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Relative Contributions of Global Warming to Various Climate Sensitive Risks, and Their Implications for Adaptation and Mitigation

*Indur M. Goklany**
Office of Policy Analysis
U.S. Department of the Interior
1849 C Street NW
Washington, DC 20240, U.S.A.

E-mail: igoklany@ios.doi.gov

ABSTRACT

A rationale for mitigating global warming (GW) is that warming might exacerbate many of today's urgent problems — hunger, malaria, water shortage, coastal flooding, and habitat conversion — which could be particularly problematic for developing countries. Recent assessments of the global impacts of climate change indicate that into the 2080s, except for coastal flooding, GW's contribution to these problems [ΔP(GW)] would be small compared to P(BASELINE), the problem's magnitude in the absence of warming, i.e., under baseline conditions. Hence, mitigation can, at best, reduce only the smaller portion of the total problem [= ΔP(GW) + P(BASELINE)]. To compound matters, costs of markedly reducing ΔP(GW) through mitigation are high; moreover, because of the inertia of the climate system, its benefits are backloaded while costs have to be borne up front for decades. Discounting further magnifies this asymmetry between costs and benefits. By contrast, approaches that would help societies cope with or reduce vulnerabilities to the urgent problems noted above would, by reducing both P(BASELINE) and ΔP(GW), deliver greater benefits. Devising and/or using such approaches *now* would allow benefits to accrue in relatively short order, and help societies adapt to GW's future impacts, if and when those impacts become significant. With regard to coastal flooding, the exception to the rule that ΔP(GW) < P(BASELINE), protecting against such flooding (i.e., adaptation) is, into the 2080s, substantially cheaper than the Kyoto Protocol despite the latter's comparatively modest reduction requirements. Thus, relative to mitigation, for the next several decades the benefits of such adaptation are likely to be larger, occur sooner, more certainly, and more contemporaneously with costs. Hence, over this period adaptation is probably more cost-effective than mitigation. In particular, the Kyoto Protocol delivers too little too late, and costs too much. Importantly, by reducing hunger, malaria, water shortage, and habitat loss now, such adaptation approaches would enable sustainable development and improve human well-being in its various dimensions, especially in developing countries. In turn, that would further enhance their ability to adapt to or mitigate climate change.

∗ Views expressed in this paper are not necessarily those of the U.S. government or any of its parts.

1. INTRODUCTION

One of the most persuasive justifications offered for instituting measures to mitigate greenhouse gases (GHG) emissions is that "developing countries will suffer the most damage [from climate change], and their poor will be at an even greater disadvantage" (Wolfensohn, 1997) because they are the least able to adapt (see, e.g., UNEP, 1993; Watson and Johnson, 2001)

This argument has acquired greater credence from a recent assessment of the impacts of climate change undertaken by an international multidisciplinary team of scientists funded by the U.K. Department of Environment, Food, and Rural Affairs. This ambitious global assessment projected the impacts of climate change on a wide variety of climate-sensitive sectors and risks including food security, malaria transmission, water shortage, sea level rise, coastal flooding, and ecosystems (Parry and Livermore, 1999; Arnell et al., 2002). The results of this team's assessment have been disseminated widely through the published literature and have been incorporated into the IPCC's Third Assessment Report (Parry et al., 2001). Focusing on the assessment's results with respect to four risk factors — hunger, malaria, water shortage and coastal flooding — a "Viewpoint" in the journal, *Global Environmental Change*, asserted that the assessment's estimates of the "additional millions who would be placed at risk" in the future as a result of different amounts of global warming can help inform: (a) the selection of climate change targets and (b) the amount of reductions in greenhouse gas (GHG) emissions that might be needed to significantly reduce the future numbers at risk from climate change (Parry et al., 2001).[1]

Specifically, the Viewpoint used estimates gleaned from the impacts assessments of the additional population at risk because of the effects of climate change on each of the four risk factors going out to the 2080s. Notably, many of the Viewpoint's authors, perhaps optimistically, consider the 2080s to be at the limit of credibility for projections of population and economic growth (Arnell et al., 2002: 418). Although its conclusion that any effort to

1. The Viewpoint's coauthors were members of the team that undertook the assessment. The lead author is also the editor of *Global Environmental Change*.

address climate change must include adaptation is well founded, the information it presents is incomplete, which could lead to poorly informed decisions and lend support for ineffective and wasteful policy prescriptions.

The critical shortcoming of the Viewpoint is that although it presents estimates of the additional population at risk due to unmitigated warming, it neglects to provide a context that would allow one to gauge the significance of those estimates. But, as with every other measure, in the absence of context even the smallest molehill can be mistaken for a Ben Nevis, if not a Mount Everest. Compared to the numbers at risk in the absence of global warming (that is, under the future "baseline"), do the additional numbers due to warming constitute mountains or molehills, or if mountains, are they the Scottish Highlands or the Himalayas?

Answers to these questions, which will be addressed in Section 2 for the four listed risk factors, are important because they can help determine whether it might be more cost-effective to reduce the numbers at risk by focusing on: (a) ΔPAR(GW), the additional population at risk due to unmitigated warming alone, (b) PAR(BASELINE), the population at risk in the absence of any warming, i.e., under baseline conditions, or (c) PAR(TOTAL), the cumulative millions at risk [= PAR(BASELINE) + ΔPAR(GW)], no matter whether they are at risk because of global warming or other agents of global change. Such a determination would, in turn, help establish the appropriate emphasis that ought to be placed on adaptation[2] relative to mitigation,[3] and vice versa. Specifically, Section 2 will provide estimates of the amounts by which total populations at risk for the various risk factors would be reduced if any climate change were to be totally

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2. Adaptation refers to activities that would help individuals or societies cope with or reduce vulnerabilities to adverse impacts of climate change, as well as activities that would help them take advantage of opportunities created by climate change.

3. As used here, the term "mitigation" refers to emission reductions undertaken to address climate change and its impacts. It is assumed that "no regret" actions, i.e., cost-beneficial actions that would be undertaken for economic or environmental reasons unrelated to climate change, would be implemented in any case. Examples of no-regret actions include elimination of subsidies, replacement of inefficient processes or appliances, or replacement of coal with natural gas in order to reduce air pollution. Also note that what constitutes a no-regret action is not static. An action that does not fit that description today may, because of technological change, appropriately be classified as a no-regret action tomorrow.

eliminated from the 1990s onward or, alternatively, reduced through full implementation of the Kyoto Protocol, and how such reductions in PAR might compare with what might be possible using adaptation approaches.

In Section 3, I will step beyond Parry et al.'s focus on the four specific risk factors to briefly compare the magnitude of the threat posed by climate change over the next several decades relative to other global changes with respect to the *extent* of forests and coastal wetlands, two ecosystems of great interest in the climate change debate. This will shed additional light on the relative merits and cost-effectiveness of adaptation and mitigation.

Section 4 tries to place in context the resources needed to implement the Kyoto Protocol relative to the resources needed to address a variety of today's urgent problems that also retard sustainable development, especially in the developing world. Finally, Section 5 discusses the implications of the information presented in the previous sections, presents this paper's conclusions, and suggests an approach for addressing climate change that would help solve today's urgent problems while also strengthening the ability to address climate change in the future. Such an approach would allow efforts to address climate change to be integrated with broader efforts to advance sustainable development.

