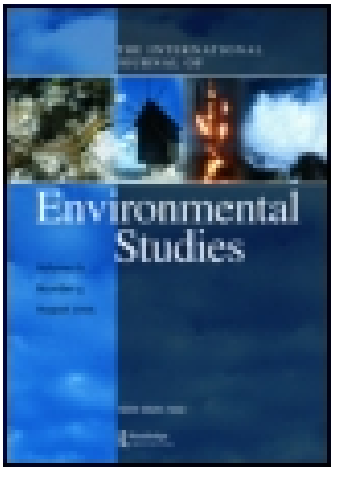

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Food security requires a new revolution

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A central responsibility of societies should be supplying adequate nourishment to all. For roughly a third of the global human population, that goal is not met today. More ominously, that population is projected to increase some 30% by 2050. The intertwined natural and social systems, that must meet the challenge of producing and equitably distributing much more food without wrecking humanity's life-support systems, face a daunting array of challenges and uncertainties. These have roots in the agricultural revolution that transformed our species and created civilization. Profound and multifaceted changes, revising closely-held cultural traditions and penetrating most of civilization will be required, if an unprecedented famine is to be avoided.

Keywords: Food; Environment; Population; Consumption; Equity; Governance

1. Introduction

Getting food, a basic task of humanity, influences all human societies and their environments. Following millions of years of hunting and gathering, the development of crop agriculture about 12,000 years ago and its rise to become a food mainstay 10,000 years ago utterly transformed the nature of human life and the magnitude of its impact on Earth. In doing so, it started *Homo sapiens* on the road to unprecedented population sizes, ubiquitous and large-scale inequality, and today's 'perfect storm' of environmental problems [1].

But civilization has never enjoyed prolonged food security. Famines have been common throughout history, caused by everything from climate-induced crop failures and war to politics and the maldistribution of wealth and food. The dictionary definition of insecurity is 'open to danger or threat; lack of protection' and today some 2–3 billion people are food-insecure. Over 800 million are malnourished, and another perhaps 2 billion lack adequate quantities of some essential nutrient [2].

Two views on the causes of, and future prospects for, global food insecurity are widely held. The first is that hunger is rooted biophysically because of constraints on how much food our environments can produce, and demographically because of the ultimate impossibility of feeding ever-increasing numbers of people. We examine the fundamental arguments in support of this perspective in Section 2. The second view asserts that the problem of hunger is one of access; sufficient food is, or can be, produced, but its production is not distributed equitably and the hungry do not have the wealth to obtain it. In this view, future food security is attainable, even with a global population that grows to 10 billion or more over the course of this century [3]. In Section 3 we argue that these two general views are

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entwined. In particular, biophysical and demographic factors not only degrade the environment but also hinder society's capacity to create the structures of governance and economics that will be necessary if society is to solve the problems of access and distribution.

In section 4 we synthesize these views and examine the prospects and necessary conditions for charting a course to a food-secure future for all of humanity. We conclude that enhancing equality, reducing human fertility, and improving ecosystem health are linked in a positive feedback with one another and with building the structures of governance needed to achieve those goals.

2. The problem is biophysical and demographic

Some of the hazards that will make producing adequate food supplies difficult are:

- Crop production decline from climate disruption: changing temperature regimes, prolonged drought, severe flooding.
- Decline of fish yields from over-fishing, ocean acidification, and dead zones, resulting from excessive fertilizer use driving eutrophication, which will be compounded by increasing temperatures from climate change, and reduction of the genetic fitness of the remaining populations.
- Increasingly constrained groundwater supplies as a consequence of expanded irrigation, overpumping, increased land-use intensity, extraction for urban uses, leading to lower water tables and groundwater salination, thus reducing crop production.
- Loss of fertile soil from both wind- and water-caused erosion, which in turn results from destruction of hedgerows, climate disruption, and too frequent tillage and cropping [4,5], and degradation of soil fertility through intensive pesticide use via impacts on the soil microbiome. Need for large amounts of lime to make fertilizer use sufficiently effective on old, acidic soils, especially in sub-Saharan Africa.
- Loss of biodiversity (including genetic diversity of crops), potentially resulting in pest outbreaks, increasing the perceived need for more pesticide use, lower yields, and less sustainable supplies of some foods [6].
- Loss of pest-control as climate warms: longer summer breeding season amplifying the reproductive rate of pest species and warmer winters reducing the degree of winter kill.
- Loss of pollinators from a combination of toxics in the environment, climate disruption, and changing land use practices [7].
- Increased likelihood of food spoilage in a warmer and in some places wetter climate, increasing risks of aflatoxin and other mycotoxins which are highly carcinogenic substances.
- Increased dependence on marginal crop and grazing lands, which are more vulnerable to all of the above risks, to meet the needs of a growing population.

