Asia Pac J Clin Nutr 2009;18(4):590-597

Review

Food security in the Asia-Pacific: climate change, phosphorus, ozone and other environmental challenges

Colin D Butler PhD

National Centre for Epidemiology and Population Health, College of Medicine Biology and Environment, Australian National University

This is the second of two articles on challenges to future food security in the Asia Pacific region. It focuses on five mechanisms, which can be conceptualised as pathways by which pessimistic Malthusian scenarios, described in the first paper, may become manifest. The mechanisms are (1) climate change, (2) water scarcity, (3) tropospheric ozone pollution, (4) impending scarcity of phosphorus and conventional oil and (5) the possible interaction between future population displacement, conflict and poor governance. This article concludes that a sustainable improvement in food security requires a radical transformation in society's approach to the environment, population growth, agricultural research and the distribution of rights, opportunities and entitlements.

Key Words: climate change, food security, phosphorus, peak oil, sustainability transition

INTRODUCTION

This is the second of two papers about the steepening challenge of providing food security in the coming decades within the Asia-Pacific region. This paper focuses particularly on the environmental threat posed by climate change, with a briefer discussion of water scarcity, tropospheric ozone pollution, the impending scarcity of phosphorus and conventional oil and, finally, the possible interaction between future population displacement, conflict and poor governance.

The earlier paper attempted to place this debate in its historical context. Human populations have always desired reliable food supplies, but history reveals many periods and places in which food supplies have become unreliable or barely adequate.

Today, humanity's agricultural activities produce sufficient food to eliminate global undernutrition. However, Sen[1] and others have pointed to governance factors which restrict and shape the distribution of food "entitlement" as the "root cause" of persisting hunger and other forms of undernutrition, the extent of which was described in the first article. Less often considered is the possibility that the inequality of food entitlement (reflecting ancient forms of social inequality)[2] may have evolved as a mechanism to ensure that elites remain adequately fed in all but the most severe famines. This possibility is now briefly discussed.

The current global abundance of food (though not food entitlement) may be a comparatively recent and unusual phenomenon. There may have been many periods in the history of agriculture when factors including climatic change, poor storage, or diseases of plants and animal led to insufficient food to nourish the entire human population in any one area, thus leading to localized undernutrition or overt famine. For example, the most comprehensive study to date of health in the early agrarian transition in Europe (about 3,000 years ago) found that, based on skeletal remains, many people's condition deteriorated markedly after agriculture became widely adopted.[3]

In the much better documented recent past, good evidence exists for the primacy but not exclusivity of social factors as determinants of undernutrition. Examples include famines in India and Ireland in the nineteenth century. More recent famines have occurred in Ukraine, Bengal, Vietnam, the Netherlands, China and, most recently North Korea and Zimbabwe. In each case, social forces either denied adequate food supply or appropriated food for a powerful minority or colonising population. However, ecological factors such as the potato blight, drought and flood also contributed in most cases, with the most likely exceptions being Ukraine, Vietnam in 1944-45 and China [1959-62]. Indeed Mike Davis, one of the harshest supporters of poor governance as an explanation for famine, implicitly accepts a contributory eco-climatic explanation in the subtitle of his book on famine: "El Niño famines and the making of the Third World".[4]

In summary, the distribution of population nutrition may be better conceptualized as an "eco-social" phenom-

Corresponding Author: Dr. Colin D Butler, National Centre for Epidemiology and Population Health, College of Medicine Biology and Environment, Australian National University, Building 62, Mills Rd, Acton ACT, Australia 2601.
Tel: 61-2-61257175; Fax: 61-2-6125-0745
Email: colin.butler@anu.edu.au
Manuscript received 21 July 2009. Initial review completed 3 September 2009. Revision accepted 19 October 2009.

enon rather than exclusively a matter of social entitlement. Additionally, even if entitlement is considered dominant, its primacy may have evolved in part because of ancient, temporal variations in the size of food harvests. If so, such a long evolutionary heritage will take time to overcome. The world may need many generations of theoretical food abundance before this translates into sufficient food entitlement for all. This is not an argument in support of the *status quo* but an appeal for nutrition egalitarians to recognise the dimension of the challenge. Incremental progress in redistributing food may still be possible, but is seriously threatened by the growing environmental challenges subsequently discussed in this paper.