2. POPULATIONS AT RISK IN THE 2080s

Table 1 provides the basic information that allows us to place in context the populations that would be at risk of hunger, malaria, water shortage and coastal flooding in the 2080s with or without any climate change. This table — based on impact assessments reported in Arnell et al. (2002) and Arnell (1999), which are also the sources of the data used by Parry et al. — allows us to compare for the four identified risk categories, estimates of the additional numbers at risk due to unmitigated global warming,[4] [i.e., ΔPAR(GW)], against those at risk in the absence of any

4. The extent to which unmitigated warming in Arnell (1999) and Arnell et al. (2002) has, in fact, accounted for no-regret actions is not transparent. Note that the former's estimates are derived using both HadCM2 and HadCM3

additional warming, [i.e., PAR(BASELINE)]. It also shows the reductions that might be obtained in the 2080s in the total populations at risk for each of the four risk categories if the Kyoto Protocol were to be fully implemented by all countries listed in Annex B assuming (a) that the Protocol would reduce the amount of warming in the 2080s by about 7% (Wigley, 1998) which, then, would (b) reduce ΔPAR(GW) by a like amount for hunger, malaria and water shortage, and by thrice that (21%) for coastal flooding. The latter assumptions are based on the approximate functional forms of ΔPAR(GW) for the four risk factors as *perceived* by an inspection of Figure 1 in the Viewpoint. That figure suggests that for the 2080s, the dependence of ΔPAR(GW) on the increase in temperature is linear or less-than-linear for each of the risk factors except coastal flooding, for which the dependence seems to be closer to quadratic or even cubic. The 21% change in ΔPAR(GW) for coastal flooding owing to a 7% change in temperature (ΔT) assumes that the dependence is cubic, i.e., ΔPAR(GW) increases as the cube of ΔT. As will become evident, the precise functional form does not affect the validity of the arguments or conclusions noted in this paper.

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model runs while the latter only employed HadCM2 model runs. HadCM2 and HadCM3 are different versions of the general circulation model developed by the Hadley Centre.

It should be noted that given the numerous shortcomings associated with analyses of the impacts of climate change (e.g., Goklany, 2000, and references therein), it is not clear how much credence can be attached to the estimates presented in Tables 1 and 2.[5] As Swart et al. (2002: 158) have pointed out, "sometimes heroic assumptions" have gone into developing these estimates. However, for the sake of argument, I will accept these estimates as valid.

2.1 Hunger

Table 1 indicates that by the 2080s, climate change could cause a relatively large increase (23-30%) in the population at risk of hunger (over the baseline case). But, in fact, this increase is the result of a relatively small (1.8% to 2.6%) climate change related drop in global food production (Arnell et al., 2002: 435, 443). These estimates essentially assume that between 1990 and 2085, crop production would increase from 1,800 million metric tons (MMT) to 4,000 MMT (or 122%) in the absence of climate change, which is equivalent to an increase of 0.844% per year.[6] However, with climate change the cumulative increase over the 95-year period is estimated to be 116% or 0.816% per year (based on the upper estimate for the reduction in production). But the world currently spends about $33 billion on agricultural research and development annually, of which only $12 billion is spent in developing countries (based on data provided in Byerlee and Echevarria, 2002). Therefore a relatively modest increase in annual investment in R&D targeted specifically toward those agricultural problems of developing countries that might be

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5. Many of the uncertainties associated with assessments of the impacts of climate change might cut either way. However, some sources of errors would systematically bias impacts upwards. As Table 1 indicates, the global population in the 2080s is assumed to be 10.7 billion (or higher). However, according to the latest UN long range projection (which is based on its 1998 projection's "medium scenario") indicates that the population in 2080 is more likely to be about 9.4 billion (UN, 2001). The difference due to this factor alone (about 13 percent) could significantly modify ΔPAR(GW) downward for each of the risk categories listed in Table 1. For malaria at least , the uncertainty associated with population estimates exceeds ΔPAR(GW). Another source of systematic upward bias comes from difficulties in accounting for technological change and human adaptability (Goklany, 1996). Often, for ease of analysis, adaptation is based on technologies available today, rather than what might become available in the future. This results in an upward bias in the negative consequences of climatic change because it underestimates the ability of human ingenuity to mitigate adverse effects (Goklany, 1996). This, moreover, is compounded by the lack of attention paid to the potential for harnessing their positive consequences.

6. A pertinent question is whether such an increase in crop production can be achieved realistically. If one assumes the entire increase in production occurred as a result of increases in yield rather than any increase in area under crops then a 122% increase from 1990 levels is equivalent to an increase in cereal yield from 2.76 kg/ha in 1990 (based on FAO, 2002) to 6.12 kg/ha in the 2080s. Such an increase is plausible given yield ceilings and the maximum theoretical yield (Goklany, 1998: 948).

exacerbated because of climate change would help bridge the entire gap between 0.816% and 0.844% per year (and more). Assuming that all lost production would be made up without increasing the area under the plough, that translates into a 3.5% increase in the base rate of annual growth in agricultural productivity.

Consider that crops are currently grown in many areas with poor climatic or soil conditions (e.g., low soil moisture in some areas, too much water in others, or soils with high salinity, alkalinity or acidity). Because of climate change, such climatic conditions could become more prevalent, agriculture might have to expand into areas with poorer soils, or both. Thus an adaptive approach that would improve agricultural production under marginal climatic and soil conditions — for example, focusing R&D into enhancing yields under such conditions, and strengthening existing or, if necessary, developing new institutions to transfer results of agricultural R&D from research institutes to farmers — would yield a double dividend in that it would increase production (and, thereby, help alleviate hunger) under both baseline ("no climate change") conditions and conditions that might become more common due to climate change. Such an R&D and institution based approach can be pursued successfully today even if one lacks much confidence in the location specific details of climate change impacts analysis. As the methods of impacts analyses and confidence in their results advance, the focus can increasingly be shifted to the development of measures that would be more sensitive to the precise conditions prevailing (or projected to prevail) at specific locations.

Similarly, since both carbon dioxide concentrations and temperatures are expected to increase willy-nilly, it makes sense to target research on developing cultivars designed for higher CO_2 atmospheres and higher temperatures. That would not only help reduce current vulnerabilities but also create new opportunities under climate change, an aspect of adaptation that is frequently overlooked (Goklany, 2001).

No less important, because such targeted adaptive measures would enhance production under baseline conditions, their benefits would be available in the near term, i.e., long before climate change poses a significant problem for crop production, as well as in the event climate changes faster than is anticipated by current impacts studies. By the 2080s, such an approach would help reduce the ΔPAR(GW) for hunger of 69-91 million due to climate change as well as the much larger PAR(BASELINE) of 300 million due to other global changes.

A subsidiary benefit of these approaches is that by raising agricultural productivity, they would reduce the need for additional cropland, which, in turn, would limit habitat conversion under both baseline conditions and conditions of climate change. Notably, such conversion is the single largest threat to global biodiversity today and, quite possibly, in the foreseeable future (Goklany, 1998, 2000). Reductions in habitat conversion would, moreover, help limit habitat fragmentation and loss of corridors that, consistent with Article 2 of the UN Framework Convention on Climate Change, might help species adapt more "naturally" to climate change via migration and dispersion. In addition, limiting cropland would, incidentally, conserve carbon stores and sinks and, thereby, aid mitigation (Goklany, 1995, 1998, 2000).

Of course, undertaking R&D, and dispersing the resulting information and technologies are only the first steps in realizing such adaptations and their multiple associated benefits. These technologies would have to be implemented, which could entail additional costs whose magnitude is unknown and, probably, unknowable. However, agricultural experience since the Second World War provides encouragement that technological change might, in fact, hold the line on, if not reduce, future food costs. Since 1950, despite global increases of 140% in population and 170% in per capita income, both of which should have raised prices, the real price of food commodities actually declined 75% (Mitchell and Ingco, 1993; Maddison 2001; WRI 2000). One result of these price reductions was that between 1969-71 and 1998-2000 the proportion of the population of developing countries suffering from chronic hunger declined from 35% to 17% (or, in absolute numbers, from 917 million to 799 million; Goklany, 1998: 941; FAO, 2002: 31).

