3 Climate change: the 21st century's most urgent environmental problem or proverbial last straw?

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Some have argued that the Kyoto Protocol and other schemes for immediately mitigating greenhouse gas (GHG) emissions are justified because human-induced global warming is, in the words of the 42nd US president, William J. Clinton, 'the overriding environmental challenge' facing the globe today.[1] Another argument, advanced by those who are more cautious and perhaps less prone to hyperbole, is that the impacts of global warming – on top of myriad other global public health and environmental threats – may prove to be the proverbial 'straw that breaks the camel's back'. They suggest that climate change will overwhelm human and natural systems by increasing the prevalence of climate-sensitive diseases, reducing agricultural productivity in developing countries, raising sea levels, and altering ecosystems, forests and biodiversity worldwide.[2]

This chapter examines whether analyses of the impacts of global warming into the foreseeable future support these arguments and, if they do, whether it is more effective to rely on mitigation strategies, or on adaptation to their impacts. In this chapter, adaptation implies measures, approaches or strategies that would help cope with, take advantage of, or reduce vulnerability to the impacts of global warming.

Global warming impacts to the present

Over the last century or more, the earth has warmed 0.4–0.8°C, perhaps due to man's influence, according to the Intergovernmental Panel on Climate Change (IPCC).[3] Over this period, there have been changes in many climate-sensitive environmental indicators or sectors of the economy – some for the better, others for the worse, and for others, neither better nor worse.

The good

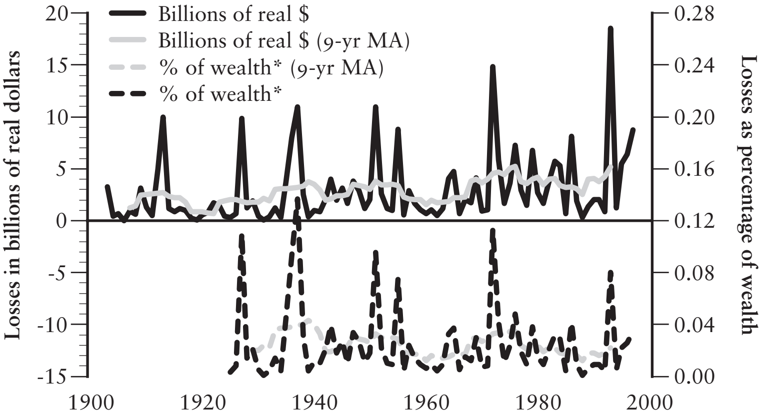
For many critical climate-sensitive sectors and indicators, matters have actually improved, especially during the last half century.[4] Global agricultural productivity has never been greater, for instance. An acre of cropland sustains about twice as many people today as it did in 1900, and it sustains them better. Based on nutrition and affordability of food, people have never been fed better or more cheaply. Between 1961 and 2001, global food supplies per person increased 24%, although global population almost doubled;[5] and between 1969–71 and 1998–2000, the number of people in developing countries suffering from chronic hunger declined from 35% to 17% or, in absolute terms, from 917 million to 799 million despite a 79% growth in their population.[6]

In wealthier countries, deaths due to climate-sensitive infectious and parasitic diseases are now the exception rather than the rule. Such deaths are declining in most developing countries thanks to better nutrition and public-health measures. Accordingly, from 1960 to 2000, the global infant mortality rate dropped by 57%, and global life expectancy at birth increased from 50.2 to 66.5 years.[7] However, in the last 10–15 years, these improving trends have been reversed in many sub-Saharan African and former communist countries, not because of climate change, but because of increasing poverty, Aids and malaria.[8,9]

The bad

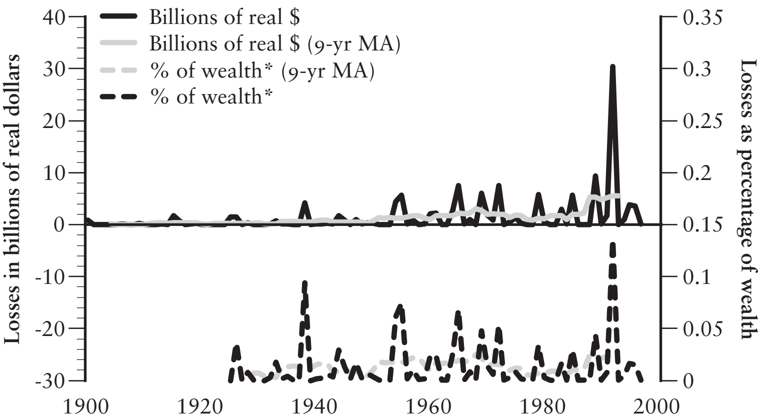
For other climate-sensitive indicators matters have, indeed, worsened, but so far human-caused warming has had little to do with these declines. Consider sea-level rise. Mean sea level is rising at a rate of about 0.1–0.2 mm per year.[10] While it is not known what fraction, if any, might be due to any human-caused warming, the IPCC's Science Assessment notes that there is no detectable acceleration of sea-level

Figure 1 **US property losses due to floods (1903–97)**



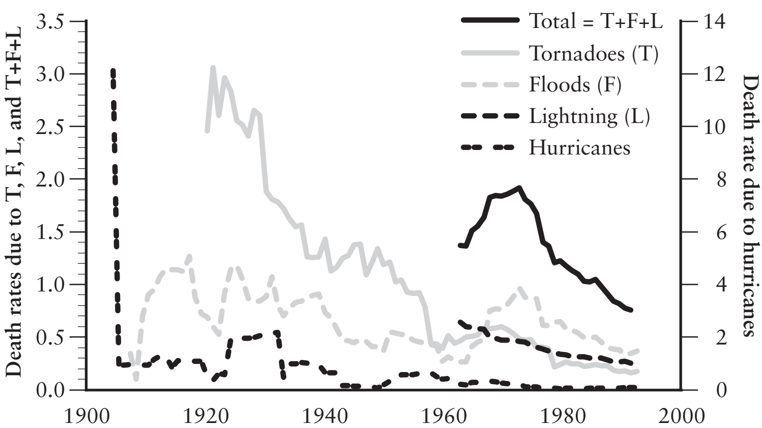
*Wealth measured as fixed reproducible tangible assets.
Source: Goklany (1998b, 2000a)

