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ORIGINAL ARTICLE

Integrated strategies to reduce vulnerability and advance adaptation, mitigation, and sustainable development

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Abstract Determinants of adaptive and mitigative capacities (e.g., availability of technological options, and access to economic resources, social capital and human capital) largely overlap. Several factors underlying or related to these determinants are themselves indicators of sustainable development (e.g., per capita income; and various public health, education and research indices). Moreover, climate change could exacerbate existing climate-sensitive hurdles to sustainable development (e.g., hunger, malaria, water shortage, coastal flooding and threats to biodiversity) faced specifically by many developing countries. Based on these commonalities, the paper identifies integrated approaches to formulating strategies and measures to concurrently advance adaptation, mitigation and sustainable development. These approaches range from broadly moving sustainable development forward (by developing and/or nurturing institutions, policies and infrastructure to stimulate economic development, technological change, human and social capital, and reducing specific barriers to sustainable development) to reducing vulnerabilities to urgent climate-sensitive risks that hinder sustainable development and would worsen with climate change. The resulting sustainable economic development would also help reduce birth rates, which could mitigate climate change and reduce the population exposed to climate change and climate-sensitive risks, thereby reducing impacts, and the demand for adaptation. The paper also offers a portfolio of pro-active strategies and measures consistent with the above approaches, including example measures that would simultaneously reduce pressures on biodiversity, hunger, and carbon sinks. Finally it addresses some common misconceptions that could hamper fuller integration of adaptation and mitigation, including the notions that adaptation may be unsuitable for natural systems, and mitigation should necessarily have primacy over adaptation.

Views expressed in this paper are the author’s and not necessarily of the U.S. government’s.

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1 Introduction

Despite longstanding calls to explore synergies and trade-offs between adaptation and mitigation to climate change and to develop integrated strategies (IPCC 1991; Goklany 1992, 1995; Parry et al. 1998), the need for such work has only recently been broadly recognized. Increased focus on such integration within the research community has led to new work in this area (Kane and Shogren 2000; Goklany 2000, 2003; Wilbanks et al. 2003; Dang et al. 2003; Klein et al. 2003; Swart et al. 2003). Catalyzed by the Delhi (Ministerial) Declaration at COP-8 and the unsteady progress of the Kyoto Protocol, such integration now figures more prominently in the discussions of the United Nations Framework Convention on Climate Change (FCCC) Kyoto Protocol 8th Conference of the Parties (COP-8) and in preparations for the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (UNIPCC).

The burgeoning interest has been fueled by greater acknowledgment that climate change is inevitable, whether due to natural or man-made causes (Goklany 1992, 1995; Smith 1997; Parry et al. 1998, 2001; Smit et al. 2001; Wilbanks et al. 2003), aided by the realization that much more drastic action than the Kyoto Protocol is necessary to significantly lower the rate or magnitude of climate change (Parry et al. 1998; Goklany 2000, 2003; Wilbanks et al. 2003). There is also wider appreciation of the inverse relationship between adaptation and mitigation. Greater adaptability could raise the threshold at which greenhouse gas concentrations could be deemed to have become ‘‘dangerous,’’ thereby reducing the urgency and/or depth of emission reductions, at least in the short to medium term (Goklany 2000). Postponing drastic cuts in emissions could, in turn, buy additional time to research and develop more (cost) effective methods of limiting climate change and, if the rate of technological change could be accelerated, net costs of mitigation might be reduced even if the emission limitations are eventually more stringent (Goklany 2000, 2003). Accordingly, development of socially, economically and environmentally optimal strategies to combat climate change must necessarily consider these trade-offs and combine elements of adaptation and mitigation (Goklany 1992; Kane and Shogren 2000; Wilbanks et al. 2003).

One challenge to the climate change community is, therefore, to identify, develop and analyze such combined strategies so that progress toward sustainable development is, at worst, not delayed and, preferably, accelerated.

This paper will examine the commonalities between factors underlying the determinants of mitigative and adaptive capacities and various indicators of sustainable development (ISDs). Based on that, it will identify strategies that would advance both mitigation and adaptation while also making progress toward sustainable development (Sects. 2 and 3). Then, noting that one reason for skepticism about adaptation is its perceived limitations with regard to natural systems, the paper will identify an adaptation strategy and several measures that would diminish both pressures on biodiversity and vulnerability to hunger—both of which could be exacerbated by climate change—while concurrently making progress on sustainable development and limiting net greenhouse gas (GHG) emissions. Section 5 will identify a portfolio of measures that would address climate change while also advancing sustainable development in an efficient manner. This portfolio would consist of a mix of measures focusing on adaptation, mitigation, and climate-sensitive hurdles to sustainable development that could be heightened by climate change. Then, before concluding, the paper will briefly discuss some commonly held misconceptions of adaptation that could delay progress toward an integrated approach.

2 Advancing mitigative and adaptive capacities in tandem with sustainable development

This section briefly examines factors underlying various determinants of mitigative and adaptive (M&A) capacities (Yohe 2001; Smit et al. 2001), and congruences between them and various indicators of sustainable development (ISDs). The initial discussion, while focusing on adaptive capacity, also applies to mitigative capacity. Based on these congruences, I will propose an integrated approach to simultaneously advance M&A capacities and sustainable development.

2.1 Correlations between determinants of M&A capacities, income and technological change

Figures 1–3 show that cereal yields, food supplies per capita, and malnutrition—all climate-sensitive ISDs—generally improve with: (a) access to economic resources as measured by gross domestic product (GDP) per capita,[1] a surrogate for per capita income or wealth, and (b) time, a proxy for changes in technology (defined here to include culture, institutions and infrastructure).[2,3]

The general pattern evident in Figs. 1–3 also holds for several other indicators that double as indicators of human well-being and sustainable development (see Appendix A).[4] Some of these indicators are directly or indirectly sensitive to climate (e.g., cereal yields, food supplies, infant mortality and life expectancy). Others, while less easily linked to climate, would, nevertheless, enhance M&A capacities (Smit et al. 2001), e.g., access to safe water and sanitation, health expenditures, tertiary school enrollment, and research and development expenditures, all of which directly or indirectly enhance access to economic resources, human capital, and technological options and the ability to utilize them (Goklany 2001a).