AGRICULTURE, FOOD INSECURITY AND CLIMATE CHANGE

Climate change and future food security have been studied since the early 1990s.[5-7] Informed opinion based on the relevant literature may be divided into neutral (1994-2005) and negative (2005-present) phases. In the first, several high-level papers presented a similar message about climate change and agriculture.[5,8-10]. Two commentaries published in *Nature* in 1994 summarise the interpretation of these findings.[5] One is broadly reassuring and became the dominant view for the next decade. The minority opinion is far less consoling. John Reilly's interpretation[1] was soothing: climate change – on balance – would not significantly worsen global food prospects. Climate change would create winners and losers but, overall, food production would hold its own. Furthermore, adaptation by farmers would make an important (compensatory contribution).[7] This comforting view dominated the literature for the next decade and, as argued in the earlier paper, influenced the Food and Agricultural Organisation (FAO), who did not rapidly perceive climate change as a large threat to global food supplies.

Every major paper on climate change and food published between 1994-2004 stressed that climate change was likely to intensify global agricultural inequality. All plants have an optimal temperature for growth. In cold regions, higher temperatures (provided there is adequate water, soil, essential elements and so on) will improve yields.[11] However, beyond the narrow window of optimal temperature, which of course varies for different crops (eg millet is more tolerant of heat than wheat), yields will decline. On balance, therefore, agricultural production in tropical (hot) countries is likely to be harmed by rising temperatures, while more temperate countries may benefit.

This predicted worsening of agricultural inequality was central to the more critical commentary made about that pioneering paper in *Nature*,[6] yet was not mentioned at all by Reilly. The other commentary, published as a letter soon after by Pittock *et al* made several other points. First, they questioned the strength of the carbon fertilization effect (CFE). The CFE was (and still is) a central mechanism to many climate and food models which partially offsets harm to crop growth due to other elements of climate change. However, recent doubts concerning the strength of the CFE have been greatly strengthened, especially for C4 plants such as maize and sugar cane.[12] Though it is fair to say that no consensus yet exists for a weak CFE,[13] it is similarly true to state that the consensus for a strong CFE no longer exists.

Pittock et al also pointed out that climate change was forecast to harm crop growth through several mechanisms excluded from the models, such as changed storm intensity, heavier rainfall and altered climatic variability. Finally, these workers questioned the feasibility and strength of adaptation strategies.

Three important additional criticisms could have been made, even in 1994. First, the quality of soil in areas predicted to gain agriculturally from climate change, such as parts of the Canadian shield, is unlikely to be sufficient to fully capitalize on a more favourable climate. Second, largely poor populations living in hot countries with poverty intensified by crop failures due to climate change are unlikely to be able to stimulate the investments necessary to convert agriculturally virgin high-latitude lands into new granaries. Such populations will lack the entitlement, the "effective demand".

The third criticism is that a "temporal mismatch" could occur, in which the climate is simultaneously sub-optimal for crops in tropical and high-latitude regions for several years. If this happens, then neither migration nor investment could alleviate global food shortages. The avoidance of global nutritional catastrophe would then necessitate either increased conversion of remaining forests and wilderness savanna to crop and pastoral purposes or massive reduction in the use of cereal and soy to feed animals. Both solutions would require the near abandonment of market forces. On the positive side, disproportionate warming is occurring at higher latitudes, making a severe temporal mismatch implausible.

In summary, these first-generation climate change and food models shared one major conclusion: that crop growth in most high-income countries would benefit, or at least be little harmed, by climate change. If the models had consistently predicted the reverse – that low-income countries would disproportionately benefit – then might the FAO and high-income countries have given greater priority to the issue of climate change and agriculture? Whether or not this is true, most low-income countries have also been slow to react to the threat of climate change.

AGRICULTURE, FOOD INSECURITY AND CLIMATE CHANGE: 2005-PRESENT

The second phase of the literature on climate change and food security has been more pessimistic. This is generating growing concern (fuelled in part by the deepening problem of hunger discussed in the first paper) and speculation that climate change is contributing to this hunger.[14] Doubts about the carbon fertilization effect have already been mentioned. In addition, several papers, using different methods, have produced results which collectively suggest additional problems.

The possibility of a "temporal mismatch" was mentioned above. Researchers have recently estimated that the warming and rainfall changes which occurred between 1980 and 2002 cost the world per annum about 2.5% of the total harvest of wheat, maize and barley, roughly equivalent to the total annual output of these grains by Argentina.[11] Australia, normally considered a major and reliable grain exporter, has experienced severe drought in the last decade, leading to two years of net grain importing (2001-02 and 2007-08). The unusually high temperatures and dryness[15] that contributed to this drought are partially attributable to climate change. The fraction of the global grain crop lost to date because of climate change through drought and heat may seem small, but food prices are sensitive to minuscule changes in supply. Additionally, other mechanisms exist by which climate change may already have reduced the global harvest, such as through extreme weather events, including typhoon Morakot, which struck Taiwan in 2009.