Figure 2 **US property losses due to hurricanes (1900–97)**



*Wealth measured as fixed reproducible tangible assets.
Source: Goklany (1998b, 2000a)

Figure 3 **US death rates due to various extreme weather events (1900–97), deaths per million population, 9-year moving averages (MA)**



Source: Goklany (1998b, 2000a)

rise during the twentieth century.[11] Suffice it to say, so far any accelerated sea-level rise due to man-made warming is unlikely to have caused anything other than a minor impact on human or natural systems compared to other environmental stresses such as development of coastlines, conversion of lands for aquaculture, drainage for other human land uses, sediment diversion due to dam construction, construction of seawalls, and subsidence owing to water, oil and gas extraction.[12]

Agricultural demand for water, probably the largest threat to freshwater species, continues to increase.[13] Meanwhile, threats to terrestrial biodiversity – primarily the conversion of habitat to agricultural uses[14] – have not diminished. Forested area declined by 124 million hectares (306 million acres) in tropical and subtropical nations between 1990 and 2000.[15] This decline, which occurred largely because increases in food demand outstripped increases in agricultural yields, is unrelated to global warming. Yet during the same period, forest cover in the rest of the world (mainly wealthy nations) expanded by

28 million hectares (69 million acres), mainly because technology-based, high-yield agriculture has reduced the demand for cropland in those countries.

The indifferent

As the higher latitudes have become warmer, spring has arrived earlier since the 1960s. As a result, we observe earlier breeding or first singing of birds, earlier arrival of migrant birds, earlier appearance of butterflies, earlier choruses and spawning in amphibians, earlier shooting and flowering of plants.[16]

This has been accompanied by later arrival of autumn and autumn colours in some places. A meta-analysis of trends for 99 species of birds, butterflies and alpine herbs, found significant range shifts averaging 6.1 km per decade towards the poles.[17] It also found a significant mean advancement of spring events by 2.3 days per decade based on data for 172 species of shrubs, herbs, trees, birds, butterflies and amphibians.[18]

Clearly, there have been changes, but are these changes adverse? The Finnish branch of the WWF notes, for example, that:

> Thanks to the warming trend, the growing season has grown … At the same time the spring migration of birds, including finches, larks, wagtails, and swifts, has begun an average of ten days earlier than before.
>
> The warmer temperatures have brought new, more southerly species of butterflies to Finland. Many existing types of butterflies have extended their habitats further north.[19]

According to the Royal Society for the Protection of Birds, some birds in the UK have also become more abundant, possibly due to milder winters.[20] Similarly, the ranges of fifteen butterfly species in the UK have expanded substantially since the 1970s, 'almost certainly' because of warming (whether or not human-induced).[21] They also appear earlier in the year and some have been able to spawn an extra generation during the summer. In addition, some moths, crickets and dragonflies have migrated into the UK.[22]

With respect to vegetation, a study of the earliest flowering dates of 385 wildflower species in the UK shows that on average they bloomed more than 4.5 days earlier in the 1990s compared to their 1954–90 average, with 16% blooming significantly earlier while 3% bloomed significantly later; one plant bloomed fully 55 days earlier.[23] Similarly, the ranges of flowering plants and mosses seem to have expanded in the parts of Antarctica that have warmed.[24] Soil invertebrates have also advanced with changes in vegetation.[25]

Obviously, warming (whether due to man's activities or nature's machinations) seems to have a measurable impact on the distribution and abundance of species, but it is far from clear whether these changes are beneficial or detrimental. More importantly, the major current threats to species come from habitat modification and loss, water diversions, and invasive species, perhaps in that order.

Summary

Despite any warming, by virtually any climate-sensitive measure of human well-being, human welfare has improved over the last century.[26] While some credit for increasing agricultural and forest productivity is probably due to higher carbon dioxide concentrations and higher wintertime temperatures,[27] most of these improvements are due to technological progress driven by market- and science-based economic growth, technology, and trade. Such progress has also reduced human vulnerability to the effects of climate change.[28] As a result, technological progress has so far had a greater impact on the climate-sensitive sectors than has climate change itself.[29]

On the other hand, matters may actually have deteriorated for some climate-sensitive environmental indicators, such as the loss of habitat and forests, and threats to biodiversity. However, so far, climate change (human-induced or not), while contributing to change, does not seem to be responsible for most, if any, of this deterioration.

Therefore, it is difficult to sustain on the basis of current evidence the notion that climate change is the greatest threat to public health or the environment today. But what about the future?

The future with and without global warming

Table 1 on page 63 allows us to assess the importance of global warming, relative to other factors that might affect public health and the environment into the 'foreseeable future'. This table is based, for the most part, on a set of impact studies sponsored by the UK Department of Environment, Food and Rural Affairs (DEFRA), many of which have been incorporated into the IPCC's 2001 Third Assessment Report (TAR). Because the DEFRA-sponsored assessments did not provide an estimate of the future forest cover in the absence of climate change, it was necessary to rely on other studies reported by the IPCC for that estimate.

Notably, analysts involved in the DEFRA studies recognise that socioeconomic projections are 'not credible' beyond the 2080s,[30] hence the selection of the 2080s in the table as the outside limit to the 'foreseeable future'. Although the TAR states that between 1990 and 2100, global temperature might increase from 1.4 to 5.8°C, it also notes that 'on time scales of a few decades, the current observed rate of warming ... suggests that anthropogenic warming is likely to lie in the range of 0.1 to 0.2 °C per decade over the next few decades.'[31]

However, the scenarios employed in the DEFRA-sponsored impact assessments are based on globally averaged temperature increases of slightly more than 0.3°C per decade;[32] therefore, they may overestimate likely impacts to the 2080s.

