Beyond Fed Up:
six hard trends that lead to food system breakdown

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Professor Jem Bendell, March 1st 2023

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"Jem Bendell's paper (and forthcoming book) is a wake-up call that our global food systems are approaching global breakdown due to a number of interlinked hard trends, from biophysical limits of food production and climate change to growing demand and the destructive implications of our profit-oriented capitalist system. The application of interdisciplinary integrative analysis and the emphasis on economic, social, technological and ecological dimensions of the challenge ahead helps to grapple with the complexity of the issue and to avoid simplistic solutions. It is an analysis that motivates the reader to act at multiple fronts and critically engage with a topic that has a huge bearing on the future of humanity."

Dr Katja Hujo, lead author of the UNRISD Flagship Report 2022 "Crises of Inequality: Shifting Power for a New Eco-Social Contract".

"We are conditioned to fear disorientation and seek safety in certainty and solutions regardless of the information available to us. Breaking that protective screen, this paper adds to the weight of analysis that the collapse of food systems and societies more broadly is inevitable. But how we are in relationship with these changes is not fixed even if, as this paper argues, we are stuck. Perhaps what this paper is calling for is the spaciousness to ask new questions, to challenge habits and myths, that may then shift perceptions. Consequently, we could be in relationship differently with the inevitability of collapse, and sense the possibilities that are perceivable with renewed care, compassion and generosity to ourselves and to all life."

Scott Williams, Contributing Lead Author for the UN Global Assessment Report on Disaster Risk Reduction 2019 and 2022 and contributing author to the International Science Council/ UNDRR Briefing Note on Systemic Risk.

"The fragility of our systems is underexplored and we need to pay attention to warnings from integrative analyses like this paper. And then act like never before, with fierce resistance on behalf of life itself."

Clare Farrell, Co-founder, Extinction Rebellion.

Preface from the author

This Occasional Paper is one output from a 2-year research project with an interdisciplinary team including an agricultural scientist, heterodox economist, and environmental journalist, as well as myself, a sociologist undertaking critical interdisciplinary research analysis on sustainable development issues. It outlines six hard trends which drive a global food system breakdown. The paper is an excerpt from my forthcoming book on the topic of societal collapse, *Breaking Together*, and shared now due to the urgent implications for both local and national governmental policies, philanthropy strategies, and organisational or personal decisions relating to food security.

As an academic it should come as no surprise when I claim that the scientific method is a powerful approach for understanding reality. But it should also be no surprise that an academic also recognises how the cultural, economic and institutional influences on the research process, and the 'siloing' of research into disciplines, constrains what specialists in specific disciplines choose to conclude and communicate. Rather than asking too much of science, we have been asking too little of it, by not interrogating sufficiently the way cultural and institutional factors, derived from systems of capital and power, are influencing questions and findings in ways that reduce the impetus for radical change.

Scientists who take these limitations seriously have been sounding the alarm for society. Two hundred of them warned of potential 'global systemic collapse' in a report that also explained why we do not hear such warnings so often and so clearly. "Many scientists and policymakers are embedded in institutions that are used to thinking and acting on isolated risks, one at a time," their report said [1].

That is why critical interdisciplinary research analysis is so important. First, it is driven by the intention of identifying knowledge that is salient to an issue of public interest. It identifies research publications from a variety of different disciplines that are potentially relevant to that issue and then analyses them for what might be the most important findings on that issue. Sometimes such findings are not what the original researchers focused on in those publications being analysed. The process of salience identification by a research analyst involves cross-referencing findings and claims from different subject specialisms. It is aided by a 'critical' approach, which stems from appreciating the many influences on any process of conducting and disseminating research. They include the financial and political pressures for remaining deferential to established ideas and institutions, the de-radicalising influence of privilege, a wish to avoid difficult emotions and the ideology of progress that can shift where the burden of proof is seen to lie when considering data.

To do critical interdisciplinary research analysis well, it can help to have experience from different cultural, professional, and disciplinary contexts. It is also useful to have training in scientific methodologies, the history and philosophy of science, the humanities, and critical literacy. The latter term refers to understanding how frames, narratives and discourse shape what is assumed, excluded or focused on, in ways that are produced by power relations and then reproduce those power relations. Without such experiences and training, when scientists generalise outside of their field of expertise, it can involve the unconsidered use of 'common sense' assumptions that reflect dominant culture and exclude analyses that challenge their worldviews.

By recognising the limitations of reductionist research and siloed disciplines, scholars who are interested in 'systems thinking' come close to such approaches but don't always critically analyse the source material for the biases described above. Unfortunately, critical interdisciplinary research analysis is a capability that is neither taught nor resourced in scholarship, nor rewarded with opportunities for professional progression. Because such analysis can lead to conclusions beyond those made within the specific disciplines being drawn upon, and can relegate to irrelevance some of the nuance and semantic detail, it can annoy discipline-restrained scholars. When the conclusions are particularly troubling, or threatening to the establishment, then reactions can be unusually negative and seek to marginalise the people, concepts and organisations involved. Typically, that can involve accusations of sloppiness, arrogance, conspiratorial mindsets, political bias, or extremism. Unfortunately, the temptation can be high for some experts to make such accusations if they seek to position themselves as more reasonable in the eyes of the establishment (whether for their professional advancement, or their theory of change, or even a subconscious need to fawn to power in response to growing anxiety).

In the case of societal collapse, and the food crisis, the issue is so important that, as scholars, we must not be deterred by such reactions. I encourage you to interrogate the arguments in this paper for yourself, via the references provided. The paper does not provide ideas on how to respond to the crisis it identifies. There are many ideas and positive activities occurring, some of which will be covered in my book *Breaking Together*. This paper is an preprint of Chapter 6 of that book, and therefore refers to the book and other chapters throughout.

Jem Bendell, March 2023

[1] Scientists Warn Multiple Overlapping Crises Could Trigger 'Global Systemic Collapse': ScienceAlert. https://www.sciencealert.com/hundreds-of-top-scientists-warn-combined-environmental-crises-will-cause-global-collapse

The six hard trends that lead to food system breakdown

I first started thinking about global food supplies in the mid-1990s. It was my first job after university, in the Forest Unit of WWF-UK, where I was working to develop demand for products certified using the guidelines of the Forest Stewardship Council (FSC). In open plan offices, people can hear what others are up to. In front of me was Simon Lyster, working on UK wildlife. On the other side was Barry Coates, working on nasty trade rules and global debt. Next to him was Richard Tapper, working on toxic chemicals. Closest on my left was Michael Sutton, on secondment from WWF International. He was working on the state of the world's fisheries, which by that time, in 1996, were already extremely bad. Nine of seventeen of the world's major fishing grounds were in serious decline and four were commercially finished. There were also terrible problems with the lethal by-catch of sea creatures unwanted by industry, such as dolphins and sharks.[1] After a few chats in the corridor about how my work was going, Michael asked me to lunch to discuss an idea. Could we copy the idea of the FSC for fisheries? Translating consumer concern into demand for products that met meaningful social and environmental criteria seemed to offer a way forward in the face of governmental inaction. I grabbed the chance to develop something new and, in the coming months, wrote a report on how to apply this model in the fisheries sector. If it was to become an actual organisation, it needed a nice name. Fish stewardship and ocean stewardship sounded like sequels to the 'she sells seashells' tongue twister, so in one of my emails I put 'Marine Stewardship Council' in the subject line. I remember thinking I'd enjoy submitting a report on something that sounded so important. And being important to the future of the world was a big driver for the twenty-four-year-old Jem.