The fraction of global agricultural productivity lost because of climate change is likely to increase. Other workers have tried to quantify the scale of future crop losses in South and East Asia using different scenarios. Even with a strong CFE, grain losses in South Asia in 2080 were forecast to be as high as 18 to 22%.[16] Rice, the staple food in much of the Asia Pacific, is also harmed by additional heat, especially nocturnal. In 2004, researchers at the International Rice Research Institute (IRRI) reported that rice grain yield declined by 10% for each 1°C increase in growing-season minimum temperature in the dry season.[17]

Studies of the agricultural effects of the very severe 2003 European heatwave[18] have found that yields for several important crops were substantially lowered. Using observational data and output from 23 global climate models, Battisti and Naylor found a greater than 90% probability that growing season temperatures in the tropics and subtropics will exceed by the 2100 the most extreme seasonal temperatures recorded from 1900 to 2006. Adverse effects to food security are inevitable.

Heat increases and drought are not the only means by which climate change is likely to harm agricultural productivity. Cyclone Nargis, which struck Myanmar in 2008, had a devastating effect upon rice production.[19] The accompanying tidal surge swamped an estimated 783,000 hectares, destroying one-third of the rice crop in the Ayeyarwady (Irrawaddy) delta, the country's rice bowl. Nargis also ruined much of the delta's rice seeds, stored in bamboo containers that were easily waterlogged. The storm also drowned over 120,000 water buffalos and robbed survivors of farm implements and fishing boats and gear. As an adviser to the U.K.'s Department for International Development commented, "Nargis made a bad food-security situation worse."[19]

While not all weather disturbances as severe as Nargis can be attributed to climate change, there is growing consensus that climate change is increasing the strongest categories of storms (4 and 5). Indeed, a research group recently concluded that the most notable increase in storms occur in the North Atlantic and northern Indian Oceans, the latter region being relevant to the Asia-Pacific. However the likelihood of this remains uncertain; other workers have suggested that the recent documented increase in North Atlantic storms may ease when the Indian Ocean warms relative to the Atlantic.[20] Typhoon Morakot, which dumped over 2 metres of rain, was not a particularly powerful storm, as measured by its windspeed.

Two additional factors are excluded from formal models of food security and climate change: sea level rise and reduced irrigation water due to shrinking glaciers. Sea level rise by the end of this century is predicted to be a metre or more - far higher than that predicted by the 2007 report of the Intergovernmental Panel on Climate Change (IPCC).[21] Sea level rise and flooding of coastal lands, including shrimp farms, will lead to salination or contamination of fresh water and agricultural lands, and to the loss of nursery areas for fishing.

Also not quantitatively modeled are the effects upon crop production of Himalayan and Tibetan Plateau glacial retreat.[22,23] These glaciers are vital to regulate flow in many of the great rivers of Asia. They accumulate snow during winter, forming a frozen "water tower" which reliably melts each spring and summer, providing reliable river flow during the dry season. This is crucial to hundreds of millions of people in the Asia-Pacific. The language used in papers discussing this topic suggests a very severe effect despite a dearth of modeled estimates. Earlier melting of spring snow may also exacerbate flooding and perhaps contribute to the overflow of glacial lakes.[24] Recently, it has been recognized that these glaciers are retreating due to the effect of black carbon, or "soot", produced by low-temperature household burning of biofuels and coal.[25] This apparently bad news could become good news. Because black carbon washes out of the atmosphere in a few weeks, this aspect of climate change could be improved quickly with the introduction of enough improved stoves to poor populations, especially in developing countries.

AGRICULTURE, CLIMATE CHANGE AND BIOFUELS: A TENUOUS ASSOCIATION

FAO estimated that in 2007–08, 4.7 percent of global cereal production would be used for biofuels.[26] Although this diversion of food to fuel is sometimes attributed to climate change,, this proposition relies on increasingly discredited arguments that ethanol and other forms of bioenergy are environmentally benign.[27] With the exception of sugar cane in Brazil,[28] whose price is subsidized by cheap labour, the "first generation" (non-cellulosic) biofuels now available are clearly unsustainable. They are not even climate-neutral, once the carbon and environmental costs of land clearing and other life cycle energy costs are considered.[29-31]