Solutions to many of these problems have been thoroughly discussed [8], but with more people on the planet, demanding more calories and animal protein [9,10], all these existing problems will likely increase. As that occurs, the probabilities of the others rise as well because the decline in food yield that accompanies each problem puts pressure on the system to deploy quick-fix approaches. Coupled with the biophysical constraints on rates of soil formation, on the sizes of the atmospheric and aqueous sinks for our effluents, and on

the minimum food requirements of people, solutions to any one of the problems listed above tend to exacerbate others; linkages among the listed phenomena can result in the whole deteriorating faster than the sum of the parts [11]. To achieve a sustainable future, the magnitude of most of the problems listed certainly needs to be reduced greatly.

There have been great recent yield gains, but maintaining even level yields in the face of the destructive forces listed might lead to further mechanization to increase labor productivity. That can result in eventual yield improvements, but more energy consumption, given the current dependence on fossil fuels, would result in a worsening climate. Regulation of pesticides, herbicides, antibiotics, and fertilizer application requires cooperation among farmers, corporations, civil society, and governments and needs to be spread much more widely than is the case at present. Protection of open spaces adjacent to farmland – spaces that support natural pollinators and predators of crop pests, reduce wind-caused erosion, and recharge aquifers – is more difficult as the pressure on land increases because of population growth. That growth leads to increases in commodity prices and the need to expand tillage so that farmers can maintain profits under conditions of declining yield.

What needs to be done just to supply the needs of today's population for calories and nutrients is daunting, considering that at least 800 million out of the 7.3 billion people today are malnourished to the point that their bodies and brains have not been able to develop properly, and perhaps half of the world's people lack access to some essential nutrient. Most but by no means all are in poor and middle-income nations. But there are numerous reasons for even greater concern about the human nutritional future [8], when in 2050 the challenge will likely be nourishing adequately – supplying both enough food calories and necessary nutrients – over 9 billion people [9]. No one approach will feed even today's hungry, and the prospects of making 2.5 billion additional people food secure by 2050 and perhaps billions more beyond that [12] seem extremely problematic [13].

It is extremely difficult to project the biophysical constraints on how much food can be harvested and distributed. For example, the US National Climate Assessment demonstrates that disruptions to food production have become more frequent over the past 40 years and are projected to increase over the next 25 [14]. We do not know how much CO_2 and other greenhouse gases will be added to the atmosphere over that period, making it difficult to project decreases and increases to food production over that period [12–14]. In addition, the extent to which rising CO_2 will decrease the micronutrient content of staple crops [15] and thus influence the overall nutritional situation of humanity is uncertain.

There are many other sources of uncertainty. Will fertilizers manage to compensate for the continuing huge losses of soils to erosion, and to what extent can the erosion be controlled [4]? Will groundwater supplies, which show disturbing signs of widespread shrinkage [17], prove adequate for projected needs in the face of growing urban demand for the same water? Will water shortage also cause serious problems in the power sector in the absence of substantial reforms initiated soon [18,19]? In some areas will energy shortages reducing groundwater pumping feedback negatively on agricultural production [20]? How important and universal will the cheering penetration into poor rural areas of dispersed solar power technologies and other forms of alternative energy prove to be? Will the winter pest-control in temperate regions, which now provide an annual blow to crop-eating insects, decline seriously as the climate warms? How will it be possible to compensate for loss of agricultural land and salt intrusion of coastal aquifers because of sea-level rise? Obtaining food from the sea is vulnerable to further substantial disruption, as overfishing, climate change, acidification, and spreading of dead zones dramatically alter oceanic ecosystems [21]. What will happen to artisanal coral reef fisheries, on which millions of