These correlations, detailed in Appendix A, are consistent with the general proposition that despite any problems associated with economic development and technological change (Goklany 1998, 2002b), both factors boost adaptability and reduce vulnerability to

[1] In this paper, GDP per capita is measured in constant (1995) US dollars at market exchange rates (MXR), unless otherwise noted. The general approach used to construct these (and subsequent) figures is from Goklany (2001a), and summarized in Appendix A. For brevity's sake, I will refer to GDP per capita as ''income'' or ''wealth.'' Unless otherwise noted, data used in the analyses presented here are from various versions of the World Bank's *World Data Indicators*.

[2] See Ausubel (1991) and Goklany (1995) for the definition of technology employed here.

[3] Prevalence of malnutrition is measured as the percentage of children under five whose height is less than two standard deviations below the median for an international reference population of ages 0–59 months (World Bank 2001).

[4] While the indicators in Appendix A seem to improve with both wealth and time, this is not necessarily true for all indicators at all times, nor is it inevitable (see, e.g., Goklany 2002b).

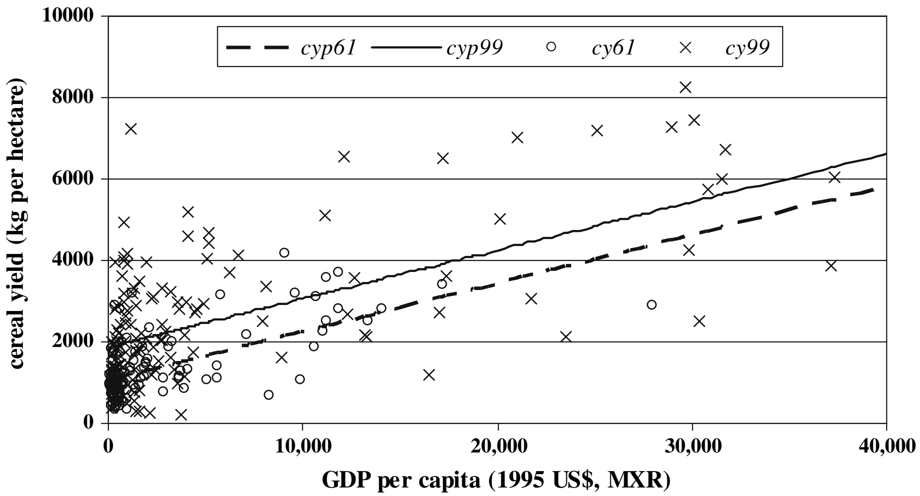

Fig. 1 Cereal yield vs. income, 1961–1999, based on World Bank (2001) data.

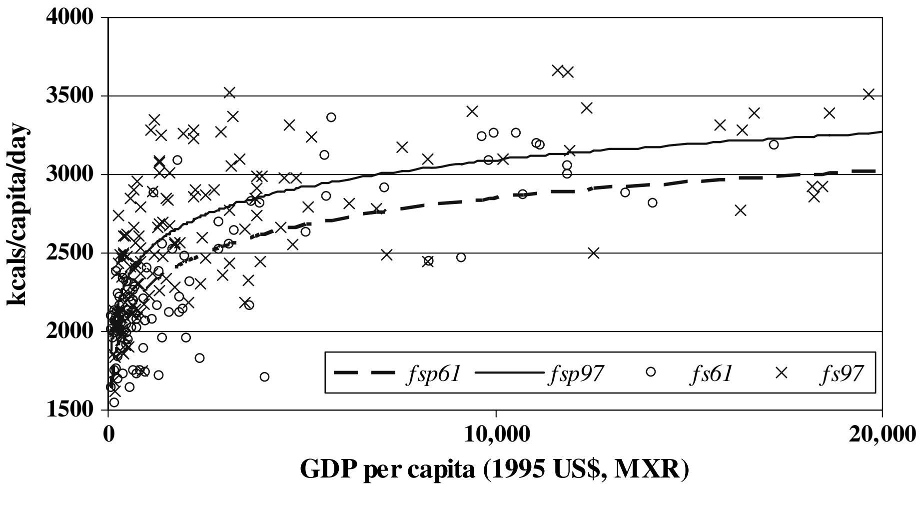

Fig. 2 Food supplies per capita vs. income, 1961–1997, based on data from World Resources Institute (2000) and World Bank (2001)

all manners of stress whether or not the stress is climate-sensitive (Goklany 1995, 2000; Smit et al. 2001). The importance of increasing incomes for poorer societies and, by analogy, the poorer segments of societies, is evident from the fact that generally these determinants improve most rapidly at the lowest levels of income. (Cereal yield is an exception; it increases linearly with income.) Third, for any given income level, each indicator has improved over time because of technological change. Thus, the income threshold at which malnutrition is essentially eliminated, for instance, dropped with time (Fig. 3). Similarly, income thresholds at which full access to safe water and sanitation are reached also decline over time (Appendix A).

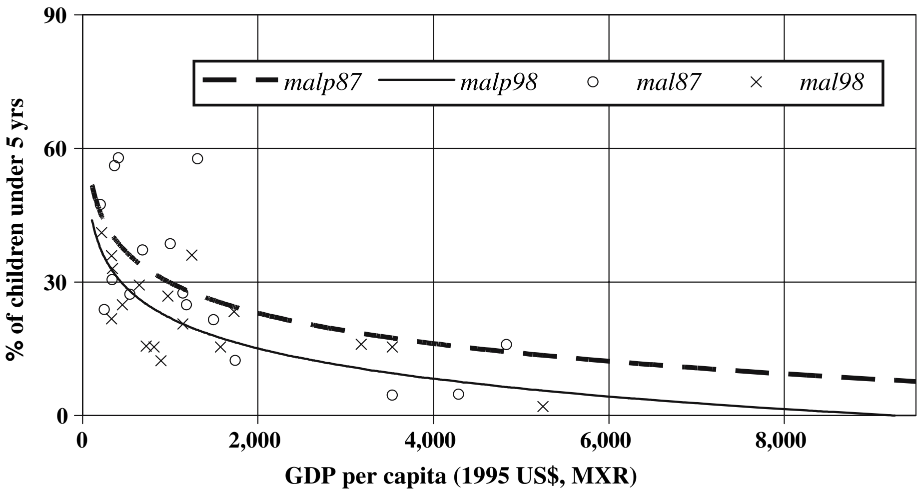

Fig. 3 Malnutrition in children under 5 years of age vs. income, 1987–1998, based on World Bank (2001) data

These associations indicate that analyses of future impacts of climate change on these indicators must necessarily account for future levels of income and technology in estimating risks and vulnerabilities (R&V) both in the absence of future climate change (i.e., under the ''reference'' case), and due to climate change. Adding to this complexity, climate change—and responses to climate change—could themselves alter income and, therefore, the ability for technological change. Although some impacts analyses (Tol and Dowlatabadi 2001; Parry et al. 2004)[5] attempt to account for such changes in their projections, frequently the accounting is incomplete, if not non-existent (Goklany 2000, 2003).