In Table 1, column 3 provides estimates of various public health and environmental risks or factors related to those risks under baseline conditions in the 2080s (i.e., in the absence of global warming). Column 4 provides the changes in risks or risk-related factors in the 2080s due to the imposition of global warming, above and beyond baseline conditions; that is, it provides estimates of the reductions in total risks if climate doesn't change after 1990. Finally, column 5 provides estimates of reductions in total risks or risk-related factors due to full implementation of the Kyoto Protocol assuming that because the Protocol would reduce temperature change between 3–7% by 2100,[33] it would reduce the impacts of global warming by less than 7% for all risk categories except coastal flooding. For the latter, it is assumed that the Protocol will decrease the impact of climate change by thrice that amount.[34]

Table 1 indicates that:

- In the absence of warming, (that is, in the 'baseline' case), *global cereal production* would increase by 123% from 1,800 megatons in 1990 to 4,012 megatons in the 2080s in order to meet additional food demand of a larger and wealthier global population.[35] Such an increase is plausible provided agricultural technology continues to enhance productivity,

Table 1 Projected climate change impacts in the 2080s, compared to other environmental and public health problems

Climate-sensitive sector/indicator	*Year*	*Impact/effect*		
		Baseline (B) in the 2080s , includes impacts of environmental problems other than climate change	*Impacts of climate change (ΔCC) in the 2080s, on top of the baseline*	*Impacts of Kyoto Protocol in 2080s, relative to baseline*+ –ΔCC*
Global agricultural (cereal) production	2080s	4,012 million metric tons (MMT), vs 1,800 MMT in 1990	production would drop 2% to 4%; and could be substantially redistributed from developing to developed countries	increase net global production by 0.1% to 0.3%
Falciparum malaria (population at risk, PAR)	2080s	8.82 billion at risk by the 2080s, vs 4.41 billion in 1990	increase PAR by 0.26 to 0.32 billion (or 2.9% to 3.7%)	reduce total PAR by 0.2% to 0.3%
Water resources (population in countries where available resources use > 20%)	2085	6.46 billion, vs 1.75 billion in 1990	increase PAR from 0.04 to 0.11 billion (or 0.6% to 1.6%)	reduce total PAR by about 0.1% or less
Global forest area	2050s 2080s	decrease 25–30(+)% by 2050, relative to 1990	increase by 5%, relative to 1990	reduce the increase in global forest area by 0.4%
Sea-level rise (SLR)	2080s	varies	~4041 cm (or 20 in), relative to 1990	reduce SLR by <1.4 in
Coastal flooding (PAR)	2080s	0.013 billion	increase PAR by 0.081 billion (or 623%)	reduce total PAR by 18.1%
Coastal wetlands (area)	2080s	decline of 40% relative to 1990	decline of 12% relative to 1990	reduce the decline by 0.8%, relative to 1990 level
Storms	2080s	unknown	unknown whether magnitudes or frequencies of occurrence will increase or decrease in any specific area	unknown

Sources: Parry *et al.* (1999) and IPCC (2001b) for agriculture; Arnell *et al.* (2002), and Goklany (2000), based on Solomon *et al.* (1996), for forest cover; Arnel *et al.* (2002) and IPCC (2001b) for *Falciparum* malaria; Arnell *et al.* (2002) for coastal flooding; Arnell (1999) for water resources.
* Assumes that the Kyoto Protocol, if implemented, would reduce climate change and its impacts by 7% by the late 21st century. See text.

sufficient investments are made in the agricultural sector and related infrastructure, and trade continues to move food from surplus areas to deficit areas.[36]

Due to global warming, agricultural production may decline in poor countries, but may increase in wealthy countries, resulting in a net decline in global production of 100 megatons to 160 megatons (i.e., 2–4% of total production in the absence of warming) in 2080. Thus, downturns in economic growth (which would inhibit investments in the agriculture and infrastructure), slower technological change, or less voluntary trade of food supplies are more likely to create a future food crisis than any potential global warming.[37] Notably, the Kyoto Protocol would result in a marginal improvement in production of less than 0.3% in the 2080s.

- The *population at risk (PAR) of malaria*, one of the most common and dreaded climate-sensitive infectious diseases, might essentially double in the absence of global warming, from 4.41 billion in 1990 to 8.82 billion in 2080.[38] With global warming, the numbers at risk of contracting malaria might increase by 0.26 billion to 0.32 billion in the 2080s (equivalent to an increase of between 2.9% and 3.7% over the 2080 baseline).[39] However, an increase in the numbers at risk does not necessarily translate into increased number of cases of malaria, or its prevalence.[40] The Kyoto Protocol would reduce the total numbers at risk of contracting malaria by less than 0.3% in the 2080s, as well. (For a more detailed explanation of climate and disease, see Chapter 1, 'Could global warming bring mosquito-borne disease to Europe?')
- The number of people living in countries who experience *water stress* (defined as countries using more than 20% of their available water resources) would increase from 1.750 billion in 1990 to 6.464 billion under the baseline (no-climate-change) case in the 2080s.[41] The latter number would increase by between 0.042 billion and 0.105 billion, depending on the precise climate model employed to estimate future climate change.[42] The impact of the Kyoto Protocol for this risk category will also be minimal into the 2080s.
- If all else remains the same (i.e., ignoring changes in land use after 1990), then by the 2080s, *global forest area* may *increase*

5% over 1990 levels due to global warming alone.[43] But if greater agricultural and other human needs increase the demand on land, as they well might (since the world's population will be larger and probably wealthier), forest cover may decline by 25–30%, putting enormous pressure on global biodiversity.[44]

- *Sea level* may rise about 40 cm from 1990 to 2080.[45] As a result, the population at risk of *coastal flooding* is expected to increase by 623% from 0.013 billion under the baseline to 0.094 billion. The Kyoto Protocol could reduce the total PAR from coastal flooding by about 18%. Sea-level rise could also lead to a loss of *coastal wetlands*, but such losses due to other human activities are expected to dominate at least into the 2080s.
- It is unclear whether the frequencies and magnitudes of *storms*, such as tornadoes, hurricanes and cyclones, will increase or decrease.[46]

Thus, with the exception of coastal flooding, the impacts of climate change into the foreseeable future are secondary to the impacts of other agents of change built into the baseline case. Moreover, for the most part, the impacts of global warming would seem to be within the noise level of these baseline problems.

