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Review Paper

A Scientist's Warning to humanity on human population growth

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ABSTRACT

One needs only to peruse the daily news to be aware that humanity is on a dangerous and challenging trajectory. This essay explores the prospect of adopting a science-based framework for confronting these potentially adverse prospects. It explores a perspective based on relevant ecological and behavioral science. The objective is to involve concerned citizens of the world in this enterprise. The overall objective is to maintain Planet Earth as a favorable home for the future of humanity. Nine ecological principles explain one major aspect of what is happening and provide critical guidelines for appropriate action. Nine social behaviors explore how we might integrate social science insights with those from ecology. Twenty predictions are proposed based on these ecological and social science principles plus existing trends. If these trends are not vigorously and courageously confronted, we will likely be on track for the demise of our civilization. As we examine these challenges, our job will be especially complicated because a major segment of humanity is not prepared to accept evidence based on science, and this generates much resistance to any efforts directed toward effective control of current and future challenges. In these complex circumstances, we must remain as cooperative and optimistic as possible so that we can promote the needed willpower and ingenuity.

This essay has broad support as it is a contribution to the Scientists' Warning to Humanity Program of the Alliance of World Scientists (Ripple et al., 2017).

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1. Introduction

Planet Earth is an absolutely amazing place. An apparent rarity in the universe, it possesses the appropriate physical conditions to support life. As a result it hosts a tremendous variety of living creatures which we recognize and classify as various species. In relatively recent times, human life evolved, and in large part due to our extraordinary intelligence, has become the dominant life form on the planet. With nuclear power technologies, we are now capable of destroying all complex life forms, including ourselves. Our dominance is recognized by the acceptance of the term Anthropocene which proclaims that we have entered a human dominated planetary phase. Our numbers are projected to increase from an estimated 7.6 billion to 10 billion by 2050 (Baillie and Zhang, 2018). Human caused species extinctions have also reached an unprecedented rate such that we are generally viewed as causing the sixth mass extinction episode for the planet. A recent effort to photograph human impacts on land use over the entire globe from 1992 to 2015 documents this rapidly increasing global-

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scale impact on land areas (Nowosad et al., 2018). The inevitable questions for humanity at this stage in our history are: “Does this matter for our species?” “Does this rapid increase in numbers along with its corresponding expansion of our utilization of the Earth’s land area matter?” What does it mean for us?” Maybe it is merely a signal that we are a very successful species, and we can celebrate our good fortune. On the other hand, perhaps it is a signal that we are over-exploiting the Earth’s resources and we should seriously be preparing for a population crash. Or, are there still other scenarios? In the following two sections of this essay, we will explore these questions from the perspective of ecological science and then again from behavioral science. Subsequently, we will look for lessons learned by considering 20 predictions that emerge from our analysis.

2. Relevant ecological principles

Nine established principles of ecological science that are relevant to the circumstances we face are as follows:

1. Population growth in numbers on a finite planet cannot continue indefinitely for any living species, including humans (Czech, 2013; Meadows et al., 2004).
2. Population growth generates three possible negative forces that collectively increase exponentially and eventually stop growth. These are increasing mortality rates, decreasing birth rates, and increasing rates of emigration relative to immigration. Only the first two of these are applicable with a global perspective. Separately or collectively, these negative processes cause population growth to stop. If access to required resources has been compromised during growth, the population may not only stop growing but decline or even crash (Lidicker, 2002).
3. Living systems require energy for their ongoing existence. The proportion of available energy that is required for maintenance of living systems increases as the size and complexity of those systems increase. This means that the proportion of energy available for other desirable activities such as reproduction, individual growth, maintenance of health, and defense against parasites and pathogens will be proportionally and progressively less and less available as numbers increase (Brown, J.H., Burnside, R. et al., 2011).
4. For social species such as humans, increasing numbers require additional energy for maintaining the integrity and cohesion of the groups to which they belong, and on which they depend for their livelihood.
5. The resources that humans need to support their food and shelter requirements are partly non-renewable and partly renewable. The first requires the extraction of various minerals, water, fuels, and building materials. Over time these resources will decline and become increasingly more difficult to extract. In the case of fresh water, supplies are becoming increasingly polluted. This not only affects us directly, but also all of the non-marine species that constitute the basis for our food supplies, medicinal drugs, other building materials, as well as a myriad of so-called “ecosystem services”. This trend also can influence weather patterns ... Recent studies have concluded that our annual supply of renewables is now being used up by about August 1 of any given calendar year. Thus for five months we are deficit spending these resources, and in the process generally doing damage such that the Earth’s capability of generating these renewables becomes diminished (Wakernagal et al., 2002). This human impact on the generation of these essential resources has been dubbed “the human footprint.” Two diverse examples illustrate the major impacts that humanity is making on renewable resources: 1) Mongolian steppe grasslands are heavily degraded because of exploding demands for cashmere wool plus a series of unusually severe winters (MacLaughlin, 2019); 2) Diadromous fish populations in the north Atlantic have declined dramatically from multiple causes (Limburg and Walden, 2009).
6. The human enterprise cannot succeed by going it alone (Crist et al., 2017; Heal, 2017). Success requires the presence of a rich biota to provide the conditions necessary for our survival. As mentioned, these enabling services have been labeled with the metaphor of “ecosystem services” (Daily, 1997; Norgaard, 2010). This concept has been reasonably successful in calling attention to our dependence on the Earth’s biota for humanity’s existence and welfare. These benefits that non-human organisms provide for us include oxygen generation, soil fertility, pollination of crops and other plant food resources, fisheries, air and water purification, pest control, medicines, genetic resources, fuel, building materials, weather moderation, dispersal of seeds and nutrients, partial stabilization of climate, mitigation of floods and droughts, decomposition of wastes, industrial applications, etc. And, this is not to mention the provision of a healthy, aesthetic, and intellectually stimulating environment (Daily, 1997).
7. Nefounding the Earth’s declining ability to supply a steadily accelerating supply of the resources upon which we depend is that the species of living organisms that are required for production of renewable resources are increasingly facing population declines and risks of extinction because of ongoing fragmentation and degradation of the natural habitats that they need for maintaining healthy populations with long term viability (Ascensão et al., 2018; Tucker, M.A., K. Bohnning-Gaese et al., 2018; Hilty et al., 2019; Laurance, 2019).
8. Fortunately, it is the case that when populations and communities of numerous species are damaged by human activities or unusual forces, they can quite often recover over time if they are suitably protected from subsequent damages. However, we now know that if a community is badly damaged, it can experience a “tipping point” or threshold such that it cannot recover (Dai et al., 2012; Roque et al., 2018), and it then becomes a different kind of community that is generally less productive, and much less useful to humans. This illustrates one of the many mechanisms that result in reduced resource availabilities, or expanded human footprints, as populations continue to build.

9. As we strive to preserve as much of our natural heritage as possible, we need to be aware of an often neglected feature of highly motile species. This is that individuals of such species often need more than one kind of suitable habitat. For example, there may be different habitat types required for different life history stages. An obvious example is species of frogs that begin life in a freshwater pond, but then metamorphose into adults that live in a forest. Many species are seasonally migratory, utilizing quite different habitats at different seasons. Some may even require particular transit habitats. An interesting case is that of caribou (*Rangifer tarandus*) in eastern Canada. Individuals that spend the winter at greater distances from their summer range survive better, but as a result such individuals will require larger home ranges (Lafontain et al., 2007). A particular hazard for some migratory species is that the travel routes may need to be learned from conspecifics (Festa-Bianchet, 2018; Jesmer et al., 2018). This implies that if social groups get too small they may lose all their potential leaders, and hence access to migratory destinations.

3. Relevant social behaviors

The following nine social behaviors can and should be recruited to help humanity respond to the ecological impacts that will surely endanger human civilization if current trends are allowed to continue.