Reducing climate change may – perhaps - have been a genuine motivation of those advocates who originally supported the introduction of biofuels. Supporters of this may yet be vindicated if more advanced "cellulosic" technology can be developed at a commercial scale. Such a possibility offers a "win-win" solution, because it would use inedible plant material as corn stover or switchgrass, perhaps grown on marginal land, to produce energy-dense liquid fuel. If that technology can be developed, then fuels such as ethanol from maize will be seen as a necessary stepping-stone. Such motoring power could prove carbon-neutral, especially if intact ecosystems such as forests are not cleared to grow them. However, there are many caveats here, and even if this technology can be developed it provides no justification for the current scale of corn (and soy) biofuels. In addition, one of the most publicized non-food biofuels crops, jatropha, has been shown to be far more water-intensive than previously thought.[27] Clearly, too, the benefit of such fuel crops is reduced if they displace food crops from fertile land, as claimed in Myanmar.[32]

The most plausible reason for the current expansion of bioenergy is to supplement scarce liquid fossil fuels. In summary, while bioenergy is an increasingly important factor in influencing the global food price, it is argued here that this has little to do with slowing climate change.

AGRICULTURE AND CLIMATE CHANGE: CONCLUSION

Despite decades of intense scientific effort, much remains uncertain about the impact of climate change, including upon agriculture. This is unsurprising, given the difficulty of the task. One prominent scientist has complained that predictions about climate change are untestable and therefore, "by definition, nonscientific".[33] However, the earliest documentation of what we now recognise as science – from Babylon 4,000 years ago – also tried to predict the future, in that case the position of celestial bodies.[34] We now take the predictive powers of astronomy for granted, and hope that future generations will value the results of predictive modeling about climate, food security and social impacts.

In the meantime, a policy of "wait and see" to detect the worst impacts of climate change upon agriculture will be to delay too long, as argued for the broader issue of climate change thirty years ago.[35] Disquieting evidence is accumulating that climate change will have a disproportionately severe impact on the agricultural productivity of poor populations, especially those living in the tropics, in the paths of storms and at low, coastal locations. Those who depend on glacial melt for irrigation will also be vulnerable, as are people farming already marginal lands. Reduced harvests will raise food prices, harming many people not directly dependent on agriculture.

The first of these linked papers placed this debate in the context of the much longer argument between optimists and pessimists, which, of course had nothing to do with climate change. Each proponent can find substantial evidence to support their worldview. For example, a paper published in July 2009 called "Population growth, increases in agricultural production and trends in food prices"[36] does not mention climate change, and uncritically mirrors the optimistic literature about world food security that prevailed in the 1990s (discussed in our first paper). The future is not identical to the past. Escapes from Malthusian traps are rarely as complete as optimists propose, as shown in the first paper. They may well be even less complete in the future.

This paper does not assert that the science of climate change and agriculture is mature, or that worst-case scenarios are inevitable. It does assert, however, that to dismiss this gathering evidence as a false alarm would be highly dangerous. In addition, as our first paper discussed, world hunger is worsening, irrespective of the opinions of pessimists or optimists. There are, unfortunately, several other reasons to be concerned about near term global food security. These will now be discussed, though in less detail.

WATER SCARCITY AND CROP PRODUCTION

Water is essential for drinking, industry, several forms of electricity production and washing. It is also vital for agriculture. The above section above considered several ways by which climate change may reduce water availability. Other aspects of global environmental change generally considered separate to climate change also have probable effects on rainfall and water supply. The most important of these is the "atmosperic brown cloud", the continental haze of aerosols from sulphate, dust, dung and soot. While it counters some of the warming effect of greenhouse gases, it is considered to reduce rainfall.[37] Concerns have also been raised that climate change and landuse change could abruptly alter the Asian monsoon.[38]

Apart from this, there are persistent warnings that ground water reserves, especially in parts of India, northern China, Pakistan and the US are being depleted at a rate much higher than their replenishment.[39-41] Of the world's fresh water, far more – perhaps 100 times as much – is found underground than in rivers, lakes and swamps.[42] Some parts of the world, such as much of Africa and north east India[43] are thought to still have large ground water reservoirs. However, in many countries, the quality of ground water is poor, due to contamination with naturally occurring arsenic and sometimes boron and pesticides. Furthermore, even if aquifer water remains, the cost of extraction can make irrigation unaffordable. For example, anecdotal reports exist that in parts of the North China Plain wells are now as deep as 1,000 metres.[39]

Brown also attributes the recent flattening of the Chinese harvest substantially to the depletion of ground water (see Figure).[39] Other explanations are plausible. Alexandratos – a long-time critic of Brown (see first paper) attributes the fall in Chinese grain (rice as well as wheat) to "reduced production incentives".[44] Surface ozone exposure may be an even more important contributor (see below).