Consequently, stabilising GHG concentrations immediately – even if feasible – would, unfortunately, do little over the next several decades to solve the bulk of the problems frequently invoked to justify actions to reduce humanity's role in warming. Land and water conversion will continue almost unabated, with little or no reduction in the threats to forests, biodiversity, and carbon stores and sinks. Food production would not be markedly increased or decreased. Populations at risk of malaria would not be affected much, nor would the numbers of people at risk of water stress. The reductions in risks due to the Kyoto Protocol would be relatively trivial, at least until the 2080s, with respect to all risk categories – again with the exception of coastal flooding.

Nevertheless, climate change could be the proverbial last straw. Moreover, the relatively large reductions in the PAR from coastal flooding might arguably, by itself or in conjunction with reductions in other risk categories, justify the Kyoto Protocol (or other mitigation schemes).

Dealing with the last straw

There are several approaches to solving the problem of the straw that might break the camel's back; none of them needs to be mutually exclusive.[47]

Focusing on the last straw

The most common approach is to focus almost exclusively on the last straw, especially on reducing or eliminating it. This is equivalent to reducing or eliminating climate change, i.e., by reducing or eliminating GHG emissions. However, as Table 1 shows, this would accomplish little except in the case of coastal flooding, because it would leave untouched the major share of the total risk burden.

Reducing the cumulative burden

Another approach would be to lighten the total burden on the camel's back before it breaks. This is tantamount to reducing the cumulative environmental burden before global warming causes significant and irreparable damage. Consider malaria, for instance. Under the first approach, mitigation, one would, at most, eliminate the 0.26–0.32 billion increase in the PAR from malaria in the 2080s by eliminating climate change – which is impossible. By contrast, under the second approach, one would attempt to reduce the total PAR from malaria, whether it was 4.41 billion in 1990 or 9.14 billion in the 2080s. This approach has several advantages.

First, even a small reduction in the baseline (or non-climate-change-related) PAR could provide greater aggregate public-health benefits than would a large reduction in the relatively minor increase in PAR due to climate change. Assuming that annual cases and deaths due to malaria vary with the PAR, reducing the base rate for malaria by an additional 0.3% per year between 1990 and 2085 would compensate for any increases due to climate change.

Second, resources employed to reduce the base rate would provide substantial benefits to humanity decades before any significant benefits are realised from limiting climate change. Considering that 1 million Africans currently die from malaria every year, and that its death toll can be cut in half at a cost of between US$0.38 billion to US$1.25 billion,[48] humanity would be better served if such sums were spent now to reduce malaria in the near future, rather than on limiting climate change only to curb a relatively minor share of the potential increase in malaria decades from now. Moreover, the benefits of reducing malaria in Africa today with the second approach are real and far more certain, and Africans would experience these benefits decades sooner than any benefits resulting from eliminating climate change.

Third, the technologies developed and public-health measures implemented to reduce the base rate would themselves serve to limit additional cases due to climate change when, and if, they occur.

Fourth, reducing the baseline rate would serve as an insurance policy against adverse impacts of climate change, whether that change is due to anthropogenic or natural causes or if the changes occur more rapidly than currently projected. In effect, by reducing the baseline today, one would also help solve the cumulative malaria problem of tomorrow, regardless of its cause.

Fifth, because of the inertia of the climate system, it is unrealistic to think that future climate change could be completely eliminated. Moreover, the Kyoto Protocol experience indicates that because of its socioeconomic impacts, even a freeze in emissions is likewise unrealistic, despite the inability of such a freeze to actually halt further climate change.

The logic of reducing the cumulative burden applies to other climate-sensitive problems and sectors where factors unrelated to climate change are expected to dominate for the next several decades. As Table 1 indicates, these problems and sectors include agriculture, food security, water, forests, ecosystems, and biodiversity.

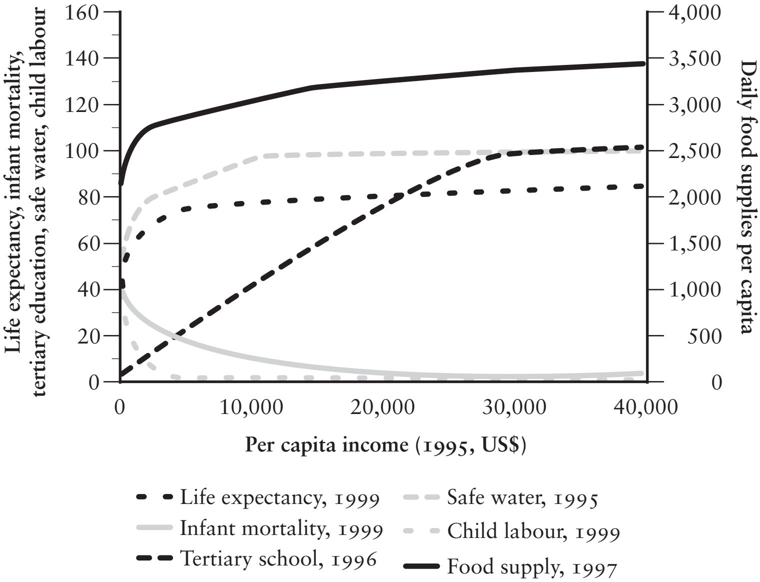
Increasing resilience and reducing vulnerability

Yet another approach to dealing with the last straw is to strengthen the camel's ability to carry a heavier load. This calls for improving resilience and reducing vulnerability.

It is generally acknowledged that poorer countries have the greatest vulnerability to climate change, not because their climates are expected to change the most, but because they lack the resources to adapt adequately to any change. But their expected difficulty of coping with climate change is only one manifestation of a deeper overarching problem, namely poverty.

If we look around at the world today, we find that almost every indicator of human or environmental well-being improves with wealth (see Figure 4).[49] This is true whether or not the indicator is climate-sensitive. Poorer countries have less food available per capita; they are

Figure 4 **Human well-being vs economic development, 1990s**



Source: Goklany, 'Affluence, Technology and Well-being', *Case Western Reserve Law Review* 53: 369–390 (2002)

hungrier and more malnourished; their air and water are more polluted; they have poorer access to education, sanitation and safe water; and they are more prone to death and disease from malaria and other infectious and parasitic diseases. Consequently, they have higher mortality rates and lower life expectancies.[50]

These populations are more vulnerable to any adversity because they are short on the fiscal and human-capital resources needed to create, acquire and use new and existing technologies to cope with that adversity. As a consequence, economic growth, by enhancing technological change, would make society more resilient and less vulnerable to adversity in general, and to climate change in particular.