1. We must explicitly recognize the need for an appropriate mixture of altruistic and self-promoting social behaviors. The first of these benefit the sociopolitical groups to which we belong (the common good), and the second group of behaviors supports the individual welfare of each of the citizens that constitute those groups (Reich, 2019). Both are essential for our ongoing welfare. This principal emphasizes the necessity of having democratic mechanisms in place that promote true feelings of participation in the crafting of sustainable societies. This spirit of cooperation is essential for encouraging discussions that generate an appropriate mixture of benefits to individuals and to the success of the sociopolitical groups to which they belong (Reich, 2019). Moreover, there will need to be a system of appropriate sanctions for individuals who have overly selfish or parasitic tendencies. This dual-purpose social behavior has a long history going back to our primate ancestors (de Waal, 2015) and is clearly expressed in the U.S. Constitution. An illustrative example of how far we have drifted from this principle is provided by a quote from David Starr Jordan, a famous fish biologist who was a Professor of Zoology and later President of Stanford University, that is preserved in a 1933 8th grade graduation diploma from a school in Hawaii. Jordan's message includes the statement that "Success means service. The more you serve the cause of others, the greater will be your own success." In modern societies, this duality of behavioral modes is rarely explicit and increasingly favors individual benefits. When it is discussed, it is often put in terms of pursuit of private wealth (money) versus self-sacrificing altruism. Another unfortunate expression of this duality that has become common in the political dialog in the USA often occurs when behaviors that support the common good are labeled as "socialism." While technically correct, this term translates for many Americans into "communism" which has widespread negative connotations. On the other hand, the single minded pursuit of money is justified as beneficial capitalism. These unfortunate interpretations of "socialism" make it more difficult to promote democracy which unequivocally requires a balance of the two modes of social behavior (Lidicker, 2003; Reich, 2019).
2. Sociopolitical groups are hierarchically arranged, and all individuals must be contributing members of one or more groups, preferably including groups at multiple hierarchical levels. For example, an individual may belong to a neighborhood group, a county government, and a professional vocational association. National citizenship is an almost ubiquitous example of group membership.
3. Dialog at all levels needs to be respectful of the huge array of world views that currently exist in and among various social groups (Reich, 2019). When serious disagreements arise within a group, it is often appropriate and effective to promote conversations with the observation that differing viewpoints generally will accommodate many objectives or components that are held in common. Hopefully, encouraging this approach will make it possible to address disagreements in a cooperative and compromising manner. An example of such a cultural impediment that needs to be confronted is the almost universal prohibition against including human population growth in relevant discussions (Bongaarts, O' Neill et al., 2018).
4. Appropriately there are often moral issues that need to be discussed or at least acknowledged in any considerations of human population growth. Moral principles are mostly acquired in childhood and as youthful adults. As such they are very difficult to modify. Our deliberations need to respect that reality. Tampering with human population growth is a topic that is loaded with moral issues. Those that accept the relevant scientific evidence are often accused of being genocidal, racist, anti-poor folks, anti-religion, and generally anti-human. These accusations are completely in error. In fact, the position taken in by the scientifically aware is the opposite. Generally, those who accept the scientific imperative feel that they have a moral responsibility to be concerned about the future of mankind. Usually they also are genuinely concerned about the huge inequities in the distribution of resources around the Earth. For many there is also a moral concern for the drift of governments away from democracies and into authoritarian regimes. This trend encourages increasing xenophobia which in turn generates a lack of cooperation among groups, and inevitably increasing negative interactions.
5. When engaging in discussion topics that deal with conservation and the future of humanity, it is generally advisable to avoid arguments based largely on aesthetics, love of nature, and related approaches. While these positions are valid in the

context of particular world views, they are all susceptible to being characterized as the products of special interest groups, and tend to be divisive. Teachers and leaders at all levels need to appreciate that opinions which humans grow up with are very difficult to change by reasoning and argument alone. The multiple viewpoints can be accommodated by compromises, cooperation, and mutually supported programs and policies.