people depend for critical protein, as corals decline with ocean warming and acidification? How will the spread of aquaculture, with its efficient production of protein but its competition for soybeans, fishmeal, fish oil, and feed grains, affect the flows of food to humanity? And will the decrease in availability of rich and easily accessed resources – of the 'low-hanging' fruit such as agricultural land in poor nations [22] – seriously interfere with attempts to solve food problems?

In sub-Saharan Africa, soils are often poor, the resources for adequate tools and for liming and nitrogen fertilizer application limited for economic reasons [23], water and water-handling infrastructure is scarce, and farm-to-market roads and distribution systems for agricultural products frequently inadequate. Agricultural and nutritional advice is scarce for the people who live in sub-Saharan Africa, with the population growing more rapidly than in any other major part of the world. Lack of access to education and the proper recognition of the rights of women and children, and other cultural factors [24] seriously retard sustainable development in the region. Diseases of various kinds are rampant, having historically received little attention from the world's industrial regions. These factors have led directly to enteropathy, child stunting, and mortality [25]. Worst of all, within 35 years, by 2050, the population of sub-Saharan Africa is projected to more than double, the needs of these people leading to a worsening of all the problems that are so evident now. This means that every night more than 90,000 additional people sit down to eat at the dinner tables of sub-Saharan Africa than required food the day before [12].

India is the most rapidly growing major nation of the world, with some 1.3 billion people, projected to pass China and become the most populous country in the world with 1.5 billion people in 15 years, and then growing on to 1.7 billion people in 2050. Over half of the population – more than 600 million people – lacks sanitary facilities and so they defecate outdoors, and almost half of the young children have stunted growth, numbering some 68 million children distributed across all income groups. The nation's rivers and streams are open sewers, and dried faecal matter is pervasive in wind-blown dust. Almost all pathogenic bacteria in India have become antibiotic resistant, creating a huge problem not only for India but for the rest of the world as well. And in many poor nations, cooking over firewood often results in severe respiratory health [26] issues for women and children breathing indoor air pollution [27], also decreasing their productivity.

The interactions among the biophysical and social problems are also daunting. Providing *all* of humanity with food security could mean increasing agricultural production some 70–100% by 2050 in response to population growth even if the critical steps to limit it were started now [28], as well as limiting demand for meat-rich diets and competition from biofuels derived from crops. Solving the food problems of the poor will require the expansion of dependable energy supplies [20], and create pressure to expand the oil subsidy to agriculture. It has been predicted that an additional 6–13 million hectares of land will be brought under cultivation annually between 2010 and 2030, [10,29] much of it by deforestation which in turn worsens climate disruption, disrupts pollination systems [30], causes pest problems, and accelerates the extinction crisis.

More emissions will further alter precipitation and temperature patterns further threatening farm productivity. Increasing yields and total food production will thus be made more difficult by the environmental effects of expected moves to both more intensive and extensive agriculture. These include accelerated loss of biodiversity, soil erosion, depletion of vital aquifers and further toxification of those aquifers as well as of surface freshwater, soils, oceans, atmosphere, and organisms by fugitive pesticides, fertilizers and antibiotics. The results of all this will be higher food prices. Steps forward in agricultural productivity

could thus be offset by steps backward; a net *reduction* in food production is possible though most believe not likely. And the accumulation of chemical contaminants in foodstuffs may, by 2050, itself become a major barrier to feeding people properly [31]. Indeed it may have already done so, especially in nations like China [32], India, Thailand, and probably in many other developing countries where pesticide regulation is extremely lax. Anthropogenic effects on human intelligence have not been limited to toxin exposures in poor or developing nations; effects of lead and mercury toxicity on mental capacity have been documented in wealthy nations as well. Also of concern is the possibility that anthropogenic toxins increasing in food and the general environment may be gradually reducing the intellectual and economic capacity of the human population to respond properly to any crises [31,33].