Focusing on enhancing economic growth should be complemented by efforts to bolster the institutions that underpin society's ability and desire to develop, improve and utilise newer and cleaner technologies.

These institutions include providing greater protections for property rights and contracts, enforcing the rule of law, providing honest and accountable government and bureaucracies, and supporting freer and open trade.[51]

Sharing the burden

Climate change might create regional winners and losers. In particular, it could redistribute agricultural production, with developing countries producing less and developed countries producing more. That would aggravate the problem of hunger in the former.

However, imbalances in production are not a new problem. Nor is a new solution needed. Currently, poor countries consume about 10% more grain than they produce.[52] Their future dependence on food imports might increase because their demand for food is expected to grow faster than their agricultural productivity. Such imbalances have traditionally been solved, by and large, through trade. Freer trade would work just as well in the future whether the imbalance is caused by climate change or another factor. In effect, trade is akin to helping solve the problem of the last straw by sharing the burden amongst more camels. However, developing countries would need the wherewithal to purchase food surpluses produced elsewhere. This is yet another reason for increasing economic growth, particularly in the non-food sectors of poor countries.[53]

Mitigation or adaptation?

The cost of the Kyoto Protocol to Annex B countries in 2010 is estimated at between 0.1% and 2.0% of their GDP.[54] Let us assume that their costs in 2010 would be 0.5% of GDP. In 2000, that would have amounted to $125 billion in 1995 US dollars.[55] Due to these expenditures, the benefits, currently at zero or less (see below), would rise over time. By the 2080s, net benefits would include a reduction of 18% in the PAR from coastal flooding, but for the other climate-sensitive risk categories listed in Table 1, the Protocol's benefits would be trivial compared to the baseline.

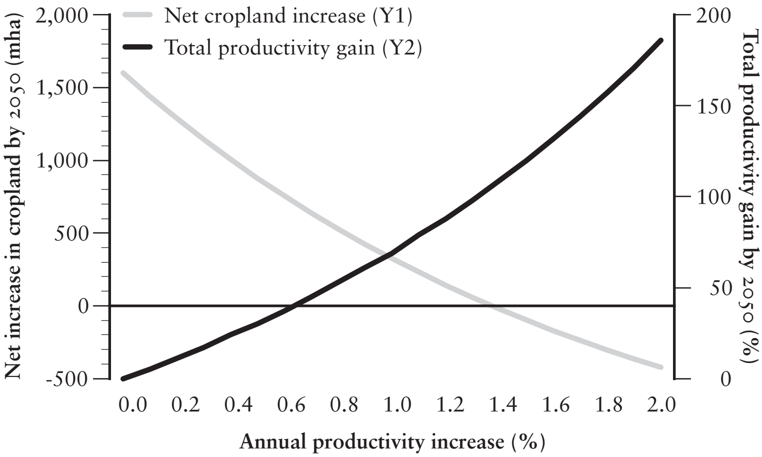
By contrast, the cost of stabilising GHG concentrations would be greater, but so would the benefits. Stabilisation at 450 ppm (parts per million), for instance, is estimated to cost a few trillion dollars between 1990 and 2100. However, despite the considerable costs, and regardless of which mitigation regime is imposed, the formidable baseline problems indicated in Table 1 would be virtually undiminished for all risk categories except coastal flooding. Moreover, one should expect that some residual impacts of global warming would persist.

Notably, some studies suggest that temperature increases of the order of 1–2°C might, in fact, result in net benefits for agricultural and timber production.[56] Consistent with these assessments, the IPCC report also suggests that a small (~1–2°C) increase might possibly be a net economic benefit to the world but an increase in excess of 2°C could be negative.[57] Therefore, the costs of any mitigation may have to be shouldered for several decades before one can be confident that they would create net benefits. This problem is magnified because of the inertia of the climate system, which magnifies the lag time between when emission reductions are initiated, and when a noticeable effect on the impacts of global warming is observed.

On the other hand, instead of mitigation-based approaches, we could employ a set of adaptation strategies based upon the principles outlined above for dealing with the last straw, and targeted to each of the risk categories in Table 1. These strategies would enhance adaptability and/or reduce vulnerability to both the impacts of warming and the other global changes included in the baseline. They would also have the added advantage that the benefits would be observed sooner after the costs were experienced. Examples follow.

- The global cost estimate for protecting against a 50 cm *sea-level rise* in 2100 is about US$1 billion per year,[58] or less than 0.005% of the overall global economic product.[59] Compared to the Protocol and any other mitigation approach, this is orders of magnitude cheaper, and would also provide greater reductions in the PAR from *coastal flooding* into the 2080s and beyond.
- A 20% increase, for example, in global agricultural research funding, which in the mid-1990s stood at US$33 billion per year (including US$12 billion in developing countries)[60] ought to, over 95 years, more than erase the entire 4% reduction in *agricultural production* due to global warming (this would be substantially more than the trivial portion that the Protocol would restore).

Figure 5 **Net habitat loss to cropland vs. increase in agricultural productivity, 1997 to 2050**



Source: FAO (2000) per Goklany (1998a, 1999a)

- No less important, to the extent the additional research funding increases sustainable agricultural productivity beyond the quantity needed to replace the shortfall, it would reduce the human demand for land. Figure 5 shows that increasing agricultural productivity would not only reduce conversion of wild land to new cropland, but it could return existing cropland back to nature. Increasing agricultural productivity is the single most effective method of preventing habitat loss and fragmentation, and conserving *global forests*, terrestrial *biodiversity* and *carbon stocks and sinks*.[61]
- Similarly, the above increases in agricultural research, if targeted appropriately, would also help to increase the amount of food that can be produced by one unit of water. Since agriculture is responsible for 85% of the fresh water consumed globally, each 1% reduction in agricultural water consumption allows consumption for other sectors to increase by 5.7%. This would not only reduce the PAR from *water stress* but also would decrease pressures on *freshwater species*.