By contrast to the above adaptive approaches, reductions in greenhouse gases (GHGs) alone would have absolutely no effect on the larger share of the total PAR for hunger in the 2080s [namely the 300 million at risk corresponding to PAR(BASELINE)], nor would they, in all probability, reduce the ΔPAR(GW) of 69-91 million significantly, unless one is willing to incur very large costs. Stabilizing CO_2 concentrations at 450 ppmv, for instance, is estimated to cost a few trillions of dollars (Swart et al., 2002: 156) but that still would not necessarily eliminate ΔPAR(GW) [see Figure 1 in Parry et al. (2001)]. More modest emission reduction schemes would cost less, but also deliver less in benefits. For example, the Kyoto Protocol, if fully implemented, would cost between 0.1% and 2.0% of Annex B countries' GDP in 2010, which translates into $25 billion to $500 billion each year (based on GDP estimates for 2000; World Bank, 2002).[7] For all that, it would reduce the amount of global warming by a paltry 7% during this century (Wigley, 1998) which, as indicated in Table 1, would reduce the numbers at risk of hunger in the 2080s by less than 2% of the total PAR (or less than 7 million out of 369-391 million).

The benefits of emission reductions in terms of reducing PAR for hunger would be even smaller in the years preceding the 2080s. This can be seen by comparing estimates of PAR(BASELINE) and ΔPAR(GW) for the 2080s in Table 1 with corresponding estimates for the 2050s in Table 2. Table 2 — constructed similarly to Table 1, except that it does not provide estimates of reductions in PAR owing to full implementation of the Kyoto Protocol — indicates that *complete elimination* of climate change would in the 2050s reduce PAR(TOTAL) by between −1% and + 4%. Therefore, for the next several decades, the effect of the Protocol on hunger would be marginal, and any costs sunk into mitigation, whether it is the marginally effective Kyoto Protocol or a more ambitious effort, would not result in significant benefits, if any.

Bringing all these factors together, there seems to be no compelling justification for undertaking mitigation in the near future in order to reduce ΔPAR(GW) for hunger in the 2080s, because at least into the 2080s:

- ΔPAR(GW) is smaller than PAR (BASELINE), and GHG emission reductions would

7. The costs depend, among other things, on the extent of emissions trading between Annex B countries (IPCC,

only address the smaller of these two components of PAR(TOTAL).

- The cost of markedly reducing ΔPAR(GW) via emission reductions that go beyond no-regret actions is high. But adaptation approaches could help reduce both PAR(BASELINE) and ΔPAR(GW), and possibly at a lower cost.
- Emission reductions would have to be initiated decades in advance before their effects on climate change becomes significant. Therefore, the benefits of emission controls would be backloaded, while its costs would be borne all along the way. On the other hand, the costs of adaptation would be incurred much more contemporaneously with its associated benefits. This asymmetry would be magnified if both benefits and costs are discounted.

2.2. Malaria Transmission

For the same reasons as outlined above for hunger, the relatively small ΔPAR(GW) for malaria transmission — estimated at 2.9-3.7% in the 2080s (see Table 1) — also offers, by itself, a poor rationale for implementing emission targets for GHGs in the near term. If one assumes that a change in PAR for malaria transmission translates into proportional reductions in the prevalence or mortality rates for malaria,[8] the best that can be achieved by completely halting climate

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2001: 10).

8. The PARs for malaria transmission provided in Tables 1 and 2 are substantially larger than the numbers of people who will actually contract or die from that disease in any given year. By comparison with the PAR of 4,410 million in 1990 (Arnell et al., 2002: 439), the number of people who actually contracted malaria each year in the 1990s was an order of magnitude lower (300 million), while the number who died (about 1 million) was smaller by more than three orders of magnitude (WHO, 1999). One reason for these differences is that the actual prevalence of malaria does not coincide either with its historical or potential range based on the presence of the malaria transmitting vectors and/or the malaria parasite. The current range of malaria is dictated less by climate than by human adaptability, and despite any global warming that might have taken place over the past century (or more), malaria has been virtually eradicated in richer countries although it was once prevalent there (e.g., the U.S. and Italy) [see Goklany (2000, 2001), and references therein]. This is because, in general, a wealthier society has better nutrition, better general health, and greater access to public health measures and technologies targeted at controlling diseases in general and malaria in particular (Goklany, 1999, 2000, 2002a). In fact, analysis by Tol and Dowlatabadi (2001) suggests that malaria is functionally eliminated in a society whose annual per capita income reaches $3,100. Taking into consideration that incomes are expected to grow few, if any, countries will be below the $3,100 threshold in the 2080s. Moreover, given the rapid expansion in our knowledge of diseases and development of the institutions devoted to health and medical research, one can be relatively confident that the $3,100 threshold will almost certainly drop in the next several decades as public health measures and technologies continue to improve and become more cost-effective. Therefore, unless we squander our human and financial resources pursuing secondary or tertiary priorities the importance of climate in determining the ranges of malaria (and other climate sensitive infectious and parasitic diseases) ought to diminish further. However, there is no guarantee against society

change — an expensive undertaking as noted above — would be to reduce the malaria prevalence and mortality rates by 3.7% by the 2080s (and somewhat less by the 2050s; see Table 2). However, adaptive measures such as the development of public health services and institutions for — or research targeted at — treatment and prevention of malaria would help not only the additional 3.7% (or 256-323 million) at risk of malaria transmission in the 2080s because of climate change but also the 8,820 million at risk under baseline conditions (see Table 1). Notably, many such measures do not need to rely on the details of impacts analyses to be implemented successfully, nor do they need to be particularly expensive relative to mitigation. According to the World Health Organization (1999), malaria's current death toll of about 1 million per year could be *halved* with annual expenditures of between \$0.38 billion and \$1.25 billion, that is, at a fraction of the cost of the minimally effective Kyoto Protocol or, for that matter, any strategy that would require greater cuts in emissions than does the Protocol.

2.3 Water Shortage

Table 1 provides three sets of figures for the additional population at risk of water shortage due to climate change, two of which are at variance with the data furnished in Parry et al.'s Viewpoint. The first set, indicated as Approach A in the first column, is based on the populations living in countries where more than 20 percent of the water resources are used. Using this approach, ΔPAR(GW) for water shortage in the 2080s increases by between 42 million to 105 million people compared to 6,464 million for PAR(BASELINE) (Arnell, 1999: S44). On the other hand, Approach B estimates ΔPAR(GW) for water shortages by calculating the net difference between the number of people for whom unmitigated warming increases water stress and for those whom it reduces stress. Using that method, ΔPAR(GW) for the 2080s, based on six HadCM2 and HadCM3 model runs, ranges from a net *increase* in water stress for 1,063 million people to a net *decrease* in stress for 2,387 million people (Arnell 1999: S44).

By contrast, Parry et al. (2002) show an increase in water stress of around 3,000 million to 3,500

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shortchanging first order priorities to address lower order problems. In fact, there is probably no better illustration of such a failure than the case of malaria where, in order to reduce the environmental impacts of DDT even its responsible use was eschewed in many parts of the world, allowing malaria to rebound (Goklany, 2001: 13-27, and million people for the 2080s (see Approach C in Table 1). These numbers are derived from Arnell et al. (2002) which, in turn, generally uses methods similar to that in Arnell (1999), itself the source for Approach B. So what accounts for the differences in ΔPAR(GW) between Approaches B and C? Firstly, Arnell et al. (2002) does not include any results from the HadCM3 model run. Also, it is not entirely clear whether Arnell et al. (2002) subtracted the millions of people for whom climate change is projected to reduce water shortage. A close reading of the text suggests that it might not have done so, although such "netting" would be appropriate since one is interested in estimating the *net* global impact.