China, of course, has an ancient history of massive water engineering. More recently, India has announced ambitious plans to interlink its many rivers.[45] The management of water resources is a potent source of conflict.[46] China has announced plans to divert the Tsang-Po, as the Brahmaputra is named in China.[47] Other engineering projects are likely to see new dams and altered river flow elsewhere in Asia, altering the distribution of food production but not necessarily the total amount. For example, agriculture, fisheries and navigation on the downstream Mekong may be harmed.[48] There are also increasing fears that dams are contributing to earthquakes in regions with many faultlines, such as Sichuan, China.[49]

TROPOSPHERIC OZONE POLLUTION AND CROP PRODUCTION

For some time it has been recognized that surface ozone, high levels of which exist due to pollution in some parts of Asia, is harmful to crops. In 2004, researchers concluded that three East Asian countries (China, Japan and South Korea) were on the cusp of substantial reductions in grain production and that high ozone concentrations since 1990 had already cost these countries 1–9% of their yield of wheat, rice and corn, and far more (23–27%) of their soybean yield.[50]

More recent studies on Asian cultivars, relying on dose-response relationships derived in Asia, have estimated that yield losses for wheat, rice and legumes range between 5–48, 3–47 and 10–65%, respectively, and that Asian grown cultivars are more sensitive to ozone than similar crops in North America.

AN IMPENDING SCARCITY OF OIL AND PHOSPHORUS?

A very large literature now exists concerning the prospect of "peak oil" – the halfway point in the exhaustion of global oil supplies.[51-53] Sceptics of peak oil point out that large reserves of "non-conventional" oil such as tar sands still remain; however, these require significant energy to recover[53] and their mining will generate large additional greenhouse gas emissions. Even the remaining quantity of coal, another fossil fuel which can be converted to liquid and used to substitute oil, has recently been questioned: reserves may be far lower than once thought. Even if large reserves of coal remain, their conversion to either electricity or liquid fuel will generate enormous quantities of greenhouse gases unless "carbon capture and storage" technology can be perfected.

Large amounts of energy are vital for modern agriculture. Energy is used to clear, till and irrigate land for planting and to transport and package food for the market. Hydrocarbons from fossil fuels are used to manufacture pesticides, while coal and natural gas are used to supply the hydrogen in ammonia, a relatively energy intense process by which nitrogen from the atmosphere is "fixed" to make fertiliser.[54] In short, the rising price of oil, coal, gas and other forms of energy is likely to lead to steep increases in the price of food. Hence, more hunger.

The rise in the oil price in 2008 to almost US$150 per barrel was an important element in the rise of food prices in 2008.[44] Indeed, higher energy costs (with commodity speculation)[55] appear a more plausible explanation than either biofuels, climate change, the use of food crops for feed or the low value of the US dollar, since food prices have declined while those other trends have continued to rise.

Whatever the proximity of "peak oil", these concerns should provide a powerful motivation to accelerate the sustainability transition away from fossil fuels and towards various forms of renewable energy.[56-58]

Less well known than peak oil though probably further away is "peak phosphorus", the maximum consumption of which has been forecast to occur in about two decades. Although the role of phosphorus as an essential nutrient was not discovered until 1840,[59] phosphorus levels had been maintained in soil for generations, particularly through the use of animal manure and human nightsoil, both of which helped retain nutrients. As populations and urbanisation developed, many soil elements were diverted, via the food system, to sewage and eventually to the ocean.[60] For a time, phosphorus levels were enhanced by the application of guano. More recently, rock phosphate has been mined, and used as fertilizer. Guano is now largely exhausted, while the quality of rock phosphate is slowly falling. It is now concentrated in only three countries: Morocco (and Western Sahara), the US and China.[59,60]

Peak oil and peak phosphorus have important differences. The most important is that phosphorus, as an element, has no substitute. On the other hand, unlike oil, phosphorus can be re-used, if it can be recovered. The importance of phosphorus for future food supplies is starting to be realised, but much more recognition is needed. Here are two examples: China is reducing its phosphorus exports[59], and two municipalities in Sweden have mandated that all new toilets must be urine-diverting. In these cases, urine is stored in large communal containers and used by local farmers.[60] However, as with so many other aspects of the sustainability transition, large behavioural, institutional and infrastructural barriers remain. Finally, Cordell *et al* (2009) draw attention to another analogy. They point to a disturbing lack of recognition of peak phosphorus by most global food bodies and reports, extending well beyond the FAO to include the International Food Policy Research Institute (IFPRI), and even the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD).[60]

POPULATION DISPLACEMENT, CONFLICT GOVERNANCE AND FOOD

If business as usual continues, then an unimaginable catastrophe looms in this century. Unprecedented number of people in the Asia Pacific will be displaced due to sea level rise and reduced water and food security. Yet, there are also two broad schools of thought, with some writers denying there such displacement will generate conflict and deteriorating feedbacks. However, it strains this writer's credulity to imagine that, beyond a threshold, our ancient human resilience in the face of stress will not be transformed into the equally ancient human capacity to make war. Population displacement and related governance stress are themselves likely to impair food production and food security. Rather than business as usual, the sustainability revolution must unfold rapidly in the coming decades.