- Annual expenditures of between US$0.38 billion and US$1.25 billion could reduce the current death toll from *malaria*, about 1 million people per year according to the World Health Organization. This too would be far more effective in reducing death and disease from malaria than either full implementation of the Kyoto Protocol or even halting climate change altogether. As previously noted, methods developed to prevent or treat baseline malaria problems (that is, the problems in the absence of global warming) can be used to address similar problems resulting from climate change.

Thus, until the 2080s, the above set of adaptation measures would cumulatively cost much less, and deliver greater benefits, than either the Kyoto Protocol or other more ambitious mitigation schemes.

Advocates of immediate GHG controls, however, might argue that regardless of the urgency of climate change during the next several decades, unless GHG emission reductions commence now those reductions may come too late to do any good. The reason, they claim, is the inertia of the climate and energy systems.

But as Table 1 indicates, even if 50 years are required to replace human energy systems from start to finish,[62] we could nevertheless wait an additional 25 years or more before initiating control actions to produce change beyond that which would be obtained automatically through continuous, long-term improvements in technologies. Meanwhile, we could implement the strategies outlined above, which would deliver benefits for people living today, while enhancing our ability to address future problems that climate change may exacerbate or cause. These strategies could be complemented by developing more cost-effective mitigation and adaptation technologies that could be implemented when they are needed.

Conclusion

Assessments of present-day and future impacts of human-induced climate change indicate that it is not now, nor is it likely to be in the foreseeable future (i.e., into the 2080s), as significant as other environmental and public health problems facing the globe. Nevertheless, global warming could be the proverbial straw that breaks the camel's back, particularly for natural ecosystems and biodiversity.

But instead of merely focusing on lightening or eliminating the last straw – analogous to reducing or halting climate change – the camel's back may also be saved in other ways. Also, reducing or eliminating the last straw does little good if the camel's back bends or breaks in the meantime.

Instead of concentrating on the last straw to reduce the cumulative burden of possible problems, we should reduce today's urgent public health and environmental threats (such as malaria, water stress, hunger and habitat loss) that might be exacerbated by climate change. As we have seen, this would provide greater, more cost-effective and quicker benefits to both humanity and the rest of nature.

We should also strengthen the camel's back so that it can withstand a heavier load, regardless of how or why the load was generated. The basic reasons as to why some societies are less resilient and more vulnerable to climate change are precisely the same reasons why they are also less resilient and more vulnerable to adversity in general, namely, they have insufficient economic development and a lower propensity towards technological change.

Not surprisingly, poorer countries with less ability to develop, afford and use new technologies have higher rates of hunger; poorer public health services; greater incidence of infectious and parasitic diseases; less access to education, safe water or sanitation; and, therefore, greater mortality rates and lower life expectancies. Accordingly, we should strengthen the institutions that drive both economic growth and technological change. Not coincidentally, many of these institutions nurture and foster each other. This approach would enhance societies' abilities to cope not only with climate change, but adversity in general, regardless of its cause, or whether it is man-made or not.

Thirdly, we should make it possible to share the burden among numerous camels. Since climate change would create regional winners and losers, the burden could be spread more evenly through trade. Thus shortfalls in agricultural production induced by climate change in some countries could be addressed through trade with others that would experience gains in agricultural production. Trade, moreover, has the added benefits of stimulating both economic growth and technological change. It particular, it allows societies everywhere to gain from innovations and inventions made elsewhere in the world, without having to reinvent wheels.

Policies based on these alternative approaches, all of which rely on improving adaptability and reducing vulnerability, are superior to the single-minded pursuit of reductions in climate change, at least into the foreseeable future. Into the 2080s, they would provide greater benefits, far sooner and far more economically than would be achieved by efforts which focus on mitigation.

Indeed, by reducing vulnerability and increasing adaptability, we might – consistent with the stated ultimate goal of the UN Framework Convention on Climate Change – raise the level at which GHG concentrations might need to be stabilised to avoid dangers to humanity and nature, which would further reduce the costs of addressing climate change.[63]

Despite the inertia inherent in both the climate and energy systems, we have at least two to three decades before we need to embark on socially and economically costly efforts to reduce GHG emissions that would go beyond 'no-regrets' actions.[64] In the interim, we should focus on: (a) solving today's urgent problems while creating the means to address future potential problems due to climate change; (b) improving our understanding of the impacts of climate change so that we can distinguish between the possible and the probable; (c) increasing information regarding the trade-offs and synergies between adaptation and mitigation; (d) reducing barriers to implementing no-regret technologies, whether they are related to mitigation or adaptation (such as eliminating needless subsidies for energy and natural resource uses); and (e) undertaking efforts to expand the portfolio of no-regret actions through greater R&D into more cost-effective mitigation and adaptation technologies.

Such a multifaceted and holistic approach would help solve today's problems to improve the lives of people living today, without compromising our ability to address future challenges, whether caused by human-induced climate change, another agent of global change, or something else entirely.