Notably, the information in Appendix A allows us to construct sector-specific scenarios for adjusting future R&V to various hazards to ensure internal-consistency with whatever socio-economic assumptions are used to generate emissions and climate change scenarios. With respect to malnutrition, for example, assuming a constant rate of technological change at the 1987–1998 level, a country whose per capita income is frozen at $100 might eliminate malnutrition by 2060, if all else stays the same, including the climate. Alternatively, under a scenario which assumes that from 1998 onward, income grows 2% annually and the rate of technological change is frozen, malnutrition would be eliminated by 2047, ceteris paribus.

[5] For instance, Parry et al. (2004) apparently consider that higher incomes translates into less hunger and greater use of fertilizers but it's unclear whether it directly or indirectly incorporated the other technologies that might be used more frequently if income levels rise (see Fig. 1). Similarly, Tol and Dowlatabadi, (2001) did not examine how malaria prevalence changed over time (i.e., with past technological change). Although over the long term technological change has reduced vulnerability to malaria (Cassman and Dowlatabadi 2002), there was a resurgence of malaria in the 1980s and 1990s that may be continuing to this day (WHO 1999; Yamey 2004). Reasons for this resurgence include increased resistance of the disease to established drugs, increased resistance of mosquitoes to insecticides, and increased institutional resistance toward the indoor spraying of DDT for mosquito control (Goklany 2000, 2001b; Yamey 2004). The last shows that technological (and institutional) change can sometimes lead to maladaptation.

2.2 Explaining the correlations

One explanation for the correlations between various ISDs and income is that economic development indeed improves these indicators[6] because wealthier societies can better afford the fiscal and human resources necessary to install, operate and maintain technologies for improving well-being.[7] With respect to hunger and malnutrition, for example, wealthier societies have higher crop yields (Fig. 1) because they have greater access to yield-enhancing technologies (Goklany 1998, 2001a). Moreover, they can use their wealth to import food (Goklany 1995, 1998, 2001a). Thus wealthier populations have greater access to food supplies (Fig. 2), and are less likely to suffer from malnutrition (Fig. 3).[8] Reduced malnutrition, a critical first step to improving public health, then helps lower mortality and morbidity associated with infectious and parasitic diseases.[9] Similarly, wealthier societies have greater access to safe water and sanitation, and greater health expenditures (Appendix A). Moreover, greater wealth increases the likelihood that societies will establish and sustain institutions and policies (e.g., food programs and safety nets) for those on the lower rungs of the economic ladder. In addition, literacy rates and educational levels, which promote better hygiene and health consciousness, are generally higher in wealthier societies. Thus, greater wealth, through a multiplicity of mechanisms, improves public health as indicated by lower mortality rates and higher life expectancies (Fig. 4).

Thus, wealthier populations ought to be less vulnerable to hazards in general, regardless of whether that hazard is due to the ‘‘normal’’ climate, climate variability, climate change or a non-climate-sensitive factor. This is reinforced by the fact that wealthier countries spend more on research and development and have higher levels of educational attainment (Appendix A). Both factors should directly or indirectly increase human and social capital, and stimulate invention, innovation and diffusion of technology (Goklany 2001a).

Second, the causation might be in the reverse direction. It might be that improvements in human well-being foster economic development, and not vice versa. Healthier people are more energetic, less prone to absenteeism and, therefore, economically more productive (World Bank 1993; Fogel 1995; WHO 1999; Bloom 1999).[10] Healthier people can also devote more time and energy to education and their intellectual development (Fogel 1995; WHO 1999). Good health is particularly important during children’s formative years. In addition, the incentive to invest in the development of human capital increases if individual beneficiaries can be confidently expected to live longer. Thus better health helps raise human capital which aids the creation and diffusion of technology, further advancing health and accelerating economic growth (Goklany 2001a).

But probably both explanations are valid, with causes and effects pushing and pulling each other in a set of interlinked, mutually reinforcing cycles. These cycles include the health-wealth cycle in which wealth begets health and health, wealth; and the cycle

[6] The following is adapted from Goklany (2001a, 2002b).

[7] This explanation is consistent with the notion that economic development is the means to the end of advancing human well-being rather than an end in itself.

[8] It is, nevertheless, possible to have hunger in the midst of plenty if individuals lack sufficient incomes and livelihoods, or if there are severe distribution problems that cannot be surmounted by the marketplace (Goklany 1995, and references therein).

[9] Caulfield et al. (2004). estimate that an adequate diet for children worldwide would prevent about 1 million deaths a year from pneumonia, 800,000 from diarrhea, 500,000 from malaria and 250,000 from measles.

[10] HUCID/LSHTM (2000) estimates, for instance, that had malaria been eradicated in 1965, Africa’s GDP would have been 32% higher in 2000.

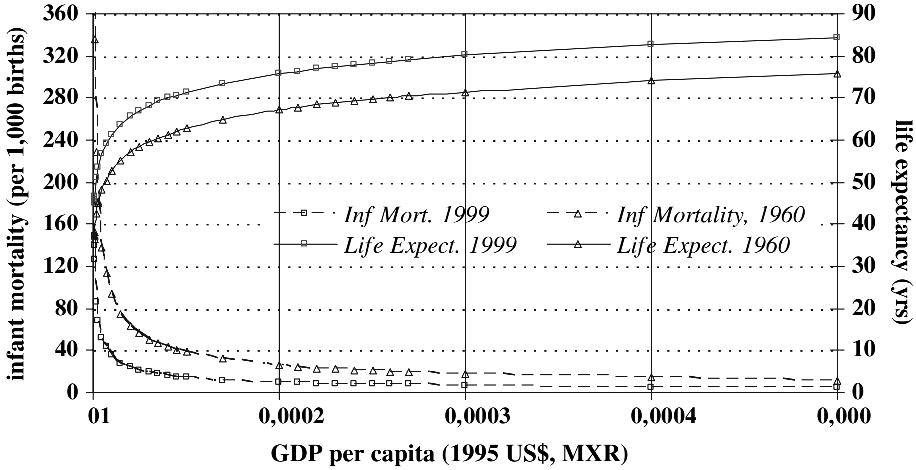

Fig. 4 Infant mortality and life expectancy vs. economic development, 1960–1999, based on World Bank (2001) data

connecting wealth, education, and R&D, which itself is linked to the cycle linking economic development and technological change (Easterlin 1996; Mokyr 1990; Goklany 1995, 2001a; Easterly 2001). These cycles are part of a larger ''Cycle of Progress'' in which economic growth, technological change, better health, and greater education reinforce each other (Goklany 2001a).