Twenty-seven years grumpier—I mean later—I can recognize that today's MSC has some numbers of importance. It employs over 140 people and certifies 12 million tonnes of fish, which is about 15% of all wild marine catch.[2] It is also important enough to attract criticism for not actually addressing the social dimensions of the fishing industry as much as we'd hoped it might. But what about the world's fish stocks? The poor guy I hired to update me on fish, as well as other food, became rather deflated because not only is the situation worse than it was almost three decades ago, but the causes of the problems are no longer ones we could choose to change if we only had political will. Instead, the damage to our ocean ecosystems is now so great and self-reinforcing there's no way of either responsibly consuming or regulating our way out of disaster. What is also depressing for me is that many of the experts working for the leading organisations are ignoring these systemic problems in order to remain upbeat about what the oceans can provide for humanity in the years ahead. Yet another instance of a refusal from establishment experts to fully integrate what's happening in the context around their topic to reveal the true extent of the disaster we already find ourselves within. It is the insularity of privilege, which afflicts so many scholars, that I explore further in the following chapter. As we have seen in a discussion of biodiversity and biosphere collapse, some experts like to criticise humankind in general as a bad thing for planet Earth by claiming that all past civilizations destroyed their environments. We have also seen the evidence for that view is patchy. But even so, no past civilization trashed life in the oceans like modern societies have done. Indeed, seafood was often the fallback option for civilizations under stress. For instance, the last large settlements of Mayans were along the coast, and there is evidence many then set sail to new lands in North America.

Fish and seafood are just a small part of the mix which makes up our global food supply. And that food supply is utterly dependent upon the favourability of the climate, the health of the biosphere, as well as the energy required to produce, store and distribute food. Its mass provision also depends on monetary, economic and social systems. History shows clearly that, should any one of these factors fail, food supply is hit, and societal disruption and collapse can result. It is why famine is identified as a key contributory cause of past societal collapses. Archeologists point to it as a factor in the Mediterranean Late Bronze Age collapse,[3] the Khmer empire of Angkor Wat,[4] a number of Meso-American societal collapses,[5]the collapse of the Nordic settlements in both Greenland and Iceland[6] and the collapse on Easter Island (although other factors including colonisation were also key).[7] Like all the other factors we discuss, a disruption to food supply does not need to be the only, or even the primary cause of collapse. But it is unquestionably a trigger for processes of both social and economic breakdown that lead to societal collapse. The revolutions and social uprisings known as the Arab Spring (2010–2011) demonstrate quite clearly the power of food shortages and associated price hikes to catalyse social upheaval, even in the modern era.

So how is the situation today? According to The Food and Agriculture Organization of the United Nations (FAO), the global supply in 2019 provided for an average of 2963 Kcal/person/day[8]—so total global food supply currently well exceeds the nominal 1800 Kcal/person/day required. The growth in global food production appears to be a modern success story, increasing by a staggering 376% since the 1960s.[9] This means the food supply *per person* increased by around 30% at the same time as the global population more than doubled—a truly astounding feat. Except that this food supply is not actually available *per person*, because it is inequitably distributed, and so much is wasted. Children suffer lifelong impacts from periods of hunger, so it is particularly upsetting that 22% of the world’s children now suffer stunted growth. Starvation is also looming larger. In 2020, there were at least 155 million acutely food-insecure people in need of urgent assistance to avoid starvation in 55 countries/territories.[10] By October 2022, that figure had more than doubled to a record 345 million people in 82 countries.[11] That’s more than 40% of the UN’s member states. And it’s getting worse—every year—for the past 7 consecutive years.[12] [13]

The problems making this situation worse are ones that humanity could fix, if we rescued food systems from monopolies and profligacy, and ones that we are unable to fix, such as the crumbling energy, biosphere and stable climate foundations of our global food systems. Even the cautious FAO reports our globalised food supply system is already “stressed to breaking point.”[14] Unfortunately, the result of my research into food from land and oceans concludes it’s worse than that: the systems are already breaking. In this chapter, I will outline six hard trends that increasingly constrain the global food supply, so that many societies which did not experience widespread food insecurity in living memory will begin to do so in a few years. And the suffering of the many societies that already experience it, will likely increase substantially. These are hard trends because they pose catastrophic implications for humanity unless all of them are reversed, and yet they are difficult or impossible to even slow, while also amplifying the negative impacts of each trend. A disruption to food supply would not need to lead to upheaval and collapse, if we learned to forego certain kinds of foods and better share what we produce. However, none of the commercial or governmental organisations at national or international level have any mandate or mechanism for such an aim to be primary and to determine food distribution.

Trend 1: Modern societies are hitting the biophysical limits of food production

There are two sides to the food security equation: demand and supply. On the supply side, there is the question of how much food the Earth can produce. This seemingly simple question is impossible to answer. The maximum possible food production of the Earth depends not only on environmental constraints like soil, rainfall, terrain and the length of the growing season, but also on human choices and culture.[15] What do people regard as food? How do they produce it and what education, technologies and infrastructure are available to support this? How do economics, trade and politics affect the availability of required inputs, or the ability of produce to reach the intended consumer?

We can use our knowledge, of the past and the present, to explore the possible limits to food production, but this falls short because innovation and new technologies sometimes break through the limits of what we know and ‘shift the goal posts’, allowing us to produce more food than we previously thought was possible.

At the beginning of the 20th Century, German chemist Fritz Haber successfully fixed atmospheric nitrogen (N) in the laboratory. Five years after that, in 1913, another German chemist, Carl Bosch, developed the first industrial-scale application of Haber’s research, producing the explosive, ammonium nitrate, for the German military. Although the Haber-Bosch process was developed for military purposes, the agricultural applications of ammonium nitrate as a source of otherwise limited nitrogen fertiliser were immediately obvious and the technology was widely adopted. It is this technology that almost single-handedly allowed the world to avert a food crisis.[16]

This is *not* to say that technological innovations are not problematic (they certainly are, as will be discussed in a moment). But it *is* to say that sometimes technological innovations have significantly shifted the limits of what we knew was possible in terms of food production. The same can be said of irrigation, mechanisation and automation, crop breeding and genetic modification and synthetic fertilisers and pesticides. All these technologies have had benefits and drawbacks, so whether you regard them on balance as ‘good’ or ‘bad’, it is historical fact that such technologies have allowed humans to break through the previously known limits to food production, and that such technologies are precisely why, for the past sixty years, growth in food supply has been outstripping growth in food demand. Is that cause for confidence about abundant food in future? One way to forecast the future food supply is to extrapolate from current trends. Although that can downplay recent and rapid changes, such as with the climate, I discovered that simply doing such extrapolations leads to a conclusion that the food security of modern societies is already coming to an end.

Up until 2019, global food supply was still growing. However, the *rate* of that growth is falling, and has been falling, consistently now, for over three decades. In the 2010s production grew 1.4% each year, in the 2000s it was 1.7% per year, in the 1990s it was 2.1% per year.[17] Should this long-term trend continue it is inevitable that food production will soon stop growing and so demand will outstrip supply. In 2017, commodities analyst Sara Menker predicted a global shortfall in total calories as early as 2027.[18]

There are numerous reasons why the rate of growth in food supply is slowing. First, we now know with certainty that climate change is constraining food production across the globe. Because this is such a critical and paradigm-changing issue for food supply, I discuss this separately below (see Trend 4). But even without the additional burden from climate change, there is strong evidence our current food production systems are hitting their biophysical limits.