There are, additionally, negative impacts on humanity from the food system not caused by inadequate supplies. Among these are unwise application of antibiotics in husbandry, temporarily improving yields but leading to disease resistance in both livestock and consumers of meat; poisoning of people from the increased use of pesticides, herbicides, and fungicides in agriculture; and increasing threats to both human and ecosystem health as a consequence of increasing nitrogen and phosphorus use on farmland.

3. The problem is access

In many parts of the world more food is produced than can be locally consumed, some is exported, and much is wasted. Poor people and poor countries have limited access to food. Framing the hunger situation as simply a curable problem of access, however, ignores a fundamental reality – curing maldistribution of food and inequity of wealth requires dramatic alterations of human attitudes and consequent changes in governance and culture. People with an abundance of food would have to be concerned about those who are hungry, and act upon that concern, if the situation is to be improved. Numerous social, economic, and political uncertainties surround this issue. What can and will be done about the long recognized problem of vast wastage and the possibility of increased spoilage with higher global temperatures [34,35]? Despite at least a half-century of recognition of the problem, too little has been done to see that a greater proportion of the food grown reaches the hungry rather than being thoughtlessly discarded or rendered inedible by fungi or bacteria or being devoured by rats and insects. Who will care and what will be done about inequities of access, both within and between nations? How hard will technological and other improvements to the food system be pushed, what will be their impact on small farmers [36], and how successful will they be [37]? How will the contentious issue of the advantages and disadvantages of global food trade work out? [38]. Can the distribution problem be solved within the nation-state international system, a growth-oriented capitalist economic system that perpetuates inequity [39], and its accompanying attitudes, institutions, and population growth-related decline in democracy [40–43]?

Nutritional problems are present in rich, middle-income, and poor nations. Nowadays, one of the most important and widespread nutritional problems, particularly in countries where food is relatively plentiful, is a serious and growing epidemic of morbid obesity that can have very different causes in different regions and different nations. In some places insufficient calories may result in starvation; in others, the more subtle impacts of inadequate intake of protein or other nutrients are pervasive. One result is the epidemic of type 2 diabetes which is severe enough to threaten development [44,45]. And developing

nations are susceptible to being caught in a 'middle-income trap' in which development stalls, one reason for which may be a failure to supply adequate micronutrients for cognitive development and education in the labor force [46].

In contrast to many nations, in the United States food is abundant, and the SNAP (food stamp) program helps minimize food insecurity, but malnutrition persists in some areas because of poverty or a lack of iron or other essential nutrients in the diet. Problems as diverse as autism, asthma, attention deficit hyperactivity disorder, malocclusion, and sleep apnea seem to be increasing. They are likely due at least in part to a series of developments in industrialized societies alone or in often synergistic combination. These include exposure to toxics [31], consuming highly processed food rich in carbohydrate, fat and salt – junk food, and poor eating/feeding habits [47–51] including early weaning [52–54]. In the US, as in almost every part of the globe, many people do not receive adequate education in what comprises a healthy diet. In sum, despite growing interest in 'health foods' and the like, US farm policy 'tends to neglect health and environmental outcomes, at home and abroad, as well as the interests and perspectives of the broader US electorate.' [55] It seems unlikely this situation will improve dramatically, especially since nutritional information is widely available but equally widely ignored under pressure from a profit-driven industrialized food system. In the US, legislation to rein in nutritional abuses, such as rising per-calorie taxes on dangerous sugary drinks [56], is very difficult to pass.

Even if redistribution and dietary change could, in principle, satisfactorily nourish all, at least today, population size and growth still matters enormously. With some 220,000 extra people being added globally every day from now to midcentury, the problem certainly seems to be a daunting one. The reason is that redistribution and revision of many other elements of the food system, such as improving sustainable agricultural productivity on our best agricultural lands and making adequate fertilizer, improved seeds, credit, and roads available to poor farmers, requires the general acceptance of the necessity of doing so and the allocation of adequate resources for those purposes. If people accept the necessity for dealing with one another in an equitable fashion, responsible governance could be put in place with the power and mandate to create a vastly improved system of growing and distributing nutritious food worldwide. Literacy, education, justice, an informed, caring citizenry that is horrified by hunger in their own nations, absence of persistent violence, open and responsible governance, and a transnational attitude, could be combined to solve the major problems we are discussing here. Absent those factors and an evidence-based culture, greed is likely to remain the main negative factor in the equation and inequality in wealth, food, and every other resource is likely to continue as the norm.