Nevertheless, regardless of which approach one uses to define ΔPAR(GW) for water shortage, Table 1 indicates that while climate change might potentially put millions at risk in the future, many millions more are at risk under the baseline case, i.e. due to global changes other than climate change. As a result, even if additional climate change is halted completely and immediately, millions would continue to be at risk of water shortage. Moreover, by comparison with PAR(TOTAL), i.e., the broader perspective, the effect of the Kyoto Protocol would be relatively small, if not minor.

Therefore, the rationale for establishing mitigation targets in order to reduce ΔPAR(GW) for the water shortage category also faces hurdles similar to those noted above for hunger and malaria transmission, but with the added difficulty that reducing climate change would reduce not only the additional number at greater risk of water shortage but also the number for whom water shortage problems might be alleviated by climate change. Thus full implementation of the Kyoto Protocol would reduce the total PAR in the 2080s by between −4% and +1% based on Approach B. In other words, there is no certainty that GHG emission reductions will necessarily be a net benefit so far as this risk category is concerned. In other words, reducing climate change is a blunt instrument for those risk factors for which climate change results in a mix of positive and negative outcomes. Moreover, even under Approach C the benefit, in terms of reducing PAR(TOTAL), is relatively small — no more than 2.5% under the Kyoto Protocol — compared

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references therein).

to the total numbers at risk from both climate change and non-climate change related causes.

Notably, many of the strategies and technologies that would help reduce PAR(BASELINE) for water shortages in the absence of climate change can also be employed to reduce ΔPAR(GW). Such strategies include water pricing and transferable water rights which would, then, stimulate efforts to use water more efficiently. Such efforts would extend from R&D into improved or new technologies to reuse, recycle and conserve water to actual implementation of those technologies (Goklany, 1998, 2002a).

In this regard, the agricultural sector deserves special attention. On average, improving the water use efficiency of agriculture by 1%, for instance, would translate into a 5.7% increase in water availability for other sectors (since agriculture consumes 85% of the water consumption worldwide; Shiklamanov, 2000). Consequently, R&D into crops that would have low moisture requirements — suggested previously as a method to help reduce the vulnerability to hunger while incidentally conserving habitat, carbon stores and sinks, and biodiversity — would also help free up substantial water for other sectors of the economy. That, in turn, would also reduce pressures to divert water away from in-stream uses, e.g., conservation of aquatic species and recreational uses.

Approaches designed to reduce water usage would probably have to be supplemented by efforts to increase the amount of water available for human consumption through, for example, cleaner and less fossil fuel intensive methods of desalination (Goklany, 1998, 2000).

Regardless of whether one uses demand side or supply side adaptation approaches, their benefits would accrue over the decades whether or not climate would change.

2.4 Coastal Flooding

According to Table 1, the population at risk of coastal flooding is estimated to increase in the 2080s from 13 million in the absence of climate change to 94 million because of a rise in the sea level of 0.40 m due to unmitigated climate change (Arnell et al., 2002: 443; Nicholls, 1999). These estimates are based on the assumption that despite increases in threats to life and property due to rising sea levels: (a) coastal areas everywhere will, in keeping with current trends, continue to grow at twice the country's population growth rate and (b) the ratio of resources employed for coastal protection to the GDP per capita will remain unchanged from today's level even as populations become richer and would be better able, and more inclined, to increase funding for protection (Arnell et al., 2002; 429-431). But sea level rise is expected to be a relatively gradual process that, moreover, should telegraph to individuals and societies that future impacts on life and property could indeed worsen. Therefore, one should expect that they would, either of their own volition or because of the pressure of higher insurance rates, take anticipatory measures such as reducing migration and development rates, and/or increasing the resources devoted to coastal protection. If losses due to coastal flooding indeed escalate rapidly in the first half of this century, as they would if they increase as the square or cube of temperature change — as assumed in Table 1 — it is not too much to expect that even misguided government policies that currently provide direct or indirect incentives and subsidies for people to build in and inhabit coastal flood plains might be modified (Goldstein et al., 1994). Nevertheless, although it could be a substantial overestimate, I will, as noted previously, assume in Table 1 that ΔPAR(GW) for coastal flooding in the 2080s would be 81 million people.

Setting aside for the moment that ΔPAR(GW) might have been overestimated, one would think that if there is one risk category for which the Protocol (or a similar emission reduction scheme) can be shown to be more cost-effective than adaptation, it would be coastal flooding because ΔPAR(GW) clearly exceeds PAR(BASELINE) for both the 2050s and 2080s (see Tables 1 and 2). According to Table 1, the Protocol might reduce PAR(TOTAL) for coastal flooding by as much as 21% (or 17 million people) in the 2080s, at a cost of tens of billions of dollars (if not more). By contrast, the global cost estimate for protecting against a 0.5 meter rise in 2100 has been estimated to be about $1 billion per year, or less than 0.005 percent of global economic product (Pearce et al., 1996: 191). Conceivably, with the passage of time, if societies get richer and have increased access to improved technologies (as they should) these costs might decline and/or become relatively less formidable in the future. Another study done for the United States estimates that the net present value of costs (including cost of protecting property and other adaptations) associated with a 0.5 m sea level rise by 2100 would be about $2.2 billion, and $6.4-7.6 billion for a 1 m rise (which works out to less than $0.4 billion in 2050 and $1.2 billion in 2100; Neumann and Livesay, 2001). Thus a Kyoto Protocol type of emission reduction scheme would not only cost more but also provide less protection in the 2080s than an approach relying on adaptation to protect against flooding. A more aggressive emission reduction scheme would undoubtedly reduce ΔPAR(GW) by a larger amount, but it would be even costlier. Therefore, for this risk category as well, appropriately designed adaptation measures would seem to be more cost effective in reducing PAR than any emission reduction scheme, at least through the 2080s.

2.5 Reducing Populations at Risk in the 2080s — Mitigation or Adaptation?

Thus if one looks at the four risk factors considered by Parry et al.'s Viewpoint either individually or cumulatively, it is unlikely that by the 2080s, mitigation will provide greater or more cost-effective reductions in PAR(TOTAL) than can be obtained through various adaptation efforts, particularly if such adaptation is targeted toward current urgent problems (such as hunger, malaria and water shortage) that might be exacerbated by climate change. This seems to be true whether the extent of mitigation is "shallow" per the Kyoto Protocol, or "deep" per targets and schedules designed to stabilize atmospheric concentrations of CO_2 to, say, 450 ppm.

However, it does not follow from the above conclusion that mitigation should necessarily be deferred in favor of adaptation until after the 2080s. If investments in adaptation reap returns at a lower rate than the rate at which the net negative impacts of climate change continue to rise, then eventually mitigation would become at least as cost-effective as adaptation. The farther we go into the future and the greater the amount of climate change, the more attractive mitigation is likely to become relative to adaptation. This is because as climate change increases, ΔPAR(GW) becomes larger relative to PAR(BASELINE), and the less likely it is that adaptation would be able to reduce ΔPAR(GW) significantly. If we denote the time when mitigation is likely to become at least as cost effective as adaptation as T_C, then based on the four risk factors examined here, T_C is likely to occur after the 2080s. However, because of the inertia of the climate and energy systems, mitigation measures may have to be instituted well in advance of that time. On the other hand, precisely because of this inertia, the costs of mitigation would have to be borne for several years before they provide significant benefits which, in conjunction with discounting, would argue for shortening the lag time. If one assumes a fifty-year lag between the initiation of mitigation and the transmission of its effect on climate change, it would be unnecessary to require that emission targets be met any earlier than the 2030s or, perhaps, even later, i.e., adaptation would be a superior strategy until at least 2030.