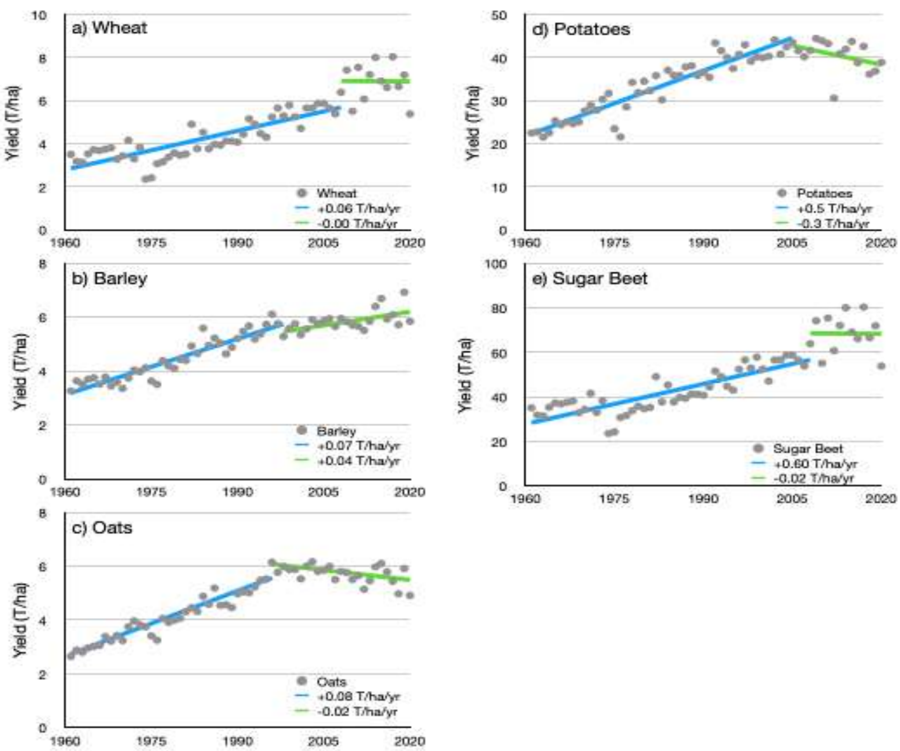
One important factor is that we have passed ‘peak agricultural land’. That was a new concept for me. While I was aware of the agricultural *expansion* and associated deforestation that is happening in parts of the Global South, such as in the Amazon, I was not aware that, globally, agricultural land is actually *contracting*. Population growth and socio-economic development that increase the demand for housing, industry and infrastructure is one major cause of land conversion.[19] But most loss of agricultural land is due to degradation of its biophysical status: increasing aridity, soil erosion, soil nutrient loss, soil salinization, soil carbon decline and vegetation decline.[20] The FAO estimates that globally the ‘biophysical status’ of 38% of the Earth’s land surface is declining. Putting that 5.7 billion hectares into perspective, it is an area equivalent to the land surface of Russia, Canada, China, USA, Brazil and Australia combined.[21] Such land degradation has already reduced the productivity of about a quarter of all the land surface on our planet.[22] Depending on the data source, the phenomenon of ‘peak land’ for agriculture occurred as early as 1990 at 4.28 billion hectares,[23] in 1999 at 4.88 billion hectares,[24] or in 2000 at 4.95 billion hectares.[25]

In concert with the degrading and shrinking land base, the gains in production realised by technological innovation and the industrialisation of agriculture in the financially richer countries are now hitting their limits. Agricultural production in such countries has stagnated (and in some cases is falling) both as the biological limits of plant and animal production are reached, and as the environmental consequences of industrial agriculture directly affect production. For instance, FAO data for the yields of major crops in the UK show clearly the era of steady growth in crop yields is over, and that yields are either stagnant or in decline and are more variable than they were in the past.[26] Similar data can be shown for many other parts of the Global North.

As food production in the Global North stagnates and falls, almost all the growth we are still seeing in the global statistics is coming from the expansion and intensification of production in the rest of the world—particularly in countries like China, India and Brazil.[27] But as farmers in the Global South follow the same path trod by their neighbours in the Global North, they must surely reach the same destination. Modern societies are reaching the biophysical limits of the land, water and solar energy that can be utilised for agriculture, aquaculture, fisheries and forestry (AAFF) production.[28]

Another biophysical limit of production is beginning to emerge as one of balance between different species and habitats. As we saw in Chapter 4, the loss and degradation of wild habitat, from various human influences, generates more stress on individual life forms, and therefore more disease. The increase in number and proximity of farmed animals also creates the conditions for the emergence and spread of diseases. Such diseases can pass between wild and farmed animals and spill over into human populations. In 2019, African Swine Fever (ASF) hit pig herds across Asia, so governments wiped out 23% of the pig herd in China and 13% in Vietnam,[29] the repercussions of which were still being felt at the time of writing. Numerous highly dangerous variants of both swine and avian influenza have emerged in recent decades, resulting in mass culls of millions of animals in order to protect the human population. I frame this problem here as the limit in how far nature can be so imbalanced by human activity, but there appear to be very few policy makers who wish to speak of such limits, despite the rise in the concept of there being 'one health' that is shared by humans, farmed plants and animals and the rest of life on Earth.[30] Whatever is done in the future, we are already in an era of 'one morbidity' that is going to regularly and severely decimate food supplies from farmed and wild caught animals.

Figure 1
Historical yields of major crops in the United Kingdom 1961-2020. Each of these crops show stagnation or decline in yields over the past 15-25 years, or in the case of barley a significant reduction in yield growth and increase in yield variability. Points are average national yields (T/ha) reported to the FAO.[31] Lines are linear regressions that highlight the changing trends in crop yields before (blue) and after (green) a directional change.



Trend 2: Modern societies are destroying and poisoning the biosphere their agriculture relies upon

Humans are now the dominant force of change on the planet, a fact that has given rise to the naming of a new epoch in geology—the Anthropocene.[32] On land, more than 75% of Earth's ice-free surface is directly altered as a result of human activity.[33] Of course, food production is not the sole source of humanity's impact on the biosphere, but it does account for the vast majority of our impact on land. About 98% of calories and 96.5% of the protein humanity eats comes from the land[34] and roughly half of the plant-habitable land surface of the Earth has now been converted to food production.[35] Human activity has always impacted the biosphere[36] but it wasn't until the advent of industrial civilisation that our impacts became so great they began to threaten even the success of agriculture across whole continents.[37]

Take, for example, the impact on forests. The present-day deforestation of the Amazon basin over the past three decades, mainly to grow beef and soy,[38] is sadly just the latest in humanity's long history of continental-scale landscape modifications performed in the name of feeding a burgeoning population. During the 20th Century, one example was farmers in Australia doing the deforestation. In the south-west of Western Australia—like the Amazon, a global biodiversity hotspot—it was government policy to deforest "a million acres a year,"[39] resulting in 95% of the native plants and more than 95% of the native animals being killed in an area the size of Portugal, in order to grow wheat and other grains for humans. Just as it does in the Amazon now, agricultural transformation came at huge cost to indigenous peoples, to native biodiversity and to the productive potential of the land itself.[40] But similar stories can be told for all the world's grain producing regions through history: in the 19th Century, it was farmers in Canada and the USA (~50% and ~75% deforestation respectively); before that it was Western Europe (~80%); and before that China (~95%).[41] The pace and scale of destruction by industrial consumer societies is what sets us apart. In the 120 years since 1900, humans have cleared more forest than they did in the entire 9,000 years before this.[42]

This deforestation causes many problems, driving climate change and new disease, as we explored earlier in the book. But it also influences agriculture, through how it contributes to the loss of pollinators, loss of soil fertility, loss of natural pest control, reduction of water retention and filtration, increase in soil erosion and the modification of rainfall patterns.[43] Sometimes this becomes stark, such as when floods, that could have been reduced by forest cover, are so extreme they wash away crops and drown livestock. The ongoing effect is far more subtle and difficult to quantify—but this doesn't mean it does not exist.

One major concern in recent years concerns the loss of pollinators: there are various theories of the cause, including climate change and chemical pollution from agriculture or even manufacturing processes. More than three quarters of global food crop types, including fruits and vegetables, and some of the most important cash crops, such as coffee, cocoa and almonds, rely on animal pollination (chiefly insects). Insect populations have plunged globally by at least 45% in recent decades and up to 70% according to some studies.[44] As they disappear, our ability to produce pollinated crops is severely compromised.[45] In economic terms, half a trillion dollars in world annual crop output might already be affected.[46] Some scientists from Harvard University decided to model what the impact on human health and wellbeing might already be. They estimated the existing decline in pollinators has caused a 3%-5% loss in each of fruit, vegetable and nut production. As these foods are crucial to health and combatting disease, their model found that about 1% of all annual deaths worldwide could now be attributed to pollinator loss—about half a million early deaths.[47] It is another reminder of the fundamental truth we explored in Chapter 4—that we are the biosphere—and as it collapses, so do we.

Impacts of agriculture on nature's cycling of fresh water is key. Agriculture accounts for about 90% of humanity's total global freshwater use.[48] In water-limited environments that has devastated the local ecology, increasing those problems we just summarised.[49] Some analysts are even trying to bring our attention to how we are disrupting nature's freshwater circulation globally.[50] Although making such claims in a massive and hypercomplex system is difficult and debatable, there is no escape from the obvious conclusion that modern agriculture is already destroying its own foundations, through having treated nature as nothing more than a lifeless resource to be consumed.