Governance that treats all people with respect might be able to create the institutions necessary to redistribute wealth from the few to the many and reduce the 'unequal access' element in the food crisis. But the conditions that create the social order needed for such fair and responsible governance, and thus avoid food insecurity, are linked to population size [41]. Teeming cities with underemployed, undernourished, and undereducated residents [57], and impoverished countrysides with too little land to sustain more, and larger, families are not conditions favoring democracy. Citizens must be able to influence their representatives, and their representatives must be able to influence decision-making. Furthermore, without profound changes in norms it is not at all clear that the people would select the kinds of governments that would bring these changes about.

There is a dramatic decline of democratic decision-making as the number of people electing each representative expands. Current conditions promote corruption and failure on the part of government to build and maintain the institutional instruments that are necessary to

advance justice and equality. As the human population, and thus the demand for food, grows, it becomes even more difficult, not less, to establish the institutions under which equitable redistribution of food is even possible. This has caused some to question whether democracy is the best form of government to solve today's human problems [58,59]. It is not clear, for example, whether democracy is required to achieve food security, or whether democracy is an outcome of food security. The complex relationships among food security, democracy, and equitability certainly deserve further study.

There can be exceptions to this dismal analysis, for there are no iron-clad rules dictating social progress and many factors besides population density influence governance. We maintain, however, that these exceptions will become ever less probable, as population grows and living conditions deteriorate further.

Proponents of the maldistribution explanation for food insecurity are correct in that economic inequity is a huge contributor to world hunger, and nothing we say should be construed to mean that efforts to achieve greater social justice, regardless of population size, should be anything other than unrelenting. But one can no more isolate maldistribution from the stresses on society and governance brought about by environmental degradation and population growth than one can isolate total consumption from population growth. Maldistribution today is both a cause of food insecurity and a consequence of the many demographic and biophysical forces that also limit the capacity of humanity to govern itself rationally for the common good.

4. Can humanity be fed?

It is possible to look at the synergistic interactions linking biophysical, demographic, and social forces discussed in reverse and envision a path to a sustainable future. As improvement is made in any one of the problems listed previously, the destructive synergies described above now work to the advantage of society. Additionally, with more emphasis on family planning, the opportunity to access education and health care will increase, and more knowledgeable farming practices and food choices would ensue; arguably, all of these would generate even better governance that might lead to improved policies to reduce the threats we face.

An enormous number of conditions have to be met if humankind is to thrive sustainably. People desire confidence that their fundamental needs, and those of their offspring, for health, food, education, justice, and absence of violence will be met. Each of those factors influences the others in a tangle of complex causal interconnections, and hence a tear anywhere in the fabric of society can spread, and unravel the social order. As population density grows, and achieving each of the factors that comprise the social order individually becomes more difficult, the quality of governance and the sustainability of the entire enterprise become further threatened and likely decline. Particularly when food becomes scarce, it is difficult to achieve any of the other desirable conditions of life.

The basic dilemma facing humanity is how to solve enough of these problems, many if not most acting synergistically [11], to avoid a disastrous decline in general health, cognitive capacity, and social order. Prediction is especially difficult because of nutritional security's sensitivity to major global changes in a structure consisting of two interacting complex adaptive systems: the social and the biophysical [60].

The language of probability provides a useful way to think about the opportunities for a sustainable, desirable, future in which food security is virtually universal. There are far

more ways for a complex adaptive system to degrade than to improve. There are so many pathways to disaster, many mediated by the negative role that ineffective governance can play. Thus, the odds are stacked against our charting a course to a sustainable future. Consider by analogy the phenomenon of increasing entropy in a non-equilibrium closed system. This is because there are more ways to arrange the elements of a system to raise, rather than to lower, entropy (a measure of unavailable energy, incoherence). There are probably vastly more ways in which a society, even one governed by market forces, can go wrong, can fail to marshal talent and resources for the public good, than it can, somehow by good fortune, achieve sustainability.