Notes

1 Clinton (1998). *See also*, Woodwell (1997), Greenwire (1998).
2 Trenberth (undated), Knowlton (2000). In fact, the Dutch government commissioned an IMAX movie by IRAS Films, *The Straw that Breaks the Camel's Back*, for screening at the World Climate Conference in The Hague, November 2000. See http://www/irasfilm.com/200101straw.htm
3 IPCC (2001a), pp. 2–3.
4 Goklany (2001a); Goklany (2002c).
5 FAOSTAT Database.
6 The 1969–71 estimate is from FAO (1996). The 1998–2000 figures are from FAO (2002): 31.
7 World Bank (2002).
8 Goklany, (2001a); Goklany, (2002c).
9 Goklany (2000a); Goklany (1999b).
10 IPCC (2001a), p. 31.
11 *Ibid*.
12 McNeely, *et al.* (1995), pp. 755–57.
13 Goklany (2002b).
14 Goklany (1998); Goklany (2000).
15 FAO (2000).
16 Walther *et al.* (2002).
17 Parmesan and Yohe (2003). *See also*, Root *et al.* (2003).
18 Parmesan and Yohe.
19 WWF Finland (2002).
20 RSPB (2000), p. 14; RSPB (2001), pp. 19–20; *Wildlife News* (2002).
21 Fox (2001a); Fox (2001b).
22 *Ibid*.
23 Fitter and Fitter (2002).
24 Walther *et al.* (2002), p. 392; Vaughan *et al.* (2001).
25 Walther *et al.* (2002).
26 Goklany (2001a).
27 Myneni *et al.* (1997); N. Nicholls (1997).
28 Ausubel (1991).
29 Goklany (2000); Goklany (1995); Goklany (1992).
30 Arnell *et al.* (2002), p.418.
31 IPCC (2001a): p. 13.
32 Hulme *et al.* (1999), p. S8, S14.
33 Wigley (1998); Malakoff (1997).
34 Goklany (2003).
35 Parry *et al.* (1999), pp. S60, S62. *See also*, Gitay *et al.* (2001), p. 259.
36 Goklany (1998).
37 Goklany (1999a).
38 Arnell *et al.* (2002), p. 439.
39 *Ibid*.; McMichael *et al.* (2001), p. 466.
40 In 1990, about a tenth of the population estimated to be at risk contracted malaria, while fatalities were about 0.2% of that. *See* WHO (1999).

41 Arnell (1999), Table 5.
42 *Ibid.*: Table 6.
43 Arnell *et al.* (2002), p. 424.
44 Solomon *et al.* (1996), pp. 492–96.
45 Hulme *et al.* (1999), p.S14.
46 IPCC (2001a), p. 73; Henderson-Sellers, *et al.* (1998a); Henderson-Sellers, (1998b).
47 This section draws heavily upon: Goklany (2001b), pp. 465–74; and Goklany (2000).
48 WHO (1999), p. 56.
49 Goklany (2002a).
50 Goklany (2000); Goklany (2001a).
51 Goklany (1995); Goklany (2000).
52 FAOSTAT Database.
53 Goklany (1995); Goklany (1999b); Goklany (2000).
54 IPCC (2001b), p.10.
55 World Bank (2002).
56 IPCC (2001b), pp. 238, 240, 259, 295.
57 *Ibid.*, pp. 957–58.
58 Pearce *et al.* (1996), p. 191.
59 Goklany (2000).
60 Byerlee and Echeverria (2002).
61 Goklany, (1998); Goklany (1999a).
62 Ha-Duong *et al.* (1997); Wigley *et al.* (1996); Wigley (1997).
63 Goklany (2000).
64 If they are not costly in a socioeconomic sense, they are, almost by definition, no-regret actions.

Bibliography

Arnell, N. W. (1999), 'Climate Change and Water Resources,' *Global Environmental Change* 9: S31–49.

Arnell N.W. *et al.* (2002). 'The Consequences of CO^2 Stabilization for the Impacts of Climate Change,' *Climatic Change* 53, pp. 413–46.

Ausubel, J. H. (1991), 'Does Climate Still Matter?', *Nature* 350, pp. 649–52.

Byerlee, D. and Echeverria, R. G. (eds) (2002). *Agricultural Research Policy in an Era of Privatization* (CABI International). Chapters 1&2 online at http://www.cabi-publishing.org/Bookshop/ReadingRoom/0851996000.asp, visited 9 July 2003.

Clinton, W. J., *State of the Union Address* (1998), online at http://www.usemb.ee/union98.php3, visited 7 July 2003.

Energy Information Administration (EIA) (1998), 'What Does the Kyoto Protocol Mean to U.S. Energy Markets and the U.S. Economy?' SR/OIAF/98-03(S), Washington: EIA.

Food and Agricultural Organization (FAO) (2001), *Global Forest Resources Assessment 2000* (Rome: FAO).
FAO (1996), *The State of Agriculture* (Rome, Italy: FAO).
FAO (2002), *State of Food Insecurity in the World 2002* (Rome: FAO).
FAOSTAT Database, online at http://apps.fao.org, visited 30 June 2003.
Fitter, A. H. and Fitter, R. S. R. (2002), 'Rapid Changes in Flowering Time in British Plants,' *Science* 296, pp. 1689–91.
Fox, R. (2001a), *Millennium Atlas of Butterflies in Britain and Ireland*, Butterfly Conservation press release, 2 March, online at www.butterfly-conservation.org/ne/news/bnm/english.html, visited 8 December 2002.
Fox, R. (2001b), *A Butterfly's Map of Climate Change*, 9 October 2001, online at www.changingclimate.org/content/articles/article/data/section_3/article_7/part_18/, visited 8 December 2002.
Intergovernmental Panel on Climate Change (IPCC) (2001a), *Climate Change 2001: The Scientific Basis* (New York, Cambridge University Press, 2001).
IPCC (2001b), *Climate Change 2001: Mitigation* (Cambridge [UK], Cambridge University Press, 2001).
Gitay, H. *et al.* (2001), 'Ecosystems and their Goods and Services,' in IPCC, *Climate Change 2001: Impacts, Adaptation, and Vulnerability* (New York, Cambridge University Press, 2001).
Goklany, I. M. (1992), 'Adaptation and Climate Change', prepared for 1992 Annual Meeting of the American Association for the Advancement of Science (Chicago IL, 6–11 February 1992).
Goklany, I. M. (1995), 'Strategies to Enhance Adaptability: Technological Change, Sustainable Growth and Free Trade', *Climatic Change* 30, pp. 427–49.
Goklany, I. M. (1998), 'Saving Habitat and Conserving Biodiversity on a Crowded Planet', *BioScience* 48, pp. 941–53.
Goklany, I. M. (1999a), 'Meeting Global Food Needs: the Environmental Trade-offs Between Increasing Land Conversion and Land Productivity', *Technology* 6, pp. 107–30.
Goklany I. M. (1999b), 'Richer Is More Resilient: Dealing with Climate Change and More Urgent Environmental Problems', in R. Bailey (ed.), *Earth Report 2000: The True State of the Planet Revisited* (New York, McGraw-Hill, 1999).
Goklany, I. M. (2000), 'Potential Consequences of Increasing Atmospheric CO_2 Concentration Compared to Other Environmental Problems', *Technology* 7S, pp. 189–213.
Goklany, I. M. (2001a), *Economic Growth and the State of Humanity* (Bozeman, MT: Political Economy Research Center).
Goklany, I. M. (2001b), 'The Problem of the Last Straw: The Case of Global Warming', in Dorf, R. (ed.), *Technology, Humans, and Society: Toward a Sustainable World* (San Diego, Academic Press, 2001).
Goklany, I. M. (2002a), 'Affluence, Technology, and Well-Being', *Case Western Reserve Law Review* 53, pp. 369–90.
Goklany, I. M. (2002b), 'Comparing 20th Century Trends in U.S. and Global Agricultural Land and Water Use', *Water International* 27, pp. 321–29.