In the meantime, one should:

- Pursue adaptation measures that would simultaneously reduce PAR(BASELINE) and lay the groundwork for reducing ΔPAR(GW) in the future. This would, moreover, help postpone T_C and, possibly, raise the level at which GHG concentrations would need to be eventually stabilized to avoid "dangerous" consequences of climate change.
- Pursue R&D that would raise the cost-effectiveness of emission control technologies.
- Continually implement "no-regret" emission reductions as such reductions move into the category of "no-regret" actions because of the continual march of technology.
- Improve methods for monitoring, analyzing and forecasting climate change and its impacts to evaluate trade-offs between adaptation and mitigation, and to provide more robust estimates of when various actions must be implemented.

3. RISK OF HABITAT CONVERSION AND LOSS OF BIODIVERSITY

One might take exception to the above conclusion on the grounds that the four risk factors which have been the focus of this and Parry et al.'s Viewpoint do not encompass the myriad other benefits that would be obtained from emission reductions. Although these additional benefits should not, by definition, include any associated with no-regret actions (that is, any emission reductions that can be justified on their own, absent any climate change; see footnote 3), they should indeed include any benefits associated with actions that would go beyond no-regrets. That should include, for example, benefits associated with limiting pressures on biodiversity and ecosystems due to climate change. On the other hand, we saw that a number of adaptation measures would also help relieve such pressures by helping increase the productivity of land and water which, then, would simultaneously reduce hunger, free up more land and water for the rest of nature, and limit GHG emissions. Thus, the benefits calculus is incomplete, not to mention complex, for both mitigation and adaptation. This section attempts to shed more light on the relative merits of mitigation and adaptation into the 2080s with regard to the impacts of climate change on habitat conversion and conservation of biodiversity by focusing specifically on the extent of global forest cover and coastal wetlands.

3.1 Global Forest Cover

Table 3 indicates that by the 2050s, greater agricultural and other human demands may reduce global forest cover by 25 percent (or more) in the absence of any global warming (IPCC, 1996: 95-129, 492-496). Needless to say, this would add to the already considerable pressures on the world's biodiversity (Goklany, 1998, and references therein).

Unfortunately, most modeling of the impacts of global warming on the extent of forest area are based on simulations of *potential* vegetation, and ignore the effects of human activities that might affect land use and land cover, which collectively are the largest threats to the conservation of habitat and biodiversity (Goklany, 1998, and references therein). Such modeling also does not fully account for vegetation-climate feedbacks (White et al., 1999: S28). Moreover, they are driven by the uncertain outputs of various, and sometimes arbitrarily chosen, GCMs.

Such modeling exercises show that with global warming, the existing margins of current forest types would, almost certainly, shift poleward. One such exercise, undertaken for the IPCC's special report on the regional impacts of warming, indicates that due to equivalent doubling of carbon dioxide concentrations in the atmosphere (and including the beneficial effects of CO_2 on photosynthesis and water use efficiency), the potential area of temperate forests could increase by 37 to 58 percent, and the area of tropical broadleaf forests by 20 to 38 percent (Neilson et al., 1998). However, the area of boreal conifer forests might either decline 36 percent or increase by 16 percent. Overall, total forested area might increase between 6 and 42 percent, depending on how one defines forests.[9] On the other hand, the extent of arid lands might shrink by 22 to 41 percent (Neilson et al., 1998). This exercise also suggests that biomass in the various biome types should also generally increase (Neilson et al., 1998: Tables C-2 and C-3).[10]

Another modeling exercise, undertaken by the team on whose work Tables 1 and 2 are based, used the outputs of two different versions of the GCM developed by Britain's Hadley Center (denoted HadCM2 and HadCM3). That exercise suggests that both temperate and tropical forests might give way to savannah and grassland (and, possibly, even deserts) and C4-grasslands might either be lost to desert or to C3-grasslands if rainfall increased, while boreal forests might expand (White et al., 1999). These models did not allow for any cooling due to sulfates. Overall, according to the HadCM2 simulations, global vegetation carbon would increase by a third between 1990 and 2080, but about half of that increase would be offset because of the loss in soil carbon. Because the one HadCM3 simulation used by this group projects a more extreme climate (namely, a global temperature increase at the rate of 0.3^{o}C per decade), its results indicate that total carbon vegetation would peak around 2050, after which carbon accumulation would be lowered both above and below ground.

Arnell et al. (2002: 424), which draws upon the work of White et al. (1999) but presents results only for the HadCM2 model runs, indicates that total global forest area could increase by about 5 percent between 1990 and the 2080s.[11] This includes a projected decline of 2.4 percent in the extent of tropical broadleaf evergreen forest, and increases of 10.8 and 17.7 percent in broadleaf cold deciduous and coniferous forests, respectively.

By contrast, in the latter half of this century, the change in the extent of arid areas and deserts is projected to range from a decrease of 41 percent to an increase of 26 percent, depending on the methods, assumptions and time frame used in the analyses (see Table 3).

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9. These are calculated from Table C-1 in Neilson et al. (1998).

10. Tables C-2 and C-3 in Neilson et al. (1998) show that for each type of biome, the area projected to increase leaf area by and large exceeds the area that will have lower leaf area.

11. These numbers are calculated from data provided in Table II in Arnell et al. (2002) for the unmitigated (IS92a) scenario, and are approximate because there might be errors introduced from rounding the numbers to the first decimal place in that table.

According to the IPCC, climate change could also increase global timber harvests by 1 to 2 percent per year which would lower prices and result in net improvement in welfare (with consumers probably gaining at the expense of timber owners) (Gitay et al., 2001: 240, 295; Perez-Garcia, et al., 2002). It might also reinforce current trends that indicate increases in developing countries' market share.

Thus, it seems that, just as for the four risk categories addressed in Section 2, with respect to global forests, present day threats and threats from non-climate related global changes would outweigh those from climate change, at least to the 2080s. Notably, unless baseline problems are addressed relatively quickly, a substantial portion of the habitat and global forest area might be converted to other uses and the benefits of mitigation efforts may arrive too late to stem the loss of habitat (and biodiversity). This also suggests that in the interim, rather than focus on reducing GHG emissions, forests and forest area might be more effectively conserved by increasing the productivity of land and water use by human activities — forestry, agriculture, as well as human habitation (Goklany, 1995, 1998, 2000) — that would otherwise divert land (and water) away from the rest of nature. This fosters *in situ* conservation, an explicit goal of the Convention on Biological Diversity. Moreover, by reducing pressures on land and water, that would also contain the socioeconomic price of conserving these resources in parks and other reserved areas, which would further reinforce *in situ* conservation (Goklany, 1998).

The analyses of changes in potential vegetation raise a host of philosophical and biological concerns and issues, the resolution of which go beyond the scope of this paper. First, change does not by itself equate to an adverse impact, although there seems to be a tendency to conflate the two when it comes to the rest of nature. Therefore, although one would expect the changes to affect the distribution and abundance of individual species, would that necessarily diminish global biological diversity in terms of the number of species or their abundance?

Second, it's not clear whether, or how fast, the landscape will actually change and, if it will, whether that would be for the worse. The bulk of existing forests might persist at their current locations for quite some time because they seem to have low sensitivity to climate (Gitay et al., 2001: 251, 296). The IPCC assessment, for instance, notes that a black spruce old growth forest persisted for more than 1,500 years despite substantial climatic swings (Gitay et al., 2001: 251). However, it has been frequently noted that if the climate changes too rapidly, there might be massive diebacks at the margins of the forests where some species might already be at the limits of their physiological tolerance. But does dieback of existing forms of vegetation at a location mean that ultimately biodiversity will necessarily be reduced, except perhaps temporarily? Such dieback, after all, would be part of the transition to a new vegetation scheme. In fact, it's unclear whether diversity would be reduced either during the transition — when, presumably, components of the old and new schemes would co-exist — or after the transition has been completed. Would the new scheme be less diverse than the old one? A further complication is that, often, wetter and warmer climatic conditions seem to harbor greater biodiversity, so long as sufficient water is available (Hawksworth, 1995; Huston, 1994: 30-35).