Fair and unsubsidized trade is an integral part of the Cycle of Progress. Such trade directly stimulates economic growth, helps disseminate new technologies, creates pressures to invent and innovate, contains the costs of basic infrastructure (including water supply, sanitation and power generation), and enhances global food security (Frankel and Romer 1999; Barro 1997; Dollar and Kraay 2000; Goklany 1995, 1998, 2001a).

A third explanation for the association between wealth and technology on one hand and the various ISDs (or human well-being) on the other is that they are propelled by the same factors: the institutions, policies and processes that fuel the Cycle of Progress stimulate both economic growth and technological change. They include legal and economic systems—free markets; secure and well-defined property rights including the right to transfer those rights; honest, predictable and fiscally responsible governments and bureaucracies; and adherence to the rule of law—that encourage competition in the commercial, scientific and intellectual spheres, and provide the necessary incentives for people to risk (or invest) their labor, intellectual capital and financial resources, e.g., by allowing them to profit monetarily or psychically from the risks they incur (Barro 1997; Dollar and Kraay 2000; Gwartney et al. 1998, 2001; Norton 1998). These institutions also contribute to M&A capacities (Smit et al. 2001; Yohe 2001), and serve as the foundations of civil societies and democratic systems.

But the best explanation is that it is an amalgam of the three explanations offered above: it is probably development writ large, i.e., sustainable development, and not just economic development, that is the most fruitful approach to integrating adaptation and mitigation to climate change. Such an approach would increase adaptability and reduce vulnerability in general, whether the stress or risk is due to a climate-sensitive or non-climate-related factor (Goklany 1995, 2000, 2003).

Just as the ability to research, develop, refine, obtain, operate and maintain technologies advances adaptive capacity so would it, by increasing technological options, economic resources, and human capital, advance a society's mitigative capacity. Thus, pursuit of sustainable economic development is not only an end in itself but also a means to specifically integrate both mitigation and adaptation to climate change. As Figs. 1–4 indicate, such an approach would benefit the poorest (i.e., the most vulnerable) developing nations the most.

2.3 Synthesis

Table 1, based on the foregoing, lists whether, and the extent to which, various determinants of M&A capacities shown in the first column (broadly related to economic resources, technology, human capital, and information and skills) are affected by the 11 ISDs listed at the top of rows 2 through 12 GDP per capita... R&D expenditures).[11] The last row of Table 1 indicates whether these ISDs are sensitive to climate and, therefore, climate change (to the extent there is an established, i.e., more-than-passing, relationship). Table 2 lists the institutions, policies and processes that underlie both M&A capacities and the Cycle of Progress.

These tables suggest that it ought to be possible to simultaneously advance M&A capacities and sustainable development. First, we can expend resources on improving the 11 ISDs, even if they are not directly sensitive to climate. Alternatively, we can focus resources on measures that would improve those ISDs that are climate-sensitive, e.g., infectious and parasitic diseases such as malaria, hunger and malnutrition. Essentially this calls for reducing current problems hindering sustainable development that are directly sensitive to climate change and are also urgent (so that one can justify spending resources on this set of problems rather than other current problems that are outstanding) (Goklany 1992, 2000, 2003). The next section examines a specific application of this principle pertinent to hunger and malnutrition.

Either approach requires that the institutions, policies and procedures that underlie the Cycle of Progress (see Table 2) be strengthened or, if necessary, developed. This long term task requires constant attention, since the conditions for sustainable development will themselves evolve as the socio-economic and environmental landscapes change over time.

Efforts based on the above approaches should be explicitly recognized as ''climate change response strategies'' because they would augment M&A capacities.

3 Economic development as a catalyst for smaller families

Sustainable economic development, in addition to advancing mitigative and adaptive capacities, would also reduce the pressure for high birthrates. Figure 5 shows that the total fertility rate (TFR), a measure of the number of children borne by a woman of child-bearing age, declines across countries as income levels rise, and over time (i.e., technology). The association between higher incomes and lower TFRs has been attributed to the notion that conditions that are conducive to economic development are also conducive to the desire for lower birthrates (Goklany 1995, 1998). Lowering of the TFR-income curve over time in Fig. 5 indicates, inter alia, availability of new technologies and, most

[11] A similar table could be constructed showing whether the determinants in the extreme left column contribute to the indicators (on the right). Such a table would have an entry in virtually each cell.

Table 1 Relationships between the determinants of M&A capacities, and various ISDs

Determinants of adaptive & mitigative capacities	Indicators of sustainable development (ISD)										
	GDP per capita	Cereal yield	Hunger (food supplies per capita)	Malnutrition	Access to safe water	Access to sanitation	Health expenditures	Infant mortality	Life expectancy	Education	R&D expenditures
Access to economic resources at both the societal and household level	P	S, except for LDCs with large ag sectors	S, except for LDCs with large ag sectors	S, except for LDCs	S, except for LDCs	S, except for LDCs	S, except for LDCs	S	S	P	P
Availability of technologies	P						P			P	P
Availability and access to the necessary human capital	P	S, except for LDCs with large ag sectors	S, except for LDCs with large ag sectors	S, except for LDCs	S, except for LDCs	S, except for LDCs	S, except for LDCs	S	S	P	P
Collection, analysis, synthesis, and dissemination of robust information and associated uncertainties	P									P	P
Are or could the ISDs be climate-sensitive?	Yes, especially for LDCs	Yes	Yes, particularly for LDCs	Yes, particularly for LDCs	No	No	Yes	Yes	Yes	Not usually	Yes

Note: P denotes that the indicator listed at the top of the column is a *primary* contributor to the determinant of M&A capacity specified in the extreme left column (but not necessarily vice versa). Similarly, S denotes a *secondary* contributor. LDCs = lesser developed countries