A counter argument is that virtually any complex system, whether it be an ecosystem or civilization, can be sustainable if it is free to adapt to adverse contingencies. Out of the numerous pathways leading to disaster, the adaptive system will beat the odds and find one of a small number of pathways to achieving robustness. Free market economists lean on this intuition, add to it the notion that economic efficiency is beneficial to humanity, and thus support the view that 'the market knows best'. The past century of economic history has taught us, however, that without regulations and numerous other interventions, a literally free market economy would be a blueprint for disaster. The economy would indeed adapt, but in a manner that would serve the short-term needs of those with money and power, not the long-term needs of humanity [39,61]. The challenge today is to design and implement the types of regulations most likely to result in a food system that can nourish all.

Planning for a sustainable and effective food production system will surely require heeding constraints from nature, avoiding loss of biodiversity and maintaining ecosystem services, halting excessive use of pesticides, herbicides, fertilizers, monoculture cropping, and antibiotics in food production [62], greatly limiting greenhouse gas production, and reducing population to a sustainable level.

But planning and then pursuing a sustainable course for humanity under the constraints imposed by nature requires a convergence of goals across the whole of society. Unfortunately, there is plenty of evidence around the world today that conflicting, not unifying, goals, dominate events. A goal of some is to use government to annihilate all but their favored religion or narrow political position. A goal of others is to annihilate government, stripping it of most of its powers to tax, maintain infrastructure, and regulate. Others would annihilate wilderness to profit from other uses of the land or (as in the case of tar sands) to obtain the riches buried beneath it.

The tightly linked goals of addressing the problem of inequity and injustice on the one hand, and surmounting the biophysical and demographic barriers to sustainability on the other, appear so daunting today precisely because the planning process that will be required to achieve them can only be carried out in a world that first recognizes that all other goals are secondary. This is, sadly, not the world we live in today.

The details of the events that inevitably emerge in the complex social and biophysical systems are unpredictable, but they include potential discontinuities that could shape the global nutritional situation. For instance, a 'small' nuclear war could make moot the issue of whether it will be possible to maintain or improve the present level of global food security through mid-century [63]. Another major problem is the two-way interactions between novel epidemics and nutrition. Poor nutrition is, along with population growth and increasing mobility, a factor raising the probability of novel pathogens invading the human population, taking hold, and spreading [64]. A global epidemic of a pathogen such as the Ebola virus or drug-resistant tuberculosis could also totally change humanity's situation,

being especially dangerous to malnourished individuals and also disruptive to agriculture production and supply, as the Ebola outbreak has shown [65]. All bets would be off. Considering the potential consequences, a novel approach to risk analysis seems required [66]. Unfortunately, no one can assign specific probabilities to the occurrence of each of the contributing elements of degradation, nor assess quantitatively the increase in those probabilities as a consequence of population growth. Nor can we assess quantitatively the decline in the social order brought about as problems pile up.

Perhaps the biggest uncertainty is whether key politicians and other decision-makers will openly recognize the building population-food-equity crisis and provide leadership. Will they move it to the top of political agendas? Many other issues are much more important to the people who elect the politicians, and many aspects of moving this one to the top of the agenda would be likely to damage their chances of maintaining political leadership. Experience has shown, however, that appropriate government leadership can make important progress even when governments suffer from substantial corruption [67]. Much more financial support needs to be given to critical agricultural research [68]. More attention is important to protecting the precious genetic resources still required to supply the raw materials for developing new more productive, pest- drought- and salt- resistant crop strains for the changing world of the future. Seed banks, such as those of the USDA, CGIAR and that at Svalbard, can be useful for preserving genetic resources, but they need to be carefully managed, which generally is labor intensive and expensive. Redesigning and remodeling the infrastructure related to agriculture, such as irrigation and storage/transport systems, will be required if humanity is to become food secure now and into the future. And much more attention to nutritional education is needed, especially with regard to how to educate parents to put infants and children on a healthy eating and dietary regime. There will be huge economic barriers to overcome. Without strong support from the public, the politicians/governments won't act, simply having many other issues that may be more important politically.