Third, can or will physiologically stressed species migrate fast enough and adapt to rapid climate change? Paleoevidence suggests that some plant communities have migrated over large distances during postglacial warmings while some plant species have migrated across large bodies of water (Pitelka et al., 1997; Gitay et al., 2001: 251). As an extreme example, consider the reestablishment of flora and fauna on the Krakatau Islands following the cataclysmic explosion in 1883 (Krakatau Research Programme, 2002; Tidemann et al., 1990).[12] However, the dynamics of plant migration are not well understood, and it stands to reason that migration would be inhibited if the habitat is extensively fragmented or natural migratory corridors are absent (Pitelka et al., 1997; Krakatau Research Programme, 2002). Of course, such problems could be minimized if man gives the rest of nature a helping hand by:

- Reducing the root causes of habitat fragmentation and loss of migratory corridors. The general adaptive strategies outlined previously — increasing productivity of land and water use by human activities — would be critical to the success of such an effort (Goklany, 1995, 1998, 2000).
- Transplanting in more hospitable areas, species that otherwise might be endangered. Some might argue against man giving the rest of nature a helping hand on the basis that would be "unnatural." However, man already does so. That is, in fact, what reforestation, soil stabilization and restoration ecology attempt to do. Moreover, if the landscape changes because of human-induced climatic change, then any new composition and distribution of species on that landscape should itself be considered to be "unnatural." So

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12. Arguably, the initial shock to the system due to the Krakatau explosion dwarfs anything anticipated from global warming.

how could it get any more unnatural if man helped the transition to a new aggregation of species?

3.2 Coastal Wetlands

To the extent that there is a net social, environmental and economic benefit associated with increasing the extent of coastal wetlands,[13] a rise in sea level is a source of concern since that could lead to a gradual loss of coastal wetlands, which already are under considerable threats due to a variety of human activities. These current, non-climate change related threats include real estate development, development of tourism, extraction of oil, gas and groundwater which might lead to subsidence of the land, and damming of rivers upstream which reduces the amount of sediment available for rebuilding eroded land. By 2080, more than 40 percent of the coastal wetlands that existed in 1990 could be lost in the absence of climate change (Arnell et al., 2002: 441; Nicholls, 1999; see Table 3). However, with climate change, 12 percent of the wetlands might be lost (Arnell et al., 2002: 441; Nicholls, 1999). So once again we see that the impacts of climate change are small compared to that of other human activities. Therefore, it is an open question whether mitigating climate change would be more cost-effective in containing losses of coastal wetlands than would addressing the other global changes contributing to those losses.

4. PUTTING COSTS OF THE KYOTO PROTOCOL INTO CONTEXT

We saw in the previous sections that going as far into the future as the 2080s, compared to the benefits of attacking baseline problems, the benefits of *halting* any further climate change would be small with respect to the risk categories addressed in this paper, while those from the Kyoto Protocol would verge on the trivial.[14] But benefits are only one crucial factor that goes into a

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13. Some studies suggest that the global value of wetlands to humanity is very high, possibly running into trillions of dollars annually mainly because of the environmental amenities and services they provide (see, e.g., Costanza et al. 1997). However, these studies seem to have neglected to account for the costs to humanity associated with such wetlands, e.g., they serve as breeding grounds of mosquitoes, prime vectors for diseases. In particular, coastal wetlands serve as habitat for a number of species of malarious mosquitoes (IAMAT, 2003). Thus, depending on the location of a particular acre of coastal wetland and the resources available to the local population for dealing with diseases that may be associated with that wetland (see footnote 8), a greater extent of coastal wetland would not necessarily be a net benefit for that population.

14. It has also been argued that mitigation could provide substantial co-benefits from improvements in air quality

policy evaluation of response strategies. It is also critical to consider costs, view them in their broader context, and understand what opportunities may have to be foregone by society in its pursuit of those strategies. This section attempts to do that with respect to the Kyoto Protocol, recognizing that other popular options surfaced for mitigation — stabilization of CO2 concentrations at 450 to 750 ppm (see, e.g., Parry et al., 2001) — will be substantially costlier and, therefore, associated with greater opportunity costs.

Some advocates of the Protocol, undeterred by either its cost or relative ineffectiveness, have suggested that it is just the first step to deeper emission reductions (Pronk, 2000). However, some of the countries that are the strongest supporters of aggressive greenhouse gas controls seem themselves to be stumbling in meeting their Kyoto targets (Environmental News Service, 2002)[15] although these targets are relatively modest (compared to what would be needed for stabilization), and notwithstanding substantial subsidies for renewable resources. This suggests that the costs — economic and social — are not as trivial as some of its advocates have claimed or hoped. In fact, the cost of Kyoto is estimated to be in the hundreds of billions of dollars over the years.

According to the IPCC, if fully implemented, the cost of Kyoto to Annex B countries in 2010 would be of the order of 0.1 to 1.1 percent of their GDP with emissions trading, and between 0.2 to 2.0 percent of GDP without emissions trading.[16] Let us assume that the costs in 2010 would be 0.5 percent of GDP. In 2000, that would have amounted to $125 billion in 1995 U.S. dollars for Annex B countries (World Bank, 2002a). To put these costs into context, consider that:

- 8 million lives per year could be saved by increasing health expenditures in the low and middle income countries by $57 billion to $94 billion between 2007 and 2015, according to the World Health Organization's Commission on Macroeconomics and Health (2001:

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for pollutants such as sulfur dioxide, fine particulate matter, and tropospheric ozone. Indeed, that is accurate, but the same magnitude of co-benefits might be obtained more cheaply through a direct assault on those air pollutants. See, e.g., EIA (2002).

15. This report notes that according to the European Environment Agency, with present policies the 15 countries of the European Union will emit 4.7 percent less greenhouse gases in 2010 than 1990 compared with its target reduction of eight percent.

16. Other cost estimates suggest that the cost of Kyoto could be much higher. An analysis done by the Department of Energy in 1998 estimates that the United States' annual GDP would be lowered $56 billion to $437 billion in 2010 (in 1992 dollars; EIA 1998).

11). This works out to $71 billion in 2010.[17]

- For an additional $19 billion to $34 billion, the number of people without access to safe water (1.1 billion) and sanitation (2.4 billion) can be halved (Medilinks, 2002).
- Annual expenditures of between $0.38 billion and $1.25 billion could halve malaria's death toll of about 1 million per year, according to the World Health Organization (1999). This would be far more effective in reducing death and disease from malaria than either full implementation of the Kyoto Protocol or, for that matter, halting climate change altogether (see Tables 1 and 2).
- An additional $4 billion dollars per year would increase global agricultural R&D budgets by 10 percent, which, similarly, would help increase food production and reduce hunger by a larger amount than what is possible by halting climate change altogether, let alone implementing the much less effective Kyoto Protocol (see Tables 1 and 2).

Moreover, the benefits from each of these four options to greenhouse gas mitigation will start to flow decades before those from any emission reduction scheme.

Some of the support for the Kyoto Protocol is based on the notion that there would be relatively large transfer payments from developed to developing countries under the guise of the Clean Development Mechanism (CDM). However, even assuming such transfer payments actually materialize — there is no guarantee they will, since the populations of the former are not necessarily predisposed to such payments — developing countries' economies would not be fully shielded from the adverse impacts of the costs of the Protocol on the developed countries. This is because a significant portion of developing countries' economic output depends on their trade with developed countries. In 1998-2000, exports accounted for 26.3 and 29.2 percent of the GDPs of the low and middle income countries, respectively (World Bank, 2002a). The corresponding figures in 1990-92 were 18.0 and 22.2 percent, i.e., in the intervening eight years the share of GDP due to exports rose 46 and 32 percent, respectively. The rise was also very rapid for the least-developed countries, which increased 43 percent (from 13.2 to 18.9 percent of GDP). An analysis done during the earlier period indicated that a 1 percent drop in the GDP of developed countries translated into a $60 billion loss in the exports of developing countries (World Bank, 1992; Goklany, 1995). It would undoubtedly be a larger figure today if adjustments were made for increased trade (and inflation). Thus, some developing countries —

17. This is based on interpolating the costs between 2007 and 2015.

especially those that might not receive sufficient transfer funds from a CDM — might be worse off economically because of the Protocol. But that would reduce their human and environmental well-being because lower levels of economic development (as measured by GDP per capita) translates into less access to safe water, sanitation and food supplies which, in turn, would increase mortality rates and reduce life expectancies (Goklany, 2000, 2002b). Moreover, these indicators of human well-being are most sensitive to economic development at low levels of economic development. Thus, reductions in economic growth will have a disproportionately large negative impact on the poorest countries.