Table 2 Advancing M&A capacities and sustainable development: institutions, policies and processes (a sample)

Secure (i.e., accepted and enforced) transferable property rights
Rule of law
Governments that are deemed legitimate by, and responsive to, those governed
Free markets
Protection for minorities and minority viewpoints
Decentralized decision making, as practicable and appropriate
Transparent and honest governments and bureaucracies (with transparent decision rules)
Fiscally responsible governments
Freer, but unsubsidized trade (with institutions to fairly enforce rules of trade)
Decision rules that do not discriminate against technologies based on whether they are new or old
Fair and free competition in commercial, intellectual and scientific spheres
Access to information and knowledge
Systems for advancing public health, education and research
Risk spreading through insurance, trade, safety nets, decentralized decision-making, and economic diversification

Sources: Barro (1997); Dollar and Kraay (2000); Gwartney et al. (1998, 2001); Norton (1998); Yohe (2001); Swart et al. (2003)

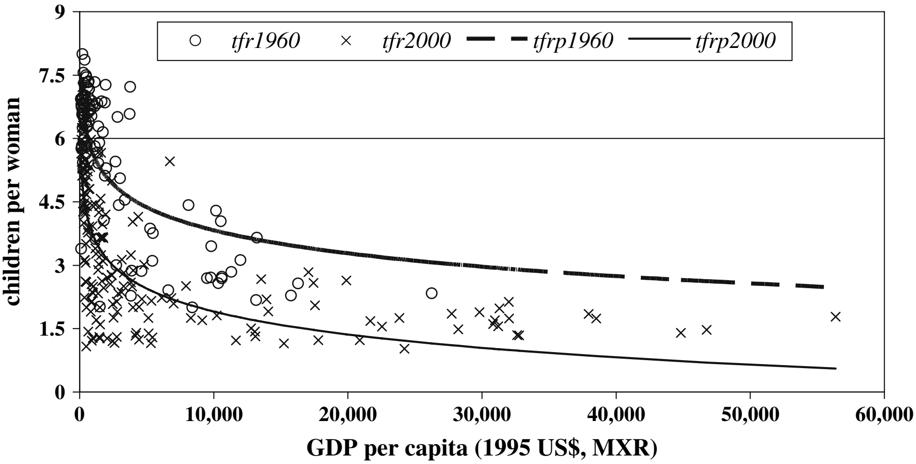

Fig. 5 Total fertility rate vs. income, 1960–2000, based on World Bank (2002a, b) data

importantly, cultural shifts that have made smaller families more acceptable and desirable, perhaps aided by the consumerism reinforced by the ubiquitous visual electronic media which overtly or inadvertently proselytizes consumerism.

Reducing birthrates would mitigate climate change, since population is one of the drivers for GHG emissions. It would also have profound effects on impacts of climate change and adaptation. Table 3, based on Arnell (1999) and Arnell et al. (2002), compares the population at risk (P) of hunger, malaria, water shortage and coastal flooding in 1990 [denoted by P(REF,1990)], the P in 2085 under the reference case in the absence of any climate change [i.e., P(REF,2085)], and the contribution of unmitigated climate change to

Table 3 Populations at risk (P) with and without climate change in 2085 (in millions)

Climate-sensitive risk factor	P(REF,1990) = numbers at risk in 1990	P(REF,2085) = ''reference'' P in 2085, i.e., in the absence of climate change	P(UCC,2085) = contribution to P in 2085 due to unmitigated climate change	Reduction in P(T,2085)[a] due to the Kyoto Protocol[b](% reduction in brackets)	Source
Hunger	521	300	69 to 91	4.8 to 6.4 (1.3% to 1.6%)	Arnell et al. (2002, p 436)
Water shortage					
Approach A[c]	1,750	6,464	42–105	2.9–7.4 (0.05–0.11%)	Arnell (1999, p S44)
Approach B[c]	1,750	6,464	−2,387 to + 1,063	−167.1 to +74.4 (−4.1% to + 1.0%)	Arnell (1999, p S44)
Approach C[c]	1,710	6,405	+ 2,831 to + 3,436	198.2 to 240.5 (2.1 to 2.4%)	Arnell et al. (2002, p 427, 443)
Malaria transmission	4,413	8,820	256 to 323	17.9 to 22.6 (0.20% to 0.25%)	Arnell et al. (2002, p 439)
Coastal flooding	10	13	81	17.0 (18.1%)	Arnell et al. (2002, p 431, 443)

Source: Goklany (2003)

[a] P(T,2085) is the total P in the year t [= P(REF,2085) + P(UCC,2085)]

[b] Assumes that full implementation of the Kyoto Protocol would reduce the increase in global temperature by 7% in 2085, which would, then, reduce P(UCC, 2085) by 7% for all risk factors except for coastal flooding, for which a 21% reduction is assumed

[c] Approach A: P defined as population in countries where more than 20% of available resources are used; Approach B: P is estimated as the net difference between the number of people for whom unmitigated warming increases water stress and for those whom it reduces stress; Approach C: This estimate apparently considers the numbers added to the reference case but not the numbers simultaneously reduced

P in 2085 [i.e., P(UCC,2085)]. It indicates that between 1990 and 2085, the growth in the numbers at risk of malaria and water shortage would be dominated by population growth rather than climate change per se.[12] If population growth were lowered, so would the total P in 2085 [i.e., P(T,2085) = P(REF,2085) + P(UCC,2085)]. That, moreover, would effectively reduce the ''demand'' for adaptation. Equally important, whether climate changes or not, lower birth rates would reduce the demand for natural resources and, therefore, the primary pressure on the world's biodiversity.

However, restraining population growth is among the most controversial of environmental issues. The main focus of this controversy has to do with method(s) of birth control, and whether and to what extent they should be government-sponsored or supported. But it should be less controversial if households reduce their sizes voluntarily, as Fig. 5 suggests they do if appropriate conditions are created to ensure sustainable economic development. Thus, policies to stimulate economic development might be sufficient. The rest should be left to individual families themselves.

