population and historical carrying capacity modeled against time.



Fig. 3: Model predictions (light blue) alongside theoretical carrying capacity (red). Beginning since 1970, environmental degradation due to exceeding the planet’s biocapacity (*13*) has resulted in less than ideal carrying capacity. As a consequence of this overshoot, the population falls below 1.73 billion in 2166.



Fig. 4: Comparison of modeled historical carrying capacity with optimal population growth according to the 80/20 rule.

**DISCUSSION**  
Historical carrying capacity (dark blue) should not be confused with theoretical carrying capacity (red). Estimates of the latter range from 0.5 billion to over 1 trillion(*14, 15*). Since 1969, humanity’s ecological footprint (*16*) has exceeded contemporary biocapacity, resulting in environmental degradation and preventing the planet’s full potential from being reached. This is the price we pay for neglecting scientifically optimized population growth and global cooperation. Prevention is better than cure. If as a species, we had bothered to adhere to optimal pace with timely scientific planning, we could’ve benefited from a considerably larger carrying capacity. The good news is that by bringing consumption levels below current biocapacity, the environment will be given the chance to repair itself (*17*), allowing the carrying capacity to gradually shift back towards higher values.

A single logistic model was used to capture the dynamics of carrying capacity. In reality, carrying capacity can be affected by multiple pulses(*18*). The limitation of using a single pulse is that the results are only valid within a restricted time frame. A more thorough approach would be to model carrying capacity as multiple super-imposed logistic pulses, while accounting for reduction in environmental size brought about by degradation. Due to uncertainty in historical population estimates(*11, 19*), this method was avoided here. The analytical equation is derived and presented for future work.

Writing an accounting equation for the closed Earth system, we have:

(Productivity rate – Consumption rate) x Equivalency factor = 

Where M represents the size of the environment at any given time.

Substituting biocapacity and ecological footprint into the equation and introducing a conversion factor that relates global hectare- years to the biological mass of providers (akin to converting apples to trees in our introductory example) , we have:

( Biocapacity –Ecological footprint ) x Conversion factor =  (1)

At any given time, the carrying capacity can be found by dividing biocapacity by the optimal per capita consumption rate (ropt, per capita). Decomposing biocapacity into its two components, and writing size as initial size, M0 plus change in size, ΔM, we have:

Carrying capacity = Biocapacity/ optimal per capita consumption rate = (Biocapacity per size) x size / ropt, per capita  = (biocapacity per size) x (M0 + ΔM) / ropt, per capita

Change in size (ΔM ) can be found by rearranging equation (1) and integrating over time. This is equivalent to the area between the ecological footprint and biocapacity curves vs time. In the special case of optimal history, ΔM would be zero. The denominator represents optimal per capita consumption rates under prevailing social and environmental conditions, and can be approximated by the 80/20 rule under normal conditions and near world average consumption under evident crisis.

**Criticisms**

A criticism of the concept of optimum population is that it only considers economic factors(*20*). One way to overcome this is by employing multi-objective optimization. Furthermore, optimal conditions must be anticipated in proportion to the population’s competence and motivation levels, as they are driven by the latter. An estimated 15% of the population live with some form of disability (*21*). Lower standards should be allocated to this category. If the United States standard of living is considered, it should not be applied to the entire population. An income gini-coefficient of 0.38 optimizes for economic growth(*22*), while equality, defined by the United Nations as a gini coefficient of 0.2 or lower corresponds with the lowest crime rates(*23*). A midway gini coefficient of about 0.29 could serve as a first estimate to optimize for both criteria. Given the context of our discussion and that homicide serves to reduce population, it seems reasonable to incline towards lower values still.

Under usual conditions, this optimum could be used to figure the carrying capacity at the present time. In the case of apparent crisis, major events are suspended, allowing for further increase of carrying capacity. This corresponds well with the model predictions. Historical carrying capacities for 1969 and 2014 are estimated at 2 and 3.25 billion respectively, in good agreement with previous findings (*24, 25*), taking into account the above modifications. The final carrying capacity corresponds to times of reduced consumption and suspension of major events, as normal conditions would not allow for such a high carrying capacity. In contrast, the theoretical carrying capacity (red dash) corresponds to an alternate history with no concerns of environmental degradation. The point of departure of historical carrying capacity from the data corresponds to the era of the First World War (figure 2).

When analyzing historical data, it only makes sense to ascribe overconsumption entirely to overpopulation. This is because carrying capacity by definition takes into account the collective intelligence of the species. If the species as a whole hasn’t shown enough intelligence to avoid scenarios of overshoot, then it must have been overpopulated. The population dynamics is unaffected by the source of this overshoot. It is the hope of the author that this article can help accelerate social awakening, thereby increasing the planet’s future carrying capacity.