Moreover, even if the Kyoto Protocol transfers wealth from developed to developing countries, it is not the most efficient method of enhancing the well-being of people living in the latter. As already noted, hunger and mortality can be reduced and access to safe water and sanitation substantially expanded at much less cost. In fact, a World Bank study estimates that the additional foreign aid required to meet the U.N.'s Millennium Development Goals by 2015 is between $40 and $60 billion (World Bank, 2002b). That would seem to be a much better bargain for the world than the Kyoto Protocol even if, for whatever reason, some of that is wasted or lost through corruption, as sometimes seem to have occurred historically in many developing areas. But there is no guarantee that transfer payments under the U.N. Framework Convention on Climate Change will be used any more wisely or effectively.

5. DISCUSSION AND CONCLUSION

The major public health and environmental problems that might be caused by global warming are, for the most part, similar to problems that already exist today. These include hunger, malaria, water shortage, coastal flooding, and habitat conversion. At least to the 2080s, with the exception of coastal flooding, the contribution of global warming to these problems [ΔP(GW)] is projected to be small relative to the baseline contribution from other non-climate change related factors [P(BASELINE)]. The portion of the total problem [P(TOTAL) = ΔP(GW) + P(BASELINE] that can be reduced through mitigation alone is even smaller. Therefore, even a shallow reduction in the total problem could well result in greater benefit than a deeper reduction in ΔP(GW), the smaller share of the problem. Moreover, for some categories of risk (e.g., hunger and malaria), adaptation can indeed effect deep cuts in both ΔP(GW) and P(BASELINE). With respect to coastal flooding, the exception to the rule that ΔP(GW) would be smaller than P(BASELINE), the cost of protecting against such flooding through the 2080s is relatively minor compared to the cost of even the minimally effective Kyoto Protocol. Thus adaptation measures instituted today to cope with or to reduce vulnerabilities to these problems could, by reducing the total problem, provide greater overall benefits than would mitigation for the next several decades. In addition, given the uncertainties associated with impacts assessments, i.e., the magnitudes and signs attached to ΔP(GW), the benefits of reducing ΔP(GW) are less likely to be realized than reductions of the same magnitude associated with P(BASELINE), at least in the near term.[18]

Benefits of course must be balanced against costs. The costs of mitigation are projected to be high, ranging from the tens — if not hundreds — of billions of dollars for the Kyoto Protocol, to the trillions of dollars for CO_2 stabilization at 450 ppm. To compound matters, due to the inertia of the climate system, these mitigation costs would have to be absorbed year after year for decades before they provide any significant benefits. On the other hand, many adaptation measures would provide substantial benefits in a matter of years rather than decades. Notably, with respect to the conservation of habitat and biodiversity, the benefits of mitigation might be realized only after much of the damage has already been inflicted — tantamount to closing the barnyard door after the horse has fled, except that in this case it would be closed with a timer. Thus, while comprehensive estimates of the costs of adaptation are unavailable, its benefit-cost ratio is likely to reach the break-even point earlier than mitigation, with the possibility that the deeper the emission reductions, the later the break-even point for mitigation. At least till the 2080s, adaptation seems to be more cost-effective than mitigation in general, and the Kyoto Protocol in particular. In fact, compared to adaptation, the Kyoto Protocol is an exercise in

18. See footnote 8, which indicates that the morbidity and mortality rates for malaria ought to drop in the future as populations become richer, and prevention and treatment technology advances. Therefore there may be little or no benefit derived from reducing the malaria baseline in, say, 2080. But by the same token, there would be even less malaria-related benefit attached to reducing the impact of climate change. Moreover, the adaptive approach presented in this paper would accelerate the reductions in the malaria baseline, whether or not climate changes or has a significant impact on damages due to malaria.

futility: it delivers too little too late, and costs too much.

It has been argued that because of the inertia of the climate and energy system, if we do not undertake mitigation now, it might be too late to affect the course of climate change before its impacts become “dangerous,” the avoidance of which is the “ultimate objective” of the UN Framework Convention on Climate Change (as stated in Article 2) But we have seen that for most risk categories these impacts are unlikely to be larger or any more dangerous than similar impacts caused by other global changes, at least until the 2080s, and probably later. If we have a 50-year lead time, that means we have a few decades of breathing space before mitigation actions would need to be implemented in earnest. In the meantime, it would be appropriate to pursue an aggressive, multi-pronged approach that would focus on:

- Implementing adaptation strategies that would help deal with the critical problems that humanity faces today, and might be aggravated by climate change. Improved adaptation could raise the level at which atmospheric concentrations of GHGs might be deemed to have become “dangerous,” which could further postpone the timing for executing mitigation efforts. Either way, the emission reduction requirements and costs associated with stabilization would be reduced (Goklany, 1995, 2000).
- Helping ensure that no-regret emission reductions are, indeed, implemented (see footnote 3).
- Conducting R&D into more cost-effective mitigation strategies and measures. This might result in the eventual cuts being cheaper, even if they also have to be deeper to compensate for later implementation of the cuts. However, as noted above, given that the depth of the cuts should itself be inversely related to the ability to adapt, it does not necessarily follow that later cuts would necessarily have to be deeper.
- Improving methods of analyzing and forecasting climate change and its socioeconomic and environmental impacts so that it is possible to better evaluate and determine trade-offs between adaptation and mitigation, and the timing, nature and intensity of response actions (including the depth of future emission reductions) well in advance of tripping any critical thresholds.

Adaptation, just like mitigation, also brings with it substantial co-benefits. The first source of these co-benefits is the accompanying reduction in P(BASELINE), which for the next several decades has been projected to dominate over ΔP(GW) for hunger, malaria, water shortage and habitat conservation. Secondly, many adaptation measures would solve multiple problems. Measures that would, for example, increase the productivity of land and water would simultaneously increase food production, reduce hunger, and reduce the amount of land and water used by agriculture. Each of these benefits spawn additional benefits that would cascade through the system: less hunger results in better health which means that populations would be better able to cope with diseases in general, and malaria in particular (WHO, 2002); reducing the amount of land and water used by agriculture means reduced habitat loss, fragmentation, water diversion, and water shortage, which are the major threats today (and in the future) to the rest of nature and its biodiversity (Goklany, 1995, 2000, 2003); and lowering the amount of land under cultivation also means lower erosion and GHG emissions (Goklany, 2001a). This list of benefits is not exhaustive for this particular set of adaptations.

It is misleading, as Parry et al. have done, to focus only on the additional millions at risk due to climate change while ignoring the millions more who might be similarly at risk because of non-climate change related causes. This error, magnified by overlooking considerations of cost-effectiveness, could divert scarce human and fiscal resources away from today's urgent problems into problems that, while potentially serious in the long term, are less critical today. This would be especially ironic from the perspective of the developing world. One of the arguments for mitigation is that developing countries have limited human and fiscal resources which inhibits their ability to adapt to climate change. Consequently, goes this argument, developing countries are "most at risk" from climate change (see, e.g., UNEP, 1993; Wolfensohn, 1997; Watson and Johnson, 2001). A related argument is that, if unchecked, the effects of climate change on developing countries would be an impediment to their sustainable development (Watson and Johnson, 2001). It is probably no accident that the risk categories addressed in Parry et al. — hunger, malaria, water shortage and coastal flooding — are problems in the developing world, which, for the most part, have been contained if not eliminated in the developed world.