4 An integrated approach to reduce threats to biodiversity and hunger

Many perceive adaptation to be unsuitable for addressing the impacts of climate change on natural systems and biodiversity (IPCC 2001c; Wilbanks et al. 2003). Nevertheless, Sect. 3 offered an indirect approach to simultaneously reduce emissions and aid adaptation by reducing threats to biodiversity, and other climate change impacts. This section offers another strategy which would concurrently reduce pressures on biodiversity, hunger, and carbon stores and sinks, and, thereby, advance sustainable development, mitigation and adaptation. However, it excludes adaptation measures and techniques that would aid biodiversity but have minimal impact on mitigation or on meeting human food demand [e.g., water pricing, conservation and other management measures that could save water for aquatic organisms (Goklany 1998, 2002a), gene banks (Wilbanks et al. 2003), measures to preserve and propagate endangered or threatened species through modern biological techniques (Estabrook 2002; Lanza et al. 2000) or techniques based on restoration biology, or adaptive management of disturbance regimes such as fires to help mediate transitions from one ecosystem regime to another as environmental conditions change].

4.1 Improving net productivity of the food and agricultural sector

Among the most important barriers to sustainable development that could be exacerbated by climate change are pressures on biodiversity, hunger and malnutrition. These seemingly unrelated problems, in fact, share a common thread. Currently, the major threat to terrestrial biodiversity is humanity's demand for land necessitated by the demand for food (Goklany 1998, 2003).[13] Agriculture accounts for 38% of global land use. It is the largest

[12] With respect to hunger, the drop in P(REF,t) from 1990 to 2085 occurs because the growth in population is projected to be more than offset by greater food production and higher incomes.

[13] What is true for terrestrial biodiversity is also true for freshwater biodiversity since agriculture is also responsible for 66% of freshwater withdrawals and 85% of freshwater consumption worldwide (Goklany 2002a). And although I will not address the issue of water use here (since there is no obvious tie-in between water use and GHG emissions), the general approach to adaptation presented here with respect to land use (and its effects on terrestrial biodiversity and hunger) is also appropriate for water use (and its effects on freshwater biodiversity and hunger) (Goklany 1988, 1995, 2003).

Table 4 Dependence of various income groups on the agricultural sector

	Year	Least developed countries	Low income countries	Middle income countries	High income countries
Agriculture (as % of GDP)	2001	33.5	24.9	9.0	1.8
Agriculture (as % of labor force)	1995	72.4 (for 1990)	57.0	38.8	4.7
Rural population (% of total)	2001	76.2	69.8	48.1	22.5
Food exports (as % of merchandise exports)	2002	27.1 (for 1998)	15.6	8.3	6.8

Source: World Bank (2004)

cause of loss and fragmentation of habitat (Goklany 1998). Agriculture also is the primary user of pesticides and nitrogenous fertilizers, which contributes to air, water and soil pollution and further impacts biodiversity. In addition, other agricultural practices—land clearing, tilling, animal husbandry—are significant sources of GHG emissions. The triple challenge—meeting the human demand for food, reducing pressures on biodiversity and reducing greenhouse gas emissions—will only multiply in the future as populations increase and, perhaps, become wealthier (see Fig. 2), ceteris paribus. Climate change will only add to this challenge (IPCC 2001c).

Perhaps the single most effective method of making progress on these three fronts simultaneously would be to increase the productivity of the food and agricultural sector (henceforth, ''food productivity'')[14] with lower inputs of fertilizers and pesticides. This once-radical idea is now more widely accepted within the agricultural and the conservation communities (Goklany 1988, 1992, 1998; Waggoner 1994; Waggoner et al. 1996; Future Harvest/IUCN 2002; McNeely and Scherr 2002).

This strategy is based on the following logic. First, greater food productivity per unit of land (or water) would reduce hunger and malnutrition,[15] the benefits of which would cascade through the system, helping improve public health, and through that, several other aspects of human well-being, eventually providing greater access to economic resources, increasing human capital, and advancing M&A capacities (see Sect. 2). These effects would be magnified for developing countries whose employment and economic well-being are much more dependent on agriculture. This dependence, moreover, generally increases with lower incomes (see Table 4). For instance, agriculture provides a quarter of the GDP of low income countries and about half (or more) of the labor force, while it accounts for a third of the GDP of least developed countries (World Bank 2004).

Second, greater food productivity would reduce the amount of land devoted to agriculture, which, in turn, would lower loss and fragmentation of habitat and threats to

[14] In the following, I will use the term ''food productivity'' to mean the productivity of the *entire* food and agricultural sector, from the farm to the plate and, beyond, to the palate. Food productivity can be enhanced by reducing loss and wastage in each link of the chain from farm to palate. With respect to land use, such productivity would be measured by the amount of food energy ingested per unit area of cropland. Factors that would enhance this productivity are higher crop yield; reductions in post harvest losses; reductions in wastage and losses during transportation, processing, marketing, preparation and cooking before it reaches the consumer's plate as well as after, in case it is stored for reuse (Goklany 1998).

[15] This logic holds even in cases where hunger is not caused by physical shortages of food but by inadequate purchasing power and/or distribution problems (for whatever reason; Goklany 1995). Greater productivity can either lead to greater food production at the same cost or the same amount of production at a lower cost. In either case, overall prices would drop, and hunger would be reduced.

biodiversity. It would also better conserve carbon stores and sinks. In fact, if over the next few decades, global population ceases to grow (as seems possible; IPCC 2001b) and agricultural productivity is enhanced sufficiently, current cropland could revert to the rest of nature without adding to hunger (Goklany 1998). Third, a reduction in cultivated area would reduce soil erosion, and lower carbon emissions into the atmosphere, and associated air and water loadings of particulate matter, pesticides and nutrients. Moreover, reductions in cultivated area would further lower inputs of fertilizers and pesticides which are frequently applied on the basis of area. That would also help limit emissions of nitrous oxide (which has a global warming potential of 296). Furthermore, lowering the demand for cropland would reduce land prices which, in turn, would reduce the socio-economic costs of acquiring or reserving land for carbon sequestration and/or habitat conservation (Goklany 1998, 2000).

Notably, strategies to reduce hunger, reduce threats to biodiversity, or conserve carbon sinks and stocks today would also help reduce these problems tomorrow or, for that matter, the day after tomorrow, because the technologies, methods and institutions needed to reduce or solve current problem would allow us to better cope with any climate change related increases in these very problems (IPCC 1991, Goklany 1992, 2000, 2003). For hunger, for instance, the strategy presented above would reduce the vulnerability of not only the 500 million people currently at risk but also the 369-91 million at risk in 2085 because of either climate-change-related or non-climate-change-related factors (Table 3).[16]

At least through 2085, this strategy would provide greater benefits than one focusing only on reducing the incremental component due to climate change [P(UCC,t)], whether that is accomplished via mitigation or adaptations keyed specifically on the increment. Moreover, its fruits should start to accumulate much sooner than measures that would only reduce P(UCC,t), even as the latter's costs continue to accumulate (Goklany 2003).