Progress will not just entail fighting for cleaner energy, or for better agricultural practices, or for sustainable management of scarce resources, or for providing women with more rights and opportunities, including access to modern contraception and abortion around the world. It will take all of those and more, including fundamental cultural change [24]. In addition progress will require redesign of the values of people and the institutions of society away from the dominance of financial motives, focusing more on resilience, a striving for virtue (in a Platonic sense), equitable distribution, and extreme vigilance to insure that governance is working in parallel, not in opposition, to achieve these goals.

Reducing the role of wealth in the electoral process is an obvious first step, and redesigning global governance systems in the face of growing evidence of the obsolescence of the nation state the ultimate goal. Doing all of this would admittedly be an enormous task, but if steady improvement in each of the contributing forces is made, then there can be hope that the benefits will synergistically multiply.

The detailed descriptions above of the destructive consequences of even just attempting to feed over seven billion people today can be viewed within the IPAT formulation of impacts. IPAT [69] makes explicit the multiplicative harms that can result from the combination of our population size, our per-capita demands, and the damage caused by the technology used to satisfy those demands. Over the past several centuries, the history of agriculture can be viewed as an increasing trend in all three of these contributors to impacts: our population size, our per-capita demand for meat and other water- and land-intensive sources of nourishment, and as described above, the harmful effects of each

unit use of agricultural technology on the sustainable food-producing and biodiversity-supporting capacity of the planet. No one or even two of the factors, P, A, T, offer enough leverage to provide for food security; all three factors need to change substantially. Humanity's task is achieving forms of governance, from local to world scale, that can peacefully bring about those substantial changes. In a perverse chicken and egg dilemma, current trends in P, A and T are all working against the capacity of humanity to get a grip on these fundamental drivers of food insecurity.

5. Conclusion

It is ironic that population pressure and climate change may both have been important factors in the evolution of agriculture [70–72], and today both are deeply involved in the nutritional fate of our species. In principle we are optimistic that the necessary increases in production *could* be attained, although likely with high environmental costs, but it would require an effort equivalent to a global Marshall Plan. Even that would likely not be sufficient without dramatic changes in norms related to the global economic system and especially toward population and economic growth and the emphasis on profits for the few. We admit that our personal view is that such change is nearly impossible, especially since we see little sign of recognition of the need for, or of real progress toward, even the most obvious of the goals such as a rapid transition away from the use of fossil fuels. It is encouraging that fertility rates are mostly declining throughout the world, but because of the existing population size, and the age structure, and consumption trends, and resource deterioration, and social/political disintegration, and loss of ecosystem services, this is not nearly fast enough. There is no humane scenario in which population size can decline to a possibly sustainable level (perhaps 2 billion people) in less than a couple of centuries. Indeed, according to one study it cannot go below the present size in this century [28]. The truth is that it is not yet clear whether the first agricultural revolution opened the door to a bright future or was the biggest mistake ever made by *H. sapiens*. Observing humanity's collective behavior, we are inclined toward the latter view. Nature is likely to run its obvious course.

But events like the civil rights revolution in the United States in the 1950s and 1960s and collapse of the Soviet Union in 1989 show that, when the time is ripe, sudden change is possible even when seemingly very unlikely [73], You can be sure complex adaptive systems will produce emergent properties, and they are not necessarily all bad. What is obvious to us is, however, that if humanity is to avoid a calamitous loss of food security, a fast, society-pervading sea change as dramatic as the first agricultural revolution will be required – and one where the consequences will be carefully considered. Will change be sufficiently great not just in food getting, but in human demographics, consumption patterns, especially in the energy sector, and in norms? For the new revolution to succeed the changes will both require, and help promote synergistically, new forms of governance and of economic relationships. And only then might the resulting nutritional bounty be equitably shared over the planet.

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