If we turn our focus to the oceans, modern society's destruction of nature's ability to produce our food becomes stark. Industrial, urban and agricultural pollution combined with commercial fishing mean that no part of any ocean has escaped damage. Industrial fishing fleets have led to the collapse or total exploitation of over 90% of the world's marine fisheries.[51] Even if our fishing industry miraculously changed to all become MSC-certified, the oceans will not return for centuries (if ever) to producing an abundant amount of wild caught fish—or fish that is healthy for us to eat. One of the reasons is the amount of toxic pollution modern societies have already produced.

Over 140,000 novel chemicals and pesticides have been developed since 1950, with 5,000 of these found widely across the global environment, yet fewer than 7,500 tested for toxicity.[52] Through mechanisms such as air circulation, agricultural run-off and direct discharge of industrial waste and municipal water into rivers, these chemicals find their way into the oceans. As we looked at in Chapter 4, many of these chemicals do not break down and are persistent 'forever' chemicals. Even in the deepest part of the oceans, at the bottom of the Mariana Trench, concentrations of extremely toxic PCBs[53] are 50 times higher than the most polluted rivers in China.[54]

The most toxic pollutants are fat-attaching chemicals that accumulate in organisms and so make their way from the bottom of the food chain onto our tables. These chemicals float on the surface of water, or form an emulsion, where they can become concentrated many thousands of times on small particles, including microplastics, where they are then eaten by plankton. Some of these chemicals are extraordinarily toxic to marine life. For example, one chemical that is found in sunscreens and cosmetics can inhibit the growth of coral reefs at the staggeringly low level of 62 parts per trillion.[55] Microplastics are themselves also toxic and can inhibit the growth of plankton. The problem with the range of toxic substances in our oceans is that by poisoning plankton they could collapse the base of the ocean food chain, leading to far less life in the food chains, including the fish that we eat. That issue has led to some heated arguments between scientists, given their different methods of assessing how much plankton die off has already been caused. Whoever is right, the situation looks extremely poor for the long-term health of the oceans. Some scientists are also concluding the various foreign chemicals in our oceans are contributing to the appearance of 'dead' zones in the deep ocean, which are new phenomena that might even cover 30% of the deep oceans.[56] At what point these processes of toxification and dead zones might end our ability to eat wild caught fish from the sea is unclear. But what is clear is that unlike our fishing methods, the general toxification of the environment is not something we can suddenly solve – this toxic sea horse has already bolted.

My colleagues and I were quite disheartened about how irrecoverable the situation is with the widespread destruction and poisoning of the biosphere, including that done through the pursuit of food supply. The tragedy is that it is already damaging food security and will continue to do so, whatever responses humanity might now marshal.

Trend 3: Current food production relies on declining fossil fuels

The ability to nearly quadruple the global food supply in the 60 years prior to 2020 was the result of a confluence of technological advances during the latter half of the 20th century that resulted in a transformation of food production commonly known as "the green revolution".[57] All but one of the key drivers of this transformation have relied on fossil fuels (the exception being the targeted breeding and selection of domesticated plants and animals).[58] A crumbling of the energetic foundation of modern societies we covered in Chapter 3 therefore spells a crumbling of current modes of industrial farming. A quick summary of the role of fossil fuels should help to make that starkly clear.

First, the application of internal combustion engine to the existing mechanization of agricultural production practices, beginning with tractors in the 1910s, then self-propelled grain threshers and reapers ('combine harvesters') progressively from the 1930s, transformed production capabilities. Since then, oil-powered machines have become crucial to every stage of the production, processing and distribution of foods. Second, synthetic nitrogen fertilisers have been central to production growth since the 1950s, and are made from fossil fuels.[59] It was estimated in 2008 that roughly half of all food produced in the world is reliant on such fertilisers.[60] Third, herbicides, pesticides and fungicides are also made from fossil fuels. These chemicals have been central to protecting yields when huge fields of genetically similar crops are susceptible to disease spreading throughout. To do without such agrochemicals is possible but requires a completely different approach from industrial 'monocultures'.[61] Fourth, irrigation has been key to bringing more land into agriculture, and typically this uses pumps and infrastructure dependent on fossil fuels, not the gravity-based systems developed over past millennia. Over the past two decades, the proportion of arable land under irrigation has increased from 21.7% in 2001 to 24.4% in 2018, and is likely to grow due to adaptations to climate change.[62] Irrigated land supplies about 30% of global food production.[63]

According to the FAO, manufacturing the inputs, then production, processing, transportation, marketing and consumption, means the food sector accounts for approximately 30% of global energy consumption, and more than 1/3 of global greenhouse gas emissions.[64] It can't be stated more clearly than this: the current food supply of most of the world's population is from industrial modes of production which are utterly dependent upon resources that are becoming less easy to obtain, and which destroy the basis for that agriculture through contributing to climate change and poisoning the biosphere. Understanding this situation means that, if we recognise modern societies are fast approaching a 'net energy cliff' where the availability of fossil fuels to society is rapidly constrained,[65] then we must recognize there is also a food cliff.

The vulnerability of our food supply to instability in fossil fuel supplies is highlighted by the current global situation with nitrogen fertilisers starting from 2019. 'Natural gas' (perhaps better termed 'fossil gas') accounts for up to 90% of the cost of these fertilisers. In three years, the price of that fossil gas soared as much as five times, leading to massive reductions in the production of nitrogen fertilisers worldwide. The world's largest producer, Yara, cut production in Europe by 40% and, in 2021, many farmers around the world paid twice as much for fertiliser as they had in 2020. That resulted in reduced fertiliser applications to the land, or no plantings at all, reduced production and additional pressure towards rising food prices from 2022 onwards. It should be noted this occurred prior to the additional price hikes in gas due to the conflict with Russia.

There are many other ways to grow food than the industrial approach that modern and modernising societies have chosen since the 1950s: ways which are better for the soils and wildlife, while providing healthier food and safer employment. However, the time required to transform agriculture is such that the decline of the industrial mode will add to food insecurity. Progressing a total transformation to forms of agroecology might further reduce overall production levels in the near term, giving rise to wider food insecurity for those not benefiting directly from such agriculture or not able to afford increased market prices.

Trend 4: Climate chaos is constraining food production at an increasing pace

Large, stable societies require large, stable food supplies. And large, stable food supplies require a favourable and relatively stable climate. The relatively stable climate of the Holocene favoured the advent of agriculture in concert with the rise of urban centres and the 'great' civilisations that grew from them. With a changing climate as we leave the Holocene and enter the Anthropocene, we are essentially in uncharted territory with respect to our food supply.

Climate change is not just a future threat to food security, as we know for certain it is already affecting our food supply. Since 1970, there has been a five-fold increase in extreme weather events which now affect twice the area of agricultural production and twice the number of people as before then.[66] These shocks increasingly affect crops, livestock and aquaculture simultaneously.[67] By 2019, weather extremes and unpredictability constituted the primary driver of food insecurity in 25 countries, with around 34 million people pushed into a situation of food scarcity.[68] More generally, yields of staple crops are already falling in every region of the world as a direct consequence of climate change. There are impacts on sowing and harvest dates, increased infestation of pests and diseases, losses due to increased frosts, floods, droughts and hail.[69] At the global level, between 1981 and 2010 climate change alone caused a drop in the mean global yield of maize by 4.1%, wheat by 1.8% and soybeans by 4.5%, even after accounting for increased CO2 fertilisation.[70] In India, the measured wheat yields declined 5.2% between 1981–2009 due to rising temperatures.[71] Across Europe, wheat and barley yields have declined 2.5% and 3.8% respectively since 1989, with losses in southern areas such as Italy being 5% or more.[72]