4.2 Specific measures

Measures to enhance food productivity in accordance with the integrated strategy outlined above include, inter alia, enhanced R&D to create new higher-yield technologies or improve existing-but-underutilized technologies and more effective and rapid technology transfer to ensure their broader adoption. Such measures should focus on:

(a) Increasing yields under marginal climatic and soil conditions that exist today but could become more common under climate change (e.g., low soil moisture in some areas, too much water in others, or soils with high salinity, alkalinity or acidity).
(b) Developing cultivars that are better adapted to conditions likely to prevail in the future because of climate change (e.g., higher CO_2; higher temperatures; at the higher latitudes, longer growing seasons; at lower latitudes, heat-shortened seasons).
(c) Developing crops with reduced need for costly or environmentally unsound inputs (e.g., fertilizers and pesticides) while maintaining yields.
(d) Developing crops and practices with lower soil erosion potential (e.g., development of crops that would support no-till or low-till agriculture).

[16] Goklany (2003) notes that with respect to hunger, comparing P(UCC,2085) to P(REF,2085) can be misleading in some ways because small reductions in agricultural production usually result in disproportionate increases in food prices and, therefore, in P(UCC, 2085). Comparing P(UCC,t) to P(T,t), in 2085, climate change would constitute as much as 30.3% of the hunger problem (Table 3). However, this is the result of a relatively small (2–4%) reduction in crop yields.

(e) Extending shelf life, reducing pre- and post-harvest crop loss, spoilage and wastage with lower reliance on external inputs of pesticides and fertilizers, and increasing utilization of harvested crop.
(f) Developing crops and/or methods to make precision agriculture more affordable and less dependent on the availability of (or access to) skilled scientists and technicians to ensure optimal utilization of inputs. This would be particularly useful for developing country farmers (see below).

These should be complemented by capacity building measures to strengthen existing or, if necessary, develop new institutions to:

(a) Monitor current conditions to develop baseline information and to identify trends and provide intelligence on relevant factors at the local, regional and global levels that would allow farmers to optimize management.
(b) Improve capabilities for, and skill in, long term meteorological, hydrological and crop forecasting.
(c) Improve or, if necessary, institute mechanisms for risk spreading.
(d) Develop institutions and methodologies for: (i) evaluating the public health and environmental risks associated with new cultivars and crops, e.g., genetically modified crops (GM), and (ii) science-based decision rules for approval or disapproval of such crops.
(e) Improve systems for timely dissemination of relevant information to users and decision makers (including farmers and others) on agricultural R&D from research institutes, agro-meteorological forecasts, market conditions and signals, and best management practices given existing local environmental conditions.

Collectively, such measures would help reduce current vulnerabilities while allowing farmers to take advantage of any new opportunities that might be created under climate change, something that is frequently overlooked.

The above strategy would provide benefits in the near term, long before climate change itself poses a significant problem for crop production, or if climate changes faster than is anticipated by current impacts studies. Importantly, the above measures can be proactive since they can be implemented now without awaiting either improvements in our current skill in estimating climate change or its specific impacts at any given geographic location.

For developing country farmers, the challenge is to provide productivity-enhancing technologies that are relatively cheap and easy to use. Arguably, many of the above measures have a greater likelihood of success and can be brought to fruition quicker if genetic modification is employed (Ruse and Castle 2002). In particular, by packaging technology within the seed (Wambugu 1999), GM crops can help bring many benefits of precision agriculture to developing country farmers (e.g., lower inputs of water, fertilizers and pesticides) without requiring costly monitoring systems or highly skilled human capital. However, in view of potential problems associated with GM crops, in accordance with the precautionary principle their introduction should be based on a case-by-case, location-specific evaluation of risks, costs and benefits (Goklany 2001b).

4.3 Relationship to Article 2 of the framework convention

The strategy (and measures) outlined above to increase food productivity would explicitly advance the UNFCCC's ultimate objective specified in its Article 2. First, they would reduce emissions. Second, by limiting habitat loss, they would also limit loss of wildlife corridors and fragmentation of habitat. And if anything can aid ''ecosystems to adapt more naturally to climate change'', it would be limiting habitat fragmentation and conserving corridors (Goklany 2000, 2003). That would help species migrate and disperse, with less need for human intervention. Third, the above strategy would reduce threats to food production. Finally, they would also contribute to sustainable economic development, particularly in developing nations whose economies usually rely more upon agriculture (see Table 4).

The strategy and measures outlined above for enhancing food and agricultural productivity are generically applicable to forestry. However, for brevity's sake, I will not elaborate any further (see IPCC 1991; and Sect. 5).

5 Toward a portfolio integrating mitigation, adaptation and sustainable development

The foregoing identified strategies (and measures) to simultaneously advance sustainable development, adaptation and mitigation, whereas this section identifies a portfolio of measures that would address climate change while efficiently advancing sustainable development. Some measures would focus on adaptation, others on mitigation, and yet others on climate-sensitive hurdles to sustainable development that could be worsened by climate change.

Dang et al. (2003), based on Fankhauser (1998), offer a method of identifying mitigation and adaptation measures that would most efficiently reduce residual damage from climate change, which consists of minimizing the following function:

$$\mathrm{MC}(\mu) + \mathrm{AC}(\alpha) + D(\mu, \alpha) \qquad (1)$$

where MC, AC and D are mitigation costs, adaptation costs, and residual damage, respectively, and are functions of mitigation (μ) and adaptation (α) actions, respectively.

The objective under this formulation is to reduce damages at least cost (with both costs and damages defined broadly to include monetized as well as non-monetized factors, and taking discounting into consideration). In particular, the expression suggests that the first measures to be implemented should be the ones that reduce a unit of residual damages at the least cost. Contrary to sentiments sometimes expressed in the literature that ''reducing GHG emissions must be emphasized as the first choice of actions to achieve the 'ultimate objective' of the UNFCCC'' (Dang et al. 2003), this expression provides no a priori reason to believe that these first measures would or should necessarily be adaptations or mitigations. Arguably, it is such sentiments that have kept the study of adaptation in the shadows.