A second criticism of the optimum population theory is that there is no evidence for an optimum population (*26*). Technological optimists even go as far as to claim that the notion of carrying capacity is not applicable to humans(*27*). While it is true that humans can change their carrying capacity, these changes still take place within the framework of the laws of our universe. At any given time there is a contemporary carrying capacity, and exceeding it will result in poverty and/or environmental degradation. (Technically, exceeding the biocapacity results in degradation, whereas exceeding the carrying capacity may initially result in poverty or conflicts).

In any event, the race is against depletion of natural capital, not the mere passage of time. We might accept that more people and necessity lead to faster innovation (making no note on the quality of this innovation and disregarding for the moment that more people also means more accidents, mistakes and shortsightedness), but when this innovation is accompanied by degradation it implies permanent loss of time. As such, drawing comparisons between countries or alternate histories without taking into account depletion is meaningless. Furthermore, it is more effective to prevent a problem than it is to deal with the consequences. The scientific, technological and environmental resources invested in mitigating avoidable problems could be well spent directly on the betterment of humanity. The key point here is not to hinder innovation, but to anticipate the dangers ahead while moving at the most efficient pace, in analogy to fuel efficient, safe driving(*28*). If with a bit of foresight and scientific planning, problems could be avoided or minimized, it would not be very wise to confront them head first. Although the system may not advance at maximal pace with regards to certain criteria, it will be overall more efficient. That’s how all biological systems operate in nature and that’s the whole point of optimization.

As such, there is no need to subscribe to fantastical views regarding humans. Modelling carrying capacity as super-imposed logistic pulses growing towards an ultimate maximum accounts for all our observations: That by the end of the day the environment is limited, that humans have the ability to raise their carrying capacity, and in more than one way, and that this potential for increase, along with the environment’s ability to continue to provide for a population in overshoot imply the possibility of surviving this overshoot for some time by relying on natural capital, a phenomenon the ideal logistic curve does not allow for.

Employing science and optimization procedures has been beneficial in all other fields, population science should be no different. Our failure to do so thus far has to do with the pleasures of sex and lack of cooperation on a global level, rather than the futility of science or optimization procedures.

**Defining an optimum**

We do not live in an ideal world. Not everyone is equally motivated. The proposed optimum must take the realities of our world into account. The degree to which we can achieve prosperity depends on the level of talent, motivation and capabilities of the individuals and the degree to which they cooperate. Taking these into consideration, it does not make sense to suggest high living standards for every person on the planet. Such wishful thinking is not compatible with reality. A more realistic optimum would account for the distribution of competence and motivation levels among individuals. This optimum can be estimated by making use of the 80/20 rule, associating high living standards with 20% of the population, and world average standards with the remainder of the world (as average distributions). The results of this approach are in close agreement with the simulation (figure 4).

It should be noted that there is a major difference between an inherently subjective criterion and estimates of an objective one. The optimal growth rate calculated here is not subjective, as it avoids bias towards a particular criterion by correlating with multiple, realistic objectives.

Reaching an optimum world population in itself does not guarantee solving all the world’s major problems, but it will make them solvable. It is the necessary condition, the first step towards solving them. For instance, restoring the population to optimal levels along with introducing free basic needs will make the world inherently safer, reducing the need for security measures and breaking an internal vicious cycle. If humanity ever reaches the point of cooperation where wasteful consumption is minimized, higher optimal standards will also be attainable.

**Final remark**

The analysis was based on the historical path that has actually occurred. Due to overshoot and degradation, the growth of carrying capacity has been hindered and will eventually decline. The resemblance between the results of figure 3 and those of natural and engineered systems is noteworthy. The ideal resting heart rate for humans is 55 to 72 bpm (*29, 30, 31, 32*). The maximum attainable heart rate is close to three times this range (*33*). The average passenger car may speed up to 190 km/h, whereas speed limits in cities usually fall between 55 to 70 km/h. Had we bothered to stick to optimal growth rates, approximately one third of the actual rate of growth at the point of departure (figure 3), the carrying capacity would’ve not degraded, vicious cycles would’ve never initiated and the optimum population growth would’ve followed a higher trajectory.

**Suggestions**

Introducing Universal basic income(*34*), postponing all major events, planning gradual change in infrastructure, setting up societies in a manner that encourages people to reuse prior to recycling; Companies should strive to provide reusable packaging. Writings should be limited, particularly on the insides, and brochures should not be included with every item of the same product. Education systems should teach kids that universal basic income, sex and a sustainable environment are not possible without cooperation, mindful consumption and individual effort to reuse materials. Should this system prove insufficient, then income could be paid conditionally to those who are mindful and reuse. As a consequence of introducing UBI, advertising will be limited and cooperation may increase.

**Data availability**

This analysis is primarily based on population data from United Nations world population database(*12*) and biocapacity and ecological footprint accounts from Global Footprint Network(*35*).

**Code availability**

All code generated and used in this analysis can be accessed at https://github.com/MIKEAA2020/warm-up under the MIT license.

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**Competing interests**

The author declares no competing interests.

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