Although climate change is adding stress to most forms of agriculture, the impact on grains is particularly important for modern societies. Civilization is grain-based, not only because they are easily cultivated in massive amounts, but because they are able to be stored for a long time, if kept dry. Just three grains—rice, maize (corn) and wheat—contribute nearly 60 percent of calories and proteins obtained by humans from plants.[73] The vulnerability of societies to disruption of production in these grains due to weather events is well illustrated by events in 2008. Demand for wheat had been surging due to more demand in Asia for meat products and more maize being directed into biofuels globally. In 2007, wheat production around the world was hit by a large number of extreme weather events, including: droughts across Australia, eastern and southeastern Asia, and Europe; heatwaves in the USA; and floods in India and a range of African nations. This came after numerous years of lower-than-expected wheat yields had left global stocks of wheat running low. Sensing the risk, major exporters such as the USA, Canada, Australia and Argentina (among others) reduced grain exports. Sensing the financial opportunity, commodity speculators began cornering the market and the price for wheat doubled within a year. Consequently, there were food riots in 23 countries spread across all continents.[74] Various studies trace the protest movements that swept the Arab world in the following years as being triggered by the cost of basic foods. Such political changes may be welcomed, but the key issue for us here is to note the ongoing relationship between climate, agriculture and societal stability.[75]

During the 2008 food crisis the actual volume of wheat being traded in global markets remained similar to previous years. The crisis was therefore due to the response to the negative impacts of weather on production, and other factors, rather than an actual significant squeeze on supply. As the resultant disruption occurred after relatively mild problems in one staple (wheat), food security experts are rightly concerned about what could happen if we experience more severe failures in multiple staples at the same time, or in close succession. My analysis of their research led me to conclude that such multi-faceted disruption is inevitable within our current decade, as I'll now explain.

Although nearly all countries of the world produce food, the international trade in the key grains of wheat, maize, soybean and rice is dominated by a few countries, which are described as the world's breadbaskets. These are the United States, Argentina, Europe, Russia/Ukraine, China, India, Australia, Indonesia and Brazil. The occurrence of extreme heat, cold, precipitation or drought across one of these regions can lead to a 'breadbasket failure'—defined as a growing season in which yields are 75% or less than the average.[76] Such events have been increasing in frequency around the world in recent decades and will become even more frequent as the planet warms further.[77] One might surmise it should not matter to global food prices, as when one region does poorly, another might do better and achieve a regularity of global supply. However, the phenomenon of a number of these breadbasket failures occurring at the same time is increasingly possible because many of these regions are climatically linked.[78] The same global drivers that cause climate volatility and crop failures in one region are simultaneously causing volatility and crop failures in other regions. The link is the jet stream of the northern hemisphere, which is becoming more 'wavy' as it slows down, due to the Arctic heating up so disproportionately fast. These longer up and down waves lead to extended periods of extreme weather, including hot, cold, wet and dry, catching multiple breadbaskets in the northern hemisphere in a single weather event—a 'multi breadbasket failure' (MBBF).[79]

A study of the world's 9 major grain producing regions over the period 1967 to 2012 showed that, apart from rice, the risk of MBBF in maize, wheat and soybean have all increased significantly since the 1960s (up 37%, 400% and 17% respectively).[80] A second study of just the 5 major grain regions showed these risks will increase substantially more as the planet warms to +2°C above pre-industrial global average temperatures (up 882%, 287% and 292% respectively).[81] This means during the lifetime of most people reading this book, widespread global crop failures of maize, wheat and soybean will go from rare events of once in 100 years or less, to at least once a decade. The projections for maize are particularly worrying with 5-region MBBFs indicated every 3 years by the time global average temperatures reach +1.5°C above pre-industrial temperatures. As astute readers will have already assessed, the latest research puts the world breaching that temperature threshold even in 2024, due to the ocean phenomena El Nino, which means a temporary decimation of global maize supply is likely by 2027, with global repercussions during 2028.[82] Let's remember that because the models making such projections are using past data, whereas we have entered a new unstable era, with multiple other damaging trends. Even their worrying outputs could be pointing to best case scenarios.

It is also important to note these dark projections are for the 5 main breadbaskets all failing simultaneously. The risk of 'just' 2, 3 or 4 of these failing at the same time are even higher, which means frequent significant hits to global grain production are unavoidable. Back in 2015, such risks alerted the world's leading insurance market, Lloyd's of London, which ran some potential future scenarios. In one scenario they posited several breadbasket disruptions in the same year, with "global crop production declines of 10% for maize, 11% for soybean, 7% for wheat and 7% for rice…" These seemingly moderate setbacks were calculated to have significant impacts on prices, with wheat, maize and soybean prices increasing about 400% and rice prices about 500%. It imagined what these price increases would mean, describing how "food riots break out in urban areas across the Middle East, North Africa and Latin America... several terrorist attacks take place across [Kenya]... Nigeria falls into civil war... Pro-Russian protests occur in Lithuania... In summary… significant negative humanitarian consequences and major financial losses worldwide."[83]

Unfortunately, we are now looking at the likelihood of even worse impacts. Every year about 23% of global grain production is held in reserve.[84] This yearly reserve equates to less than 3 months' normal grain supply—or nearer 4 months if the 32% normally fed to livestock was allocated directly to people instead. Recalling that a breadbasket failure is defined as a fall of 25% or more in yield, it is easy to see that a 23% global reserve of grains is not going to be an effective buffer against repeated and frequent shocks. Climate change is therefore smashing the security of our global grain supplies, and if the 2007–08 global food crisis teaches us anything, it must surely be that even a whiff of widespread food insecurity can cause market problems that lead to social unrest and breakdown.

These changes in the regularity and price of supply of key grains do not occur in isolation from all the other hard trends listed in this chapter, which affect all other forms of agriculture, including domestic grain production, fruits, nuts and vegetables. Could there be any silver lining at all? Yes, but not enough to make a difference to most countries. Climate change means sometimes there is increasing precipitation in areas that were formerly too dry, and increasing temperatures in areas that were formerly too cold, for agriculture. Even the increasing concentration of CO2 in the atmosphere can potentially contribute to some gains in production in some regions. In China, for example, wheat growth in the North has been positively impacted by climate change to date, whereas wheat growth in the south has been negatively impacted.[85] But even if the yields of some cereals can increase under higher temperatures and CO2, the quality of the grain can fall, with lower protein and mineral content.[86] Let's recall also simply maintaining our current production by balancing gains and losses would not be enough to avert crisis and collapse: because projected food demand means only a doubling of food supply in the next thirty years would be enough.

Back at sea, the effects of a warming planet on our food supply are not any better. Warming oceans are more acidic, more stratified and hold less oxygen, all of which have very serious implications for the future of wild fisheries, which currently account for about half of the seafood we eat.[87] A couple of these issues are worth looking at here for their implications on fish stocks—warming and acidification.

The oceans have absorbed about 90% of the additional heat from global warming.[88] Fisheries catches in many regions are already impacted by the effects of that warming, with an average decrease of about 3% per decade in population replenishment. That has already challenged the management of some important fisheries.[89] A related issue is ocean acidification, which we considered in Chapter 5 on climate. Given how severe the impact is on the future of fisheries, it is worth repeating here. The basic mechanism is that as CO2 concentration increases in the atmosphere, much of it is absorbed into the oceans—taking up as much as a third of all the CO2 humans have pumped out since the 1980s.[90] This dissolved gas forms carbonic acid and so the pH of the seawater falls. Prior to the Industrial Revolution, the global average ocean pH was 8.2, whereas today it is at least 0.1 lower and falling. Because pH is a logarithmic scale, this 0.1 fall means the ocean is thirty times more acidic today than 200 years ago. Some independent analysts even claim the pH is nearer to 8.04, which would mean we are on the verge of a catastrophe due to the impact on sea life.[91] Half of all the organisms in the ocean are partially formed by a mineral form of calcium carbonate.[92] More acidic water makes it more difficult for juveniles of those plants and animals to form their shells and body structures.[93] It becomes near impossible in ocean surface waters at a pH of 8.04. That means human pollution is increasingly dissolving away the life at the base of the ocean's food web. Some researchers claim the current rate of acidification means a collapse of marine ecosystems globally within 25 years.[94] A collapse of fish stocks is just one of the many impacts that will occur along the way, with others being climatic, as we saw in Chapter 5. Although there is controversy about just how bad the situation is in the oceans, the controversy is not about how okay everything is.