6. Community discussions are much more likely to succeed if the participants have sufficient education so that they can differentiate truth from falsehoods, and know how to think critically. This means that successful societies must provide good public education that is readily available to all children (Lidicker, 2003; Reich, 2019).
7. Related to this last array of social behaviors is the extremely important and yet very difficult social issue of the appropriateness of humans deliberately manipulating their own species numbers. One world view on this is that humans should do what they can to have as many members of their own species living on our planet as they can. This view was ingrained in our genes for almost all of human history, and surely has contributed to our successful survival and expansive distribution. It is also ingrained in many of our cultural behaviors and beliefs. A logical corollary of this viewpoint is that any effort to control population growth is genocide and inherently racist. However, in recent decades other issues relating to population growth have emerged. For example, it is now widely believed that women should be able to determine when and for how many times they should become pregnant. Known outcomes of this view are: smaller families that are less likely to live in poverty, improved education and hence job opportunities, communities with higher average standards of living, less criminal activity, healthier citizens, democratic governing structures, etc. Moreover, it is increasingly apparent that without constraints on population growth there is also the inevitability of genocide of a different type (see ecological principles 1–3) along with the following 20 realistic predictions. Peacefully debating the virtues of these two modes of so-called genocide will be a monumental challenge, but one we must face (Kopnina and H. Washington, 2016; Kopnina and B. Taylor et al., 2018; Washington et al., 2019). The good news is that there is abundant worldwide evidence that if adults have the tools and understanding needed for controlling their own reproductive output, it will be modest and sustainable.
8. An aura of optimism is important. Pessimism leads only to inaction followed by failures and more pessimism (Lidicker, 2011). An encouraging hopeful sign is the recent widespread mobilization of youthful activists in support of numerous progressive causes.
9. Conservationists should more aggressively confront the social tendency to minimize or ignore long term consequences of development projects, and take advantage of opportunities to educate the public about the issues involved (Laurance et al., 2014). Litigation also can be a tool for delaying projects long enough for public education to become effective (Florens and Vincenot., 2018).

4. Realistic prospects and problems

Obviously we need to muster all our resources and social skills to prevent continuing in our currently unsustainable trajectory. Equipped now with an ecological and behavioral framework, we can begin to carefully construct guidelines to inform our future efforts. A reasonable place to begin would seem to be an outline of our goals for humanity in the immediate future. Do we accept a fate of massive poverty, massive mortality from wars, terrorism, and disease, and uncontrollable migrations to the places where basic resources are still available? This is our current trajectory (Brown, 2006; Heal 2017; Kopnina and Washington (2016); Stokstad 2019). We can assume, I hope, that we would prefer a future that features a comfortable standard of living with minimal disparity among individuals and social groups, high levels of education, and democratic organizational structures for social groups at all levels of organization. In this way, everyone can feel they have input into decisions being made that likely will affect them. Especially important is respectful coexistence of diverse cultures and world views.

In the recent past, there has been much discussion as to whether our deteriorating situation should be blamed mainly on human population growth or whether affluence and pollution should share as major contributors (Ehrlich and Holdren 1971). Actually, these three factors interact in complex ways. For example, while improving the standard of living of people everywhere is clearly a desired objective, this certainly would add to the consumption of renewable and non-renewable resources. On the other hand, if affluence were more equally distributed than it currently is, it would improve the situation so that people in general are more content with their lives and hence are more likely to be cooperative and productive. Pollution of our environment also reduces our standard of living through its negative impacts on our health, and by increasingly deleterious impacts on our agriculture, parks, and natural areas. This in turn reduces the health benefits of natural areas (Weinstein et al., 2015), and diminishes the rate of replenishment of renewable resources.

An often heard argument is that technological advances will allow us to overcome the negative effects of population growth. Technology can and certainly will contribute to a slowing of the current negative trends. However, at this time in our history it is apparent that rapid human population growth along with out-of-control climate change will not only quickly cancel out many of the benefits for humans that technology may contribute, but it will continuously add new challenges as population growth, resource depletion, and climate change continue. Mann (2018) engagingly discusses this dichotomy of prevailing beneficial natural processes dominating our future versus a technology based “green revolution.” Probably some combination of these two survival strategies will prevail. The reality, however, is much more complicated. Superimposed on these two approaches, we face the real possibility that current and future climate changes will force humanity worldwide to

confront widespread disruption of human communities and ecosystem services, not to mention negative impacts on biodiversity (Norgaard, 2010; Nolan et al., 2018). For example, we can anticipate warming climates increasing crop losses to insect pests, especially at temperate latitudes (Deutsch et al., 2018). Moreover, it is especially important that we plan for anticipated extreme weather events and catastrophic fires. An example of a positive recent research finding is that restoring large grazers to depleted range lands can blunt the impacts of major fires in those situations (Pennisi, 2018).