In 2008, several countries in the Asia Pacific restricted rice exports. China is already restricting phosphorus export. It is naïve to imagine that other restrictions will not proliferate if similar constrained food-growing or food-price circumstances appear. Retaliatory food export bans are plausible and could spill into other forms of retaliation and exclusion. Dialogue and goodwill between nations is essential to maintain long term population health.

CONCLUSION: PROMOTING FOOD SECURITY IN THE ASIA PACIFIC

These two papers have outlined numerous interacting pathways by which future food security in the Asia Pacific region is at risk. The first paper reviewed the long-standing debate between optimists and pessimists and found that at present the scales are tilted towards a cautionary outlook. This paper has provided more details for several of these pessimistic mechanisms. Of these, surface ozone, groundwater depletion and climate change are likely already to harming crop growth. The high price of oil in 2008 probably contributed to high food prices. Worsening climate change and more expensive energy and phosphorus are likely to worsen agricultural production, food security and thus health in coming decades.

Addressing these problems requires an enormous co-ordinated global effort. It is difficult to understate the complexity and potential magnitude of these inter-related challenges. Solving them will be an important contribution to the even broader sustainability transition. While comparatively high income and low population growth will help some parts of the Asia Pacific cope with these problems, other regions, especially in South Asia, are at high risk of heightened undernutrition and more fragile security.

It is likely that the rate of increase in animal product consumption, including of meat, predicted for many parts of the Asia Pacific will be lower than is now forecast, as the enormous quantity of grain and soy now diverted to feed animals provides an emergency human food buffer. However, it is likely that market forces will restrict the use of this reserve and that the intensified food crisis which seems inevitable, this century will see even larger food, nutritional and health consequences than presently exist.

Bio-energy expansion, especially of “fuel foods” which compete directly with humans will also slow, and may well be reversed if food grows sufficiently scarce. If cellulosic technology can be developed, then biofuel crops need not compete directly with food. Other breakthrough technologies such as carbon capture and storage and genetically engineered crops to cope with climate change or drought are possible, but it would be imprudent to rely principally on the development of such technologies to solve our problems.

A much preferable, lower risk strategy would be to aggressively expand existing clean energy technologies such as wind, solar and energy conservation, to promote public transport over private transport and to improve air quality. Strategies to improve equity, child survival and smaller families should also be pursued, especially in South Asia. Further ecosystem conversion to grow food and feed appears inevitable, though far from desirable, and is a method which carries additional risks.

Finally, policy makers, world leaders and funding bodies must recognise the dimension of this growing crisis and commit substantial, visionary resources in order to address it. In particular, technologies which can replace fossil fuels will enhance energy security while at the same time slowing climate change.

AUTHOR DISCLOSURES

None declared.