The other half of global seafood consumption comes from aquaculture, which has supplied all the growth in global seafood consumption in the past 30 years.[95] Two thirds of aquaculture is land-based,[96] and most is fed from a combination of wild fish and grains.[97] So that means it is really a water-based version of intensive livestock production, and faces the same risks of unsustainable feed requirements, energy use, environmental pollution, disease and food safety risks.[98] Meanwhile, non-fed aquaculture, such as oysters and mussels, faces many of the same issues as wild marine fisheries, especially ocean acidification, warming and de-oxygenation. Consequently, there will be no seafood escape from the looming food crisis.

When delving into the data on the already-existing impacts on our food supply, from the ways modern societies have changed our atmosphere, oceans and climate, it becomes even more peculiar anyone can doubt this is a crisis of our own making. Today's climate skeptics, who appear on YouTube channels as 'citizen scientists', display a lack of awareness on what is happening with farming today. That might be due to the urban bubbles lived in by people entertaining online audiences with their views of current affairs. In the real world that grows their burgers and lattes, the ongoing and irreversible environmental changes are already crumbling their supply lines. Helping the public understand this, was the basis of my advice to the founders of Extinction Rebellion ahead of their launch in 2018. We needed to emphasise that climate change is not just about being nice to nature or to people on the other side of the world. Rather, it means more of us won't be able to afford to feed ourselves or our families in the near future. Which also means growing social unrest, as a hungry country can become an ungovernable one. At the time, such messaging did indeed 'cut through' and shift the sense of why climate change is an emergency. However, that focus appears to have dissipated in subsequent years, despite it being more clearly articulated in the scientific literature since then.[99]

Trend 5: The demand for food is growing rapidly and cannot be easily reduced

Until this point, we have looked at the problems with the future supply of food. The other side to the equation of food security is demand. On that side is the overall size of the human population and the average food consumption per person. Both these things are growing—and both are very difficult to constrain.

Driven by the expansion of industrial consumer societies, animal-based protein consumption has surged worldwide over the last 50 years, rising from 61 grams per person per day in 1961 to 80 grams in 2011. There is a clear correlation between GDP growth and meat consumption. In that time, a key factor has been the rise of the new middle classes in Asia and Latin America, where meat has partly replaced plant protein rather than just added to it.[100] Although some may wish to regard this as a natural progression as people have more disposable income, there is a strong role of commercial entities that advertise meat products as part of a higher status and healthier lifestyle.[101] That meat consumption increases environmental impacts compared to plant-based foods. Accounting for less than 20% of global calories consumed, meat and dairy use 70% of all agricultural land and 40% of the arable cropland, and account for about two-thirds of all food-related greenhouse gas emissions.[102]

Even if the global trend towards more meat eating was urgently and substantially reversed, there is the huge challenge of a massive and increasing global population. It is a topic some people discuss in very insensitive terms, revealing their own privilege and bias: for instance, by focusing on population growth in poorer countries, despite the consumption implications being far lower than in the richer parts of the world. On the other hand, critics of any attention to world population too easily overlook the desires of many women the world over, including in poorer countries, to live with the levels of economic security and low child mortality, as well as control over their reproductivity, meaning they would voluntarily choose smaller family sizes—choices they inevitably do make in such circumstances, according to all data and research. The fact that many critics of a discussion of population tend to overlook is one of scale. Few of us would be able to say what the global population was in the year we were born, let alone in the year our mother or grandmother was born (if you are interested to know, and have the epub version of this book, then you can check this link). When I was born, I was about the three-billionth, eight hundred-and-forty-millionth human to be alive that year. At the time of writing, I'm still here alongside 8 billion others. The graph of human population growth during the Holocene geological era helps to give us some historical context for the 8 billion humans who are currently being fed, and the roughly 10 billion humans who, if collapse were not to occur, are officially predicted to be needing food by 2050.

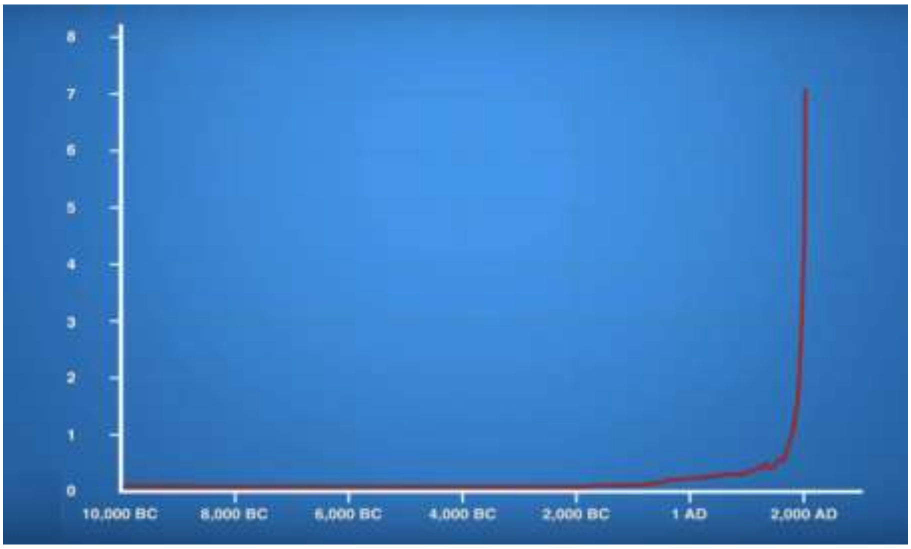


Figure 2. Global population during the Holocene.

Of course, it is not just the total number of wonderful humans that is growing, but the quantity of food each of these wonders is expecting to eat. As the availability of food outstripped population growth in the latter half of the 20th century, the real price of food fell and consumption per capita increased. Not only did meat eating increase, but excessive consumption and excessive waste became hallmarks of the lifestyle of the world's most financially rich economies—a lifestyle that lower income economies seem to aspire to emulate, and increasingly do. Food consumption in China soared from 1,427 kcal per day per person in 1961 to 3,375 kcal per day per person in 2019—an increase of 237%. In India, it rose 126% over the same period. And even in the highest income countries, per capita consumption continued to rise during that time.[103]

On current trends of population and consumption growth it has been estimated, rather unrealistically, that global food production would need to approximately double by 2050.[104] This would represent a need for greater growth in production in the next thirty years than achieved over the previous fifty. The previous hard trends outlined in this chapter show that is an impossible feat. When analysing current trends in food consumption, including meat eating, some food security specialists conclude that to try and produce sufficient food would "likely lead to the collapse of some global ecosystem functions on which humanity crucially depends."[105] Given all the data in this chapter and book, I think the word 'likely' is just being polite with the reader. One reason I am so certain of that is because the way our food system is managed by commercial interests militates against any significant effort to address the problem.

Trend 6: The globalised food system prioritises efficiency and profit over resilience and equity, compounding the hazard of food system collapse

It is important to remember that today's global food production largely exceeds what is needed to feed the entire world population—hunger is caused by an unequal distribution of food and artificial scarcity.[106] Our current food system, that consistently leaves nearly a billion people without adequate food and over a hundred million people in acute hunger, is already dysfunctional—even murderous. The future declines in food from multiple sources due to multiple factors will exacerbate those flaws, starving ever greater numbers in countries that are more exploited by foreign capital.