Hopefully, the negative projections might increase the awareness of the public and governments regarding the necessity to confront the drivers of climate change more vigorously. Inevitably, this will incorporate an increasing focus on slowing of human population growth. Unfortunately, many humans, probably more than half, are opposed to any plan that would involve slowing and eventually stopping human population growth. There are many reasons for this point of view that makes folks unwilling to confront the risks we collectively face. One important reason for this reluctance is that since the late 1970's, most world cultures have moved toward rewarding individual benefits over supporting the common good. This trend compromises the feeling of cooperation within the social groups to which we all belong and depend on for our survival (Reich, 2019). More troublesome is the realization that, as mentioned, many folks view any efforts to contain population growth as homicide, etc. In reality, efforts to control our runaway population growth are precisely and explicitly the opposite. We want to improve the welfare of people everywhere, and strive to eliminate poverty, racism and other forms of xenophobia. Lastly, we would want to maintain an individual's freedom to control their own reproductive activities. The only constraint on an individual's behavior is that it must be compatible with the needs of the social groups to which they belong.

5. Realistic predictions

Realistic predictions can be derived from ecological and sociopolitical knowledge as well as from already existing trends, and can serve to motivate appropriate actions. An example of a well-established existing trend is that of global warming. Scientists have been concerned about this human caused trend at least as far back as 1966 (Landsberg, 1970). Predictions, however, are inherently risky, especially given the power of human ingenuity to address perceived problems. Three examples of failures to predict accurately are: 1) the much faster than predicted sea level rises associated with the deltas of large river systems (Voosen, 2019); 2) The unanticipated huge wave of unusually hot water that beginning five years ago swept across the Pacific Ocean causing widespread havoc with fisheries, seabird populations and whales, and is currently developing again (Cornwall, 2019); and 3) Concentrations of the greenhouse gas methane are increasing in the atmosphere more rapidly than predicted (Mikaloff Fletcher and Schaefer, 2019). In general, modern chaos theory supports the generalization that when dealing with complex systems, longer term predictions are more reliable because they are guided predominately by deterministic processes, while shorter term predictions are less reliably accurate since they often are strongly influenced by random processes. In general it will be very difficult to predict the ability of species and the communities of which they are a part to adapt successfully to the rapidly changing conditions in our future (Bridle and van Rensburg (2020). In this cautious spirit, the following 20 predictions are offered as potential warnings.

- a) The Earth's per capita ability to supply basic food resources for humans will decline (Deutsch et al., 2018; Riegler, 2018).
- b) Supplies of potable water will decline.
- c) The average standard of living will decline, probably with a continuously increasing unevenness of access to resources.
- d) Human immigration pressures will increase dramatically, mostly directed to those places on the planet that retain the highest levels of access to the remaining resources.
- e) Health maintenance levels and average life expectancies will diminish.
- f) The prevalence of disease outbreaks and pandemics will increase (Pongsiri et al., 2009). In part this will be due to progressive diminution and loss of favorable gut microbiota, especially in urban areas (Dominguez Bello et al., 2018).
- g) The proportion of individuals with debilitating mental illnesses will increase along with a general increase in the proportion of folks unhappy with their living conditions.
- h) Earthquakes will increase in numbers as a result of the proliferation of injection wells (Goebel et al., 2018). These wells generate significantly destructive earthquake activity up to 30 km distance from the wells.
- i) The Earth's climate will continue to warm into the foreseeable future (Naff, 2016) leading to increasing instances of extreme weather conditions (Murakami et al., 2018).
- j) Saltwater intrusion into coastal communities, sometimes for many kilometers, will endanger coastal forest wetlands (Gewen, 2018), modify greenhouse gas emissions, increase methane production, and jeopardize coastal real estate values (Worth and Dahl, 2018).
- k) Increasing ocean acidification will endanger marine life compromising an extremely important source of food for humans.
- l) Concentrations of methane, a powerful climate altering compound has nearly tripled in the atmosphere since 1800 and is expected to continue increasing driven by many causes, especially by agriculture and use of fossil fuels (Mikaloff Fletcher and Schaefer, 2019, Voosen, 2019, Voosen, 2020).
- m) Extinction rates for the Earth's biota will continue to increase alarmingly (Stokstad (2019).