Goklany, I. M. (2002c), 'The Globalization of Human Well-being', *Policy Analysis*, no. 447, Cato Institute.

Goklany, I. M. (2003), 'Relative Contributions of Global Warming to Various Climate Sensitive Risks, and Their Implications,' (in review; paper submitted to journal for review).

Greenwire (1998), *Worldview – Climate Change II: Scientists Fear Warming* (cited 5 February 1998), available through search engine at www.nationaljournal.com/pubs/greenwire/extra/search.htm.

Ha-Duong, M., Grubb, M. J. and Hourcade, J. C. (1997), 'Influence of Socioeconomic Inertia and Uncertainty on Optimal Co^2-Emission Abatement', *Nature* 390, pp. 270–73.

Henderson-Sellers, A. *et al.* (1998a), 'Tropical Cyclones and Global Climate Change: a Post-IPCC Assessment', *Bulletin of the American Meteorological Society* 79, pp. 19–38.

Henderson-Sellers, A. (1998b), 'Climate Whispers: Media Communication about Climate Change', *Climatic Change* 40, pp. 421–56.

Hulme, M., Mitchell, J., Ingram, W., Lowe, J., Johns, T., New, M. and Viner, D. (1999), 'Climate Change Scenarios for Global Impact Studies', *Global Environmental Change* 9, pp. S3–S19.

Knowlton, Nancy (2000), 'The Future of Coral Reefs', in *The Future of Evolution*, National Academy of Sciences Colloquium.

McMichael A. *et al.* (2001), 'Human Health', in IPCC (2001b).

McNeely, J. A. *et al.* (1995), 'Human influences in biodiversity', in V. H. Heywood, *et al.* (eds), *Global Biodiversity Assessment* (Cambridge [UK], Cambridge University Press, 1995), pp. 755–57.

Malakoff, D. (1997), 'Thirty Kyotos Needed to Control Warming', *Science* 278, p. 2048.

Myneni, R. B. *et al.* (1997), 'Increased Plant Growth in the Northern High Latitudes', *Nature* 386, pp. 698–702.

Nicholls, N. (1997), 'Increased Australian Wheat Yield Due to Recent Climate Trends', *Nature* 387, pp. 484–85.

Parmesan C. and Yohe, G. (2003), 'A Globally Coherent Fingerprint of Climate Change Impacts Across Natural Systems', *Nature* 421, pp. 37–42.

Parry, M. L., Rosenzweig, C., Iglesias, A. Fischer, G. and Livermore, M. (1999), 'Climate Change and World Food Security', *Global Environmental Change* 9, pp. S51–S67.

Pearce, D. W., *et al.* (1996), 'The Social Costs of Climate Change: Greenhouse Damage and the Benefits of Control', in IPCC, *Climate Change 1995: Economic and Social Dimensions of Climate Change* (New York, Cambridge University Press, 1995).

Root, T. L., Price, J. T., Hall, K. R., Schneider, S. H., Rosenzweig, C. and Pounds, J. A. (2003), 'Fingerprints of Global Warming on Wild Animals and Plants', *Nature* 421, pp. 57–60.

Royal Society for the Protection of Birds (RSPB) (2000), *The State of the UK's Birds 2000*.

Royal Society for the Protection of Birds (RSPB) (2001), *The State of the UK's Birds 2001*.

Wildlife News (2002), 'Climate change turns up the heat on UK's threatened birds,' 10 August 2002, visited 8 December 2002.
Solomon, A. F. *et al.* (1996), 'Wood Production under Changing Climate and Land Use', in IPCC, *Climate Change 1995: Impacts, Adaptations and Mitigation* (Cambridge, Cambridge University Press, 1996).
Trenberth, K. (undated), 'Does Climate Change Cause More Extreme Weather? Yes', in *Washington Post*, Issues from Global Climate Change, undated, online at www.washingtonpost.com/wp-adv/specialsales/nei/global/article9.htm, visited 4 December 2002 (no longer available).
Vaughan, D. G., Marshall, G. J., Connolley, W. M, King, J. C. and Mulvaney, R. (2001), 'Climate Change: Devil in the Detail', *Science* 293, pp. 1777–79.
Walther, G. R. *et al.* (2002), 'Ecological Responses to Recent Climate Change', *Nature* 416. pp. 389–95.
Wigley, T. M. L. *et al.* (1996), 'Economic and Environmental Choices in the Stabilization of Atmospheric CO^2 Concentrations', *Nature* 379, pp. 240–43.
Wigley, T. M. L. (1997), 'Implications of Recent CO_2 Emission-Limitation Proposals for Stabilization of Atmospheric Concentrations', *Nature* 390, pp. 267–70.
Wigley, T. M. L. (1998), 'The Kyoto Protocol: CO_2, CH_4 and Climate Implications', *Geophysical Research Letters* 25, pp. 2285–88.
Woodwell, G. (1997), 'Exaggeration or underestimate', *Nature* 390, p. 547.
World Bank, *World Development Indicators 2002*.
World Bank, *World Development Indicators*, CD-ROM (Washington DC, World Bank, 2002).
World Health Organization (1999), *World Health Report 1999* (Geneva: WHO).
WWF Finland (2002), *Climatic Change Has Altered Finnish Flora and Fauna*, press release, 17 May 2002, on file with author.