Changes over recent decades, which continue at the time of writing, have been increasing the impacts of the other hard trends I have described above. The global food system is dangerously and increasingly optimised for efficiency and profit rather than ensuring everyone has food. For instance, buffer stocks have been reduced in line with an understanding of supply volatility consistent with the previously stable environment even OECD researchers recognise no longer exists.[107] Those stocks are increasingly in the hands of speculators. Previously, governments kept strategic grain reserves to feed their citizens. Now they prefer the greater efficiency of global markets (with the notable exception of certain countries such as China or India). A troubling aspect of this development is that sometimes the countries most in need of reserves are those least able to pay for them.[108] Reserves are controlled by a handful of corporations, which are not averse to manipulating commodity prices if it increases their profits. For example, the World Bank estimates that for the 2008 food crisis "up to 30 percent price increases occurred based on anticipated fallout (from drought impacts and biofuel production on corn crops) rather than the shocks themselves."[109]

A key aspect of contemporary food systems is their international, complex and 'just-in-time' model of sourcing. That system developed due to commercial aims for maximising consumer choice and corporate profit. This situation means there is little latent capacity in food supply chains when they experience disruptions. That was highlighted when policy responses to Covid-19 in many countries resulted in movement restrictions of workers, changes in demand from consumers, closure of food production facilities, delayed border processing and financial disruptions to businesses within the food supply chain. The result in many countries for many product lines was a hiatus in availability and rising prices.[110] Some food system specialists are therefore calling for reducing reliance on long international supply chains and unwinding some of the dependence on just-in-time systems as a form of risk management by corporations and better food security within countries.[111] However, very little has changed and the kind of disruptions to the global food system that arise from the six trends I summarise in this chapter will make disruptions from Covid-19 seem minor.

I agree with analysts who argue our food systems do not need to operate in the way they do today. Radical and detailed alternatives exist, in theory. The French agronomist and 'collapsologue', Pablo Servigne, has outlined a comprehensive program for food systems around Europe and the world that would be more resilient to potential disruptions with climate and oil supply. These food systems, centered on agroecological principles, would be localised and diversified, decentralised and autonomous, circular and transparent.[112] Many of Servigne's recommendations align with those of the FAO. In a special 2016 report on climate change, agriculture and food security, the organization recommended a focus on increasing the efficiency of resource use, conserving and enhancing natural resources and cycles, adopting agroecological approaches and greater crop diversification.[113]

Because the dynamics of our capitalist system promote one direction for the global food system, the many warnings, as well as good ideas for addressing the problems, have been systematically ignored. The analysis in this chapter is not the first to conclude the global food system is on a trajectory towards collapse. Back in 2015, one of the top models on food systems projected "society will collapse by 2040 due to catastrophic food shortages"—unless everything important to that outcome changed.[114] Eight years later, nothing has changed in the global food system, other than the situation having become worse. Looking back at my own suggestions in 2019 for simply moderating a food system breakdown rather than preventing it (Box 1), I note that no such ideas have been seriously discussed by policy makers, let alone applied. Perhaps only when the food system breaks will the dominance of capital also begin to break, and changes become possible.

Unfortunately, the first five hard trends described above mean even radical policies could only delay, not avert, a tragedy from disrupted food supplies.

Box 1: Text from 2019 on potential policy responses[115]

"Being new to food security, I am very aware there are far more trained, experienced and skilful people than I who will be able to develop policy. To help their conversations, I have jotted down some initial thoughts on what they might consider:

• First, importing countries need to increase domestic production of basic foods, including, through irrigation, the use of greenhouses as well as urban and community-based agriculture.

• Second, importing countries need to geographically diversify sources of food imports rather than rely on whatever is cheapest or habit.

• Third, all countries need to diversify the range of species involved in their domestic agriculture, with a focus on a wider range of resilience to weather stress, and this be done with a holistic agroecological approach, recognising the threat from collapsing biodiversity.

• Fourth, governments need to re-instate the sovereign management of grain reserves and prepare for requisition of private grain reserves in crisis situations.

• Fifth, a treaty and systems may be needed to help keep the international food trade going despite any future financial or economic collapse.

• Sixth, national contingency plans may be needed to prepare for food rationing so that any rapid and major price rises are not allowed to lead to malnutrition and civil unrest.

• Seventh, in the absence of significant new forms of government action on food security, local governments need to act, including through partnerships with companies that can manage food distribution.

• Eight, we should undertake controlled experiments with Marine Cloud Brightening (MCB) over the Arctic Ocean, to try and reduce the warming in the Arctic and slow down the damaging changes to northern hemisphere weather. That does not mean wider geoengineering makes sense but that MCB is important to try, in this limited way, given the catastrophic potential of further Arctic warming."

The foundations are breaking together

In this chapter we have looked at the six hard trends that are *already happening*, and lead to food system breakdown:

1. We are hitting the biophysical limits of food production and could hit 'peak food' within one generation;
2. Our current food production systems are actively destroying the very resource base upon which they rely, so that the Earth's capacity to produce food is going down, not up;
3. The majority of our food production and all its storage and distribution is critically dependent upon fossil fuels, not only making our food supply vulnerable to price and supply instability, but also presenting us with an impossible choice between food security and reducing greenhouse gas emissions;
4. Climate change is already negatively impacting our food supply and will do so with increasing intensity as the Earth continues to warm and weather destabilises, further eroding our ability to produce food;
5. Despite these limits, we are locked into a trajectory of increasing food demand that cannot easily be reversed;
6. The prioritisation of economic efficiency and profit in world trade has undermined food sovereignty and the resilience of food production at multiple scales, making both production and distribution highly vulnerable to disruptive shocks.

Considered *individually,* each one of the hard trends presents a very significant challenge to global food security. Considered *collectively and interdependently,* it becomes clear we have created a predicament on a scale and depth unprecedented in modern history, and unprecedented for the sheer number of people who will be affected.

Unfortunately, many experts and institutions still downplay the severity of the situation. One reason for this could be they do not look at *all* the significant factors affecting the future of food. For instance, one large consortium of researchers has argued the production of fish and seafood could increase by up to 74% by the year 2050. But their study took no account of the impacts from ocean warming, acidification, de-oxygenation and pollution, nor how the energy crisis will hit feedstocks for aquaculture.[116] Although more sober in expressing their hopes, the FAO[117] also ignore these factors when making their projections of seafood production towards 2030. Another reason for the lack of alarm from some scientists may be their 'normalcy bias' of expecting the way one experiences life today to continue. That means the burden of proof is assumed to be on those analysts who extrapolate current trends to conclude the future is bleak, rather than those who imagine all those hard trends will change enough to avert disaster (something we explore further in Chapter 7).

For any analyst or commentator to believe global food insecurity will not become worse in the years ahead requires them to believe that most of the hard trends I have identified here can be halted in the next few years. For any of them to believe food systems will not collapse in most countries in the coming years is to believe that all the hard trends will be reversed, including the ones that appear impossible to reverse even if the whole world responded to the complexity, scale and urgency of this challenge in a perfect way. Privileged people may continue to choose to live in such a dream world, as they can pay to temporarily avoid the worsening situation. That privilege means the daily pain is not the price, availability and quality of food, but the opinions of people who trigger feelings of fear, anger, sadness or guilt. However, the majority of people on the planet are not so privileged. The majority need greater efforts at national and global redistribution, as well as local and national resilience strategies through diversifying food sources (Box 1). Since capitalist mechanisms within food systems mean that none of that is being done, in recent years, some people are turning to technological innovation as a source for hope. I was curious whether such ideas might have merit, rather than being new forms of psychological pain relief by privileged people. So before concluding, let's review what is being claimed about the new era of 'food tech'.

What's brewing to avert breakdown?

I wasn't sure if it was the fried grasshoppers or the fact they were offered as a topping on a croissant. I was in Oaxaca, Mexico, and my fellow conference goers tucked into what we were told was a local delicacy. What counts as food is cultural: grasshoppers in Mexico; snails in France; horses, pigs and humans in some places, not others. But I didn't want grasshoppers for breakfast. A popular story in YouTube-land is that the ecofascists want to make us eat bugs and fungal sludge. They don't just mean Marmite or Mexican delicacies. Some of the backlash comes from the meat and dairy industry, worried that policies on greenhouse gas emissions might impact their business. But what is the reality with novel foods?

For years some researchers have worked on ideas for how we might feed ourselves if there was a global disaster that, for instance, blocked out the sun.[118] Their ideas were largely ignored until the last few years, when some investors have realised we are already within an unfolding environmental disaster that threatens our food supply. They are investing billions of dollars into companies that either grow meat and milk from individual animal cells (sometimes called cultivated meat) or use microbes to grow proteins (sometimes called precision fermentation). Because of the capital involved in this sector increasingly called 'food tech', there is now a lot of promotional content in written and video form, coming from think tanks, experts and journalists. Although I have discovered some of that to be quite misleading, the recent claims of some enthusiasts that food tech could save the world from societal collapse and allow us to restore the living world, rather than just be an interesting new food business that doesn't harm animals, calls for some close attention given our current predicament.