- n) Insect biomass has declined dramatically in Germany (Vogel, 2017), and this may be a prelude for similar trends elsewhere.
- o) Rapid expansion of infrastructure, such as roads, to support human population growth will generate multiple hazards for humans and the rest of the global biota (Laurance et al., 2014; Laurance, 2019).
- p) Criminal activity in general will increase (Weinstein et al., 2015) as well as both domestic and international terrorism.
- q) Governments at all levels will become more authoritarian.
- r) Social groupings above the levels of neighborhoods and small towns will become increasingly xenophobic.
- s) Pressure for recreation will increasingly and negatively impact protected areas.
- t) Support for education and basic research will decline as they are threats to dictatorships.

6. Guidelines

Here are six guidelines for all concerned citizens of this planet that summarize recommended approaches for achieving a sustainable human civilization. In addition, please note that Kopriva et al. (2016) have provided a most welcome list of human behaviors that non-coercively will help to guide us to population stability.

- 1) Pay attention to scientific understanding, and support future research. To make this effective, scientists need to do their part by making the effort to explain their findings in ways that can be understood by educated non-scientists and especially by government leaders.
- 2) Remain as optimistic as the evidence permits. No one wants to contribute time and financial support to lost causes, even if they are presented as important for various reasons. On the other hand, optimism encourages enthusiastic support for even difficult but important programs.
- 3) Maintain respectful dialog with as large a component of the Earth's citizenry as possible. While local and regional projects are important for improving limited areas, and for education of residents and visitors, in the long term we will not succeed without significant cooperative involvement of all parts of Earth. We need to encourage the recent trends toward eliminating gender, ethnic, and racial biases in all aspects of human civilization. All women of reproductive age should have access to the tools needed to prevent unwanted pregnancies. Relevant to human population growth, it is important to note that when women have control over their reproductive activities, they typically make choices that are appropriate to their social and environmental circumstances. Population numbers then become stabilized. It is also critical for all sex-related decisions that all world citizens have access to education at least through the secondary school level.
- 4) Encourage cooperation and democracy in the organizational structure of social, governmental, and other groupings of various sizes and complexity. The Earth is full of countries with various levels of autocratic governments, and therefore we know that autocrats are not cooperative. Their primary job is maintaining their personal power. The welfare of their citizenry is low on their priorities, and may even be absent. Moreover, maintenance of the natural environment that in the long run supports their government may also be ignored or perhaps be exploited for monetary gain. Unfortunately, many countries, including the USA, are moving in the direction of autocracy, or are already there.
- 5) Be constantly aware of finding the appropriate balance of activities that support both the common good and those that enhance individual fitness. This dual support is essential for survival of social species such as *Homo sapiens*. However in some countries, including the USA, this duality is rarely mentioned and is certainly not emphasized. When it is mentioned, at least in the United States, it generally is put in terms of making money for the rich and large corporations versus unselfish giving to the poor. These behaviors are justified as appropriate capitalism on the one hand and admirable charity on the other. Recently, another tactic is to give to the financially poor and call it "socialism." Of course it is socialism but in some countries, such as the US, this name is translated to unacceptable communism. Meaningful support for the financially stressed is threatened or absent, and yet is important to find ways to keep those struggling with financial poverty as contributing members of a democratic society.
- 6) Don't underestimate the need for rapid progress in confronting the 20 predictions listed above. Cooperative social support is needed now. The current Covid 19 pandemic offers some helpful lessons in social behavior. Cooperation is now widespread and appreciated. Altruism is more and more common. Search for an appropriate vaccine is a worldwide endeavor. Even some corporations are considering giving to the common good. And, as predicted, there are individuals who compromise the cooperative spirit by intentionally not wearing masks when asked to do so, and thereby endangering the larger community in which they are a part. In such a social context, societies would be justified in protecting themselves from such dangers.

A final thought: Nine decades ago, Anne Frank gave us this wisdom: "How wonderful it is that nobody need wait a single moment before starting to improve the world."

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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