REFERENCES

1. Sen AK. Poverty and famines: an essay on entitlement and deprivation. Oxford, New Delhi: Clarendon Press; 1981.
2. Price TD, Feinman GM, editors. Foundations of social inequality. New York: Plenum Publishing Corporation; 1995.
3. Gibbons A. Civilization’s cost: the decline and fall of human health. Science. 2009;324:588.
4. Davis M. Late Victorian holocausts: El Nino famines and the making of the Third World. London: Verso; 2001.
5. Rosenzweig C, Parry ML. Potential impact of climate change on world food supply. Nature. 1994;367:133-8.
6. Pittock AB, Whett P, Wang Y. Climate and food supply. Nature. 1994;371:25.
7. Reilly J. Crops and climate change. Nature. 1994;367:118-9
8. Parry ML, Rosenzweig C, Iglesias A, Fischer G, Livermore M. Climate change and world food security: a new assessment. Global Environmental Change. 1999;9:S51-S67.
9. Fischer G, Shah M, Velthuizen Hv, Nachtergaele FO. Global Agro-ecological assessment for agriculture in the 21st century: International Institute of Applied Systems Analysis; 2001.
10. Parry M, Rosenzweig C, Livermore M. Climate change, global food supply and risk of hunger. Philos Trans R Soc Lond B Biol Sci. 2005;360:2125-38.
11. Lobell D, Field C. Global scale climate–crop yield relationships and the impacts of recent warming. Environmental Research Letters; 2007 available at http://www.iop.org/EJ/article/-search=66768330.3/1748-9326/2/1/014002/erl7_1_014002.pdf?request-id=c0a2cc49-7def-4949-9178-3a0d8d185e26
12. Long SP, Ainsworth EA, Leakey ADB, Nösberger J, Ort DR. Food for thought: lower-than-expected crop yield stimulation with rising CO2 concentrations. Science. 2006; 312:1918-21.
13. Tubiello FN, Amthorb JS, Boote KJ, Donatelli M, Easterling W, Fischer G, et al. Crop response to elevated CO2 and world food supply A comment on "Food for Thought" by Long et al., Science 312:1918.1921, 2006. Eur J Agron. 2007;26:215–23.
14. Sheeran J. The challenge of hunger. Lancet. 2008;371:180-1.
15. Karoly D, Risbey J, Reynolds A. Global warming contributes to Australia's worst drought: WWF; 2003 available at http://www.climnet.org/pubs/WWF_2002_Drought_web.pdf
16. Tubiello FN, Fischer G. Reducing climate change impacts on agriculture: Global and regional effects of mitigation, 2000–2080. Techn Forecasting Soc Change. 2007;74:1030-56.
17. Peng S, Huange J, Sheehy JE, Laza RC, Visperas R, Zhong X, et al. Rice yields decline with higher night temperature from global warming. Proc Natl Acad Sci USA. 2004;101: 9971-5.
18. Battisti DS, Naylor RL. Historical warnings of future food insecurity with unprecedented seasonal heat. Science. 2009; 323:240-4.
19. Stone R. One year after a devastating cyclone, a bitter harvest. Science. 2009;324:715.
20. Vecchi GA, Swanson KL, Soden BJ. Whither hurricane activity? Science. 2008;322:687-9.
21. Richardson K, Steffen W, Schellnhuber HJ, Alcamo J, Barker T, Kammen DM, et al. Climate change. Global risks, challenges & decisions. Synthesis report. 2009. available at www.climatecongress.ku.dk/pdf/synthesisreport/
22. Ren J, ZF J, JC P, X Q. Glacier variations and climate change in the central Himalaya over the past few decades. Ann Glaciol. 2006;43:218-22.
23. Barnett TP, Adam JC, Lettenmaier DP. Potential impacts of a warming climate on water availability in snow-dominated regions. Nature. 2005;438:303-9.
24. Regmi BR, Pandit A, Pradhan B, Kovats S, Lama P. Climate change and health in Nepal 2008. Capacity strengthening in the least developed countries (LDCS) for adaptation to climate change (CLACC) CLACC working paper 3.
25. Tolleson J. Climate's smoky spectre. Nature. 2009;360:29-32.
26. Food and Agricultural Organisation of the United Nations. The state of food insecurity in the world 2008: High food prices and food security – threats and opportunities. Rome: FAO; 2008.