The potential is interesting, with some innovations looking better than others. There are companies growing fake meat from fungi, without needing either any genetic engineering or complicated processing. As long as you can source the water, energy, substrate inputs and fermentation vats, this form of food production could be done anywhere. I see no reason to object to a new choice of protein like that, which has lower ecological impact and does not harm animals.[119] However, with the breakdown of global food systems underway, the question is what the energy and substrate demands will be for growing these meat-like products at a significant scale, as well as the industrial infrastructure required. And that's where it gets more complicated than the food tech optimists like to tell us.

All the substrates used to grow the meat cells or the microbes require nitrogen in the form of ammonium (sulphate or nitrate), which is currently produced with natural/fossil gas as the main input.[120] An assessment of viability at scale would need to examine what inputs would be needed for each ton of protein produced. Food tech optimists promote the potential for ammonium being produced using hydrogen from the electrolysis of water instead of from natural/fossil gas.[121] Recognising the huge amounts of energy required for such a process, other enthusiasts imagine genetic engineers will find ways to fix into ammonia the nitrogen in our atmosphere. However, I have not yet seen any substantial evidence on which to assess such a claim. A report on the industry by McKinsey consultants mentions these issues but did not attempt calculations for what might be required for the visions of food tech promoters to be realised.[122]

By swapping out the use of photosynthesis by plants with industrially produced food that uses huge amounts of energy for hydrogen production, the energy crisis facing humanity would not be helped. It is helpful when proponents, such as journalist George Monbiot, attempt calculations of the energy requirements of replacing all human consumed protein with fermented protein. Although he concluded it would raise the world's electricity demand by 11 percent, it was unclear to me whether he included all the energy requirements for the production of the substrates.[123] No research I have come across has attempted a full lifecycle analysis of any of the food tech methods. Although we might hope technology will overcome its difficulties or limits, a central part of a scientific worldview is to estimate with data rather than treat technology as a magic that always delivers. When food tech optimists claim new nuclear reactors will solve the energy problems, they are ignoring the research we saw in Chapter 3 which demonstrates that is not possible.

'Precision' is an interesting choice of word, as it offers a positive connotation. Yet a more accurate term would be 'genetically modified fermentation'. Because what most instances involve is the insertion of genetic code into a microbe so that it produces a desired protein substance during fermentation. Many of the food tech entrepreneurs reframe this by describing genetic engineering microbes as simply '3D printing' the molecules they want. Except it is not that at all. Genetic engineering any organism poses the problem not only of potential allergic reactions in consumers, but the escape of the novel genetic arrangements into nature—something called 'transgene escape', which is well documented already for existing GM crops. Food tech poses its own risks of genetic pollution.[124] Once outside of the vats, it is unclear what novel risks there might be. Due to their number and simplicity, gene mixing with non-GM microbes is likely and they might not be possible to contain once in the environment. The novel DNA arrangements will be producing compounds that are entirely novel from those microbes. Could these microbes end up producing such compounds in the gut of animals, including humans? Due to the particular mix of needs for such microbes to thrive, it is unlikely that would happen. But is it a risk worth taking? Who should decide and are they deciding for the whole of humanity? The regulations differ in different countries and tend to be focused on the direct impact on the consumer from eating residues in final products, rather than the issue of transgene escape affecting the environment.[125] A better international framework, which would examine the potential hazards from each novel GM microbe, would help avoid mistakes that would be difficult or impossible to put back in the bottle.

With food system breakdown looming, clearly the stakes are high. Unfortunately, the discussion about food tech is polarised by people who think there is a binary choice to make about how to save the world. On the one side, people claim food tech is the answer and on the other side people claim agroecology is the answer.[126] As a recent organic agroforester myself, I know that mimicking natural processes can successfully replace many of the industrial inputs to agriculture without decimating productivity, while requiring much more manual labour. However, I know there is no one answer to the global food crisis, nor even a multifaceted answer of both food tech and agroecology. Instead, the six hard trends outlined in this chapter mean the situation will continue to deteriorate. We can encourage a range of options that might help people feed themselves and others as best they can, while regenerating more patches of nature, whether gardened or wild, and focus as much on a more equitable and sufficiency-minded approach to food (which we explore more in Chapters 11 and 12). The polarisation reveals how anxious people who work on food and the environment have become. Some wish for a technological salvation from the situation, and so adhere to their view in a quasi-religious fashion. The fact that there are billions of dollars sloshing around food tech now is certainly not a disincentive for their continued devotion.

Will food tech feed billions of people as agricultural systems collapse due to changes in climate and biodiversity? The short answer is no, due to its resource demands, yet if managed and governed well, some novel food technologies will help to feed *millions* of people, while also presenting some uncertain risk of genetic pollution of the natural world. At present, the understanding is too influenced by, on the one hand, capitalist-funded entrepreneurs and promoters who sometimes mislead with their communications (to both oversell the potential and downplay risks), and on the other hand, people who want to ignore the looming food crisis and demonise all food tech (through commercial or ideological interests). It is unhelpful for food tech optimists to present their ideas in opposition to agroecology and agroforestry. Without urgent attention to redistribution, to cope better during the unfolding food crisis, more people may become suspicious that green capitalists and authoritarians in government want people to swap their cheeseburgers for a future of eating 'fungal sludge' and 'insect goo'.

Conclusion

In the annual report to mark the 25th anniversary of their founding, the Marine Stewardship Council noted a problem from our warming oceans: "several major fisheries have lost their MSC certification because of climate-related changes." They also reported octopus and squid could benefit from that warming, so "this could open up opportunities to increase supplies of sustainable seafood and help fishing communities to adapt to climate change." However, no attention was given to how a warming ocean could disrupt the whole fishing industry, and with it the MSC. No mention was made of ocean acidification, de-oxygenation, stratification, toxic pollution, microplastics or plankton decline, all of which present catastrophic risks to the fishery sector and humanity.[127] But if they did, what could usefully be said? Recognising the six hard trends that lead to food system breakdown are so paradigm-changing, they leave the mainstream sustainability professional dumbfounded. Like I did for decades, they work from the false premise that we have time to reform and transition. And as I did, some of them work nights, take risks and put their heart and soul into creating change. But with the latest information on the environmental predicament, such work can lose its meaning. What then might be done instead?

The first step is to allow the latest information to sink in and reconstitute one's sense of reality. In 2019 I wrote "If you think humanity will change production systems quickly to reduce dependence on rain-fed grains, while also changing our commercial food system as quickly to help ensure everyone is fed, then I can understand if you think there will not be widespread societal collapse. In my experience and analysis, I do not think people in political systems can respond that quickly across the world. Which is why my own conclusion, as sad and shocking as it may be, is that near-term societal collapse is now inevitable."[128] Four years later, and with the benefit of a research team that spent many months working with me to look closer at the myriad issues, I believe a plausible case can be made that the global food system has already begun to break down. The six hard trends are not merely intractable—they appear unstoppable and many of their consequences irreversible. Worse, the climate change trend could trigger massive global disruption through a multi-breadbasket failure, within only a few years. I no longer anticipate that publishing such findings will help to influence any policies, but hope more people will take action in their own lives and communities as a result. That may sound defeatist, but I believe there are new victories to be won in transforming food systems locally, while resisting the ongoing destruction from global capitalist enterprises, challenging those who dilute the severity of what humanity is already experiencing and encouraging informed rather than ideological or magical stances on new food technologies.[129]

Note: the references that follow are listed prior to formatting for the book.

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[129] In 2019 I also wrote that "I am not going to try and become an expert in the field of food security and intend this to be both the first and last article I write on it. Rather, I am sharing ideas here to encourage those internal debates within research organisations and government agencies, that need to be had so that those of us in wider society can have honest conversations about how we reduce harm in the face of climate-induced disruption to our way of life." However, 4 years later, I have seen no serious attention to this matter from policy makers, and the situation continues to deteriorate. I worked with experts on agriculture to produce this chapter to help myself and those who are interested to assess the scale, complexity and urgency of the problem.