However, if the underlying objective is to help developing countries and to ensure their sustainable development, it would be better to invest resources in addressing these problems now, rather than expend them on mitigation. The latter, moreover, will not provide any significant benefits for decades. No less important, the adaptation approach outlined above would help develop solutions *now* which will also be applicable in the future if and when $\Delta P(GW)$ begin to swell and rival P(BASELINE) in magnitude, or if the climate changes earlier than currently anticipated.

Moreover, reductions in hunger and malaria now would also help spur economic growth in the developing countries. Africa's GDP, for instance, might have been a third higher in 2000 had malaria been eliminated in 1965 (HUCID and LSHTM, 2000). At the same time, virtually every objective indicator of human well-being — access to food, safe water and sanitation, educational attainment, child labor, mortality rates, life expectancy — improves with wealth (Goklany, 2000, 2002b). Thus, just as health begets wealth, so does wealth beget health (Goklany, 2000, 2002c). This, in fact, is the essence of a path to sustainable development that will promote progress rather than perpetuate poverty (Morris, 2002).

A healthier and wealthier developing world will find it easier to cope with and reduce its vulnerability to climate change, which would help address one of the major reasons advanced to justify mitigation actions in the near term. A wealthier developing world is also more likely to have the human and fiscal resources needed to develop, obtain and operate newer and more effective technologies for the sustainable development and use of energy and other natural resources (Goklany, 1995, 2002b). In addition, healthier and wealthier countries also have lower birth rates, a prime determinant of future GHG emissions. Hence, wealth not only enhances a society's ability to adapt to climate change but also to mitigate GHG emissions (Goklany, 1995, 2000).

Thus the approach outlined above, by addressing today's urgent problems now while creating the wherewithal to address future problems due to climate change, would advance the developing world's quest for sustainable development. On the other hand, mitigation, by diverting scarce human and fiscal resources for decades before providing any tangible benefits even as today's critical problems stay unsolved, may well retard that quest over the next few decades.

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Table 1: Populations at Risk (PAR) With and Without Climate Change in the 2080s. PAR estimates are based on the assumption that global population in the 2080s will be between 10.7 billion (Arnell et al., 2002: 415) and 11.0 billion (Arnell, 1999: S43).

Climate-Sensitive Risk Factor	Numbers at risk in 1990	PAR(BASELINE) = Baseline numbers at risk in the 2080s, i.e., in the absence of climate change	ΔPAR(GW) = Net change in the numbers at risk in the 2080s due to unmitigated climate change[A]	Overall reduction in PAR due to full implementation of the Kyoto Protocol[B]	Source
Hunger	521 million	300 million	69 million to 91 million (23.0% to 30.3%)	4.8 million to 6.4 million (1.3% to 1.6%)	Arnell et al. (2002: 436)
Water Shortage					
Approach A	1,750 million[C]	6,464 million[C]	42 million to 105 million[C] (0.6% to 1.6%)	2.9 million to 7.4 million (0.05% to 0.11%)	Arnell (1999: S44)
Approach B	1,750 million[C]	6,464 million[C]	−2,387 million to +1,063 million[D] (-36.9% to +16.4%)	−167.1 million to +74.4 million (-4.1% to +1.0%)	Arnell (1999: S44)
Approach C	1,710 million[C]	6,405 million[C]	+2,831 million to +3,436 million[E] (+43.8% to +53.2%)	198.2 million to 240.5 million (2.1% to 2.4%)	Arnell et al. (2002: 427, 443)
Malaria Transmission	4,413 million	8,820 million	256 million to 323 million (2.9% to 3.7%)	17.9 million to 22.6 million (0.20% to 0.25%)	Arnell et al. (2002: 439)
Coastal Flooding	10 million	13 million	81 million (623%)	17.0 million (18.1%)	Arnell et al. (2002: 431, 443)

[A] Figures in parentheses are the changes due to unmitigated global warming expressed in terms of the PAR for the 2080s baseline (i.e., "no climate change" case). [B] Assumes that full implementation of the Kyoto Protocol would reduce the increase in global temperature by as much as 7% (see text). [C] PAR defined as population in countries where more than 20% of available resources are used. [D] Estimated as the net difference between the number of people for whom unmitigated warming increases water stress and for those whom it reduces stress. [E] This estimate apparently considers the numbers added to the baseline but not the numbers simultaneously reduced (see text).

Table 2: Populations at Risk (PAR) With and Without Climate Change in the 2050s. PAR estimates are based on the assumption that global population in the 2050s will be between 9.5 billion (Arnell, 1999: S43) and 9.8 billion (Arnell et al., 2002: 415).

Climate-Sensitive Risk Factor	Numbers at risk in 1990	PAR(BASELINE) = Baseline numbers at risk in the 2050s, i.e., in the absence of climate change	ΔPAR(GW) = Net change in the numbers at risk in the 2050s due to unmitigated climate change[A]	Source
Hunger	521 million	312 million	−3 million to +12 million (−1.0% to +3.8%)	Arnell et al. (2002: 436)
Water Shortage				
Approach A	1,750 million[C]	5,974 million[B]	−352 million to +56 million[B] (−5.9% to +0.9%)	Arnell (1999: S43-44)
Approach B	1,750 million[C]	5,974 million[B]	−2,137 million to +899 million[C] (−35.8% to +15.0%)	Arnell (1999: S43-44)
Approach C	1,710 million[C]	5,914 million[B]	+2,209 million to +3,195 million[D] (+37.4% to +54.0%)	Arnell et al. (2002: 427, 443)
Malaria Transmission	4,413 million	8,072 million	197 million to 258 million (2.4% to 3.2%)	Arnell et al. (2002: 439)
Coastal Flooding	10 million	27 million	50 million (185%)	Arnell et al. (2002: 431, 443)

[A] Figures in parentheses are the changes due to unmitigated global warming expressed in terms of the PAR for the 2050s baseline (i.e., “no climate change” case). [B] PAR defined as population in countries where more than 20% of available resources are used. [C] Estimated as the net difference between the number of people for whom unmitigated warming increases water stress and for those whom it reduces stress. [D] This estimate apparently considers the numbers added to the baseline but not the numbers simultaneously reduced (see text).

Table 3: Projected Changes in Extent of Various Ecosystems, With and Without Climate Change

Ecosystem	**Change in baseline relative to 1990**	**Impact of unmitigated climate change, relative to 1990**	**Impact of Kyoto Protocol**[A]
Global Forest Area	Decrease 25-30% in the 2050s relative to 1990 (IPCC, 1996: 95-129, 492-496)	Increase by 6% to 42% in the 2060s (IPCC, 1998: 443) Increase by 5% in the 2080s (Arnell et al., 2002: 424)	Limit the increase in global forest area by less than 3% relative to1990 level Limit the increase in global forest area by less than 1% relative to 1990 level
Arid Areas/Deserts		Change by −41% to +20% in the 2060s (IPCC, 1998: 443). Increase (+20%) assumes no direct CO_2 effect on vegetation. Increase by +26% in the 2080s (Arnell et al., 2002: 424)	Limit changes in area by −3% to +1%. Limit changes in area by less than −2%
Coastal Wetlands	Decrease by 40% in the 2080s relative to 1990 (Arnell et al., 2002)	Decrease by 13% in 2080s relative to 1990 (Nicholls 1999; see also Arnell et al., 2002: 441)	

[A] Assumes that impacts vary linearly with the amount of climate change.