27. Gerbens-Leenes W, Hoekstra AY, van der Meer TH. The water footprint of bioenergy. Proc Natl Acad Sci USA. 2009;106: 10219-23.
28. Goldemberg J. Ethanol for a sustainable energy future. Science. 2007;315:808-10.
29. Pimentel D, Patzek TW. Ethanol production using corn, switchgrass, and wood; biodiesel production using soybean and sunflower. Nat Res Res. 2005;14:65-76.
30. Fargione J, Hill J, Tilman D, Polasky S, Hawthorne P. Land clearing and the biofuel carbon debt. Science. 2008;318: 1235-8.
31. Scharlemann JPW, Laurance WF. How green are biofuels? Science. 2008;319:43-4.
32. Hookway J. Agriculture policies worsen food shortages. Wall Street Journal. 2008. available electronically at http://online.wsj.com/article/SB121025970878577295.html
33. Randolph SE. Perspectives on climate change impacts on infectious diseases. Ecol. 2009;90:927-31.
34. Gordin MD. Babylon, Newton, and all that. Science. 2009; 325:149.
35. Charney JG et al. Carbon dioxide and climate: a scientific assessment: National Academy of Science; 1979 cited by Peterson TC, Connolley WM, Fleck J. The myth of the 1970s global cooling scientific consensus. J Climate. 2008; 89:1325-13.
36. Southgate D. Population growth, increases in agricultural production and trends in food prices. Elect J Sust Devel. 2009;1(3). available at http://www.ejsd.org/public/journal_article/13
37. Ramanathan V, Chung C, Kim D, Bettge T, Buja L, Kiehl JT, et al. Atmospheric brown clouds: Impacts on South Asian climate and hydrological cycle. Proc Natl Acad Sci USA. 2005;102:5326-33.
38. Zickfeld K, Knopf B, Petoukhov V, Schellnhuber HJ. Is the Indian summer monsoon stable against global change? Geophy Res Lett. 2005;32:L15707. doi:10.1029/2005GL02277
39. Brown L. Aquifer depletion. In: Cleveland CJ, editor. Encyclopedia of Earth. Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment; 2007. available at http://www.eoearth.org/article/Aquifer_depletion
40. Wang J, Huang J, Rozelle S, Huang Q, Blanke A. Agriculture and groundwater development in northern China: trends, institutional responses, and policy options. Wat Pol. 2007; S1:61–74.
41. Rodell M, Velicogna I, Famiglietti JS. Satellite-based estimates of groundwater depletion in India. Nature. 2009;460: 999-1002.
42. Barlow M. Blue covenant – the global water crisis and the coming battle for the right to water. New York: The New York Press; 2007.
43. Sharma KD. Groundwater management for food security. Curr Sci. 2009;96:1444-7.
44. Alexandratos N. Food price surges: possible causes, past experience, and longer term relevance Popn Devel Rev. 2008;34:663-97.
45. Gurjar BR. Interlinking of rivers: A climatic viewpoint. Curr Sci. 2003;84:1381-2.
46. Varis O, Keskinen M, Kummu M. Mekong at the crossroads. Ambio. 2008;37:146-9.
47. Ramachandran S. India quakes over China's water plan Asia Times. 2008. available at http://www.atimes.com/atimes/China/JL09Ad01.html
48. Zeng N, Ding Y, Pan J, Wang H, Gregg J. Climate change—the Chinese challenge. Science. 2008;319:730-1.
49. Kerr RA, Stone R. A human trigger for the great quake of Sichuan? Science. 2009;323:322.
50. Wang X, Mauzerall DL. Characterizing distributions of surface ozone and its impact on grain production in China, Japan and South Korea: 1990 and 2020. Atmos Env. 2004;38:4383-402.
51. Kaufmann RK. The descent of Mount Petroleum. Nature. 2005;434:960.
52. Hanlon P, McCartney G. Peak oil: Will it be public health's greatest challenge? Public Health. 2008;122:647-52.
53. Hall CAS, Day J.W. Revisiting the limits to growth after peak oil. Am Scientist. 2009;97:230-7.
54. Erisman JW, Sutton MA, Galloway J, Klimont Z, Winiwarter W. How a century of ammonia synthesis changed the world. Nat Geosci. 2008;1:636-9.
55. Pace N, Seal A, Costello A. Food commodity derivatives: a new cause of malnutrition? Lancet. 2008;371:1648-50.
56. McMichael AJ, Smith KR, Corvalan CF. The sustainability transition: a new challenge. Bull World Health Org. 2000; 78:1067.
57. Pacala S, Socolow R. Stabilization wedges: solving the climate problem for the next 50 years with current technologies. Science. 2004;305:968-72.
58. Hoffert MI, Benford G, Criswell DR, Green C, Herzog H, Jain AK, et al. Advanced technology paths to global climate stability: energy for a greenhouse planet. Science. 2002;298: 981-7.
59. Zhu YG. Soil science in the understanding of the security of food systems for health. Asia Pac J Clin Nutr. 2009;18:516-9
60. Cordell D, Drangert J-O, White S. The story of phosphorus: global food security and food for thought. Glob Envtl Change. 2009;19:292-305.

Review

Food security in the Asia-Pacific: climate change, phosphorus, ozone and other environmental challenges

Colin D Butler PhD

National Centre for Epidemiology and Population Health, College of Medicine Biology and Environment, Australian National University

亞太地區的糧食安全：氣候變遷、磷、臭氧層及其他環境的挑戰

這是兩篇討論亞太地區未來糧食安全性挑戰的第二篇文章。討論重點放在五個機制，藉由它們被概念化為途徑，使得第一篇文章中提到的馬爾薩斯悲觀的情境，變得明顯。這些機制為 (1)氣候的改變 (2)水資源的缺乏 (3)對流層中臭氧的污染 (4)磷及常規石油的急迫短缺 (5)未來的人口流離、衝突及管理不善間的可能交互作用。本篇文章的結論是，要使糧食安全性永續地改善，需要從社會對環境的施為、人口成長、農業研究及分配的權利、機會與配額來做徹底的改變。

關鍵字：氣候變化、糧食安全、磷、石油峰值、永續性、變遷