Dang et al. (2003), for instance, justify giving primacy to mitigation by appealing to the precautionary principle. However, an alternative argument could be made that although the principle might justify mitigation in the medium-to-long term, in the short term resources that could be dedicated to mitigation might be more gainfully used to reduce current vulnerabilities to climate-sensitive risks. In that case, it would be more precautionary at this time to go with the latter option (Goklany 2000, 2001b, 2003), particularly if it provides some mitigation, as we have seen is possible. Table 3 suggests that the alternative argument is plausible since, in many cases, the risks associated with unmitigated climate change are for the next few decades smaller than corresponding risks in the absence of climate change, i.e., P(UCC,t) < P(REF,t).[17] This, however, does not preclude the need for mitigation in the longer term, or as an insurance measure in the near term (see below).

To help evaluate these arguments, and to account for the fact that climate change issues are intertwined with others, an additional term (or terms) should be introduced into the above expression. Specifically, I propose an additional term to account for the impacts of, and responses to, climate change that will spill over into issues of sustainable development that are also climate-sensitive. Accordingly, to keep track of these spillovers, the above expression should be modified to include the costs (denoted by SDC) of actions (represented by σ) to advance sustainable development that would also reduce climate-sensitive risks.

The rationale behind using SDC is that actions σ would also reduce vulnerability to climate change, i.e., σ would reduce both P(REF,t) and P(UCC,t). They might also directly lead to some mitigation (Sects. 3 and 4). Moreover, in order to maximize welfare, it makes little sense to reduce the damages of climate change by one unit if an equivalent reduction in damages could be obtained at lesser cost through other means. This would be consistent with the UNFCCC's admonition in Article 3.3 ''that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost.''

Consider, for example, malaria, which annually strikes over 300 million and kills over a million people, mainly children in Sub-Saharan Africa. For the remainder of this century, the contribution of climate change to malaria is projected to be minor relative to the contribution of non-climate change related factors, i.e., P(UCC,t) < P(REF,t) (see Table 3). The WHO (1999) estimates that the current death toll due to malaria can be halved at an annual cost of \$1.25 billion, or less. Consider, however, the efficacy of the Kyoto Protocol[18] with respect to malaria (see Table 3). Assuming malaria deaths scale with P, then the Protocol would reduce malaria deaths by 0.25% by 2085 at an estimated cost of between \$25 billion and \$250 billion per year (in 2010, assuming full participation in the Protocol and full trading; IPCC 2001a). Thus, human well-being would be advanced further over the next few decades if, instead of diverting resources toward mitigation, current vulnerabilities to malaria were reduced.[19] That would also help societies cope with malaria in the future, whether or not it is caused by climate change. Moreover, diverting significant resources toward mitigation could exacerbate an already inequitable situation, with inhabitants of developing countries continuing to fall victim to malaria in disproportionately high numbers (Tol and Dowlatabadi 2001).

However, the above analysis does not account for the other benefits that would be associated with mitigation (such as reduced pressures on biodiversity and, per Table 3, water quantity, coastal flooding and hunger, or its value as insurance against threshold events), but neither does it account for the co-benefits of halving malaria in developing countries, such as the increase in economic development, with all its associated benefits for sustainable development and human welfare (see, e.g., HUCID/LSHTM 2000, and Sect. 2).

Also, the analysis does not consider other opportunities that might provide equivalent or greater benefit at the same or lesser costs. The additional cost of meeting the Millennium Development Goals (MDGs) by 2015 has, for example, been estimated at between \$40–60

[17] Coastal flooding is, however, an exception, but see Goklany (2003)

[18] Since the Protocol is an initial step in mitigation, it should have a larger risk-reduction-to-cost ratio than other more ambitious mitigation regimes with the same target dates (assuming full trading and no threshold effects).

[19] This argument is valid even if WHO's estimates are too rosy by an order of magnitude.

billion per year (World Bank 2002b),[20] at the lower end of the range estimated for the Kyoto Protocol. But the MDGs would, in general, provide much deeper and broader improvements in environmental and human well-being than would the Protocol, partly because MDGs would reduce both P(REF,t) and P(UCC,t). Regarding hunger, for instance, the MDG goal is halving hunger by 2015. Even total elimination of future climate change would, however, have a lesser effect on global hunger over the next few decades (Goklany 2003) (see Table 3). In addition, the MDGs also include halving poverty and the proportion of the population without access to potable water; reducing child and maternal mortality rates by two-thirds or more; and combating HIV/AIDS, malaria and tuberculosis. No less important, per Sect. 2, progress toward MDGs would enhance M&A capacities.

Another issue that must be considered is that with the passage of time, P(UCC,t) should sooner or later exceed P(REF,t). Therefore, in the long term, mitigation would be warranted. Nevertheless, comparing (a) the cost of reducing existing problems associated with the lack of sustainable development and (b) the magnitude of reductions that are possible via implementation of the MDGs, in the next few decades the emphasis should probably be on reducing these existing problems (i.e., because they are here-and-now, and larger; Goklany 2003). This, of course, begs the question: when should mitigation efforts be brought on line, and how deep should the reductions be?

While fuller discussion of this issue lies outside this paper's scope, the above discussion emphasizes that expression (1) should account for both the costs and reductions in residual damages associated with actions that would, in advancing sustainable development, also reduce vulnerability to climate-sensitive risks or limit climate change.

Accordingly, the residual damage term [$D(\mu, \alpha, \sigma)$] should include damages reduced by actions μ, α and σ. Thus the function to be minimized should be reformulated as,

$$\mathrm{MC}(\mu) + \mathrm{AC}(\alpha) + \mathrm{SDC}(\sigma) + D(\mu, \alpha, \sigma) \tag{2}$$

Note that D should account for the co-benefits of mitigation and adaptation actions, as well as the reductions in damages associated with actions to reduce climate-sensitive hurdles to sustainable development, whose cost is denoted by SDC.

In light of the foregoing, this expression suggests a number of broad strategies that could be used to construct a wide portfolio of actions and measures to launch a coordinated attack on the interlinked problems of mitigation and adaptation to climate change, and climate-sensitive hurdles to sustainable development. Some of these actions and measures, grouped by broad strategies, are listed below. The list, however, is not comprehensive. Note that there is overlap between the strategies offered in previous sections and the following list. To avoid repetition, measures that meet the objectives of multiple strategies are listed only once.

1. Attack today's urgent public health and environmental problems that might be aggravated by climate change (Goklany 2000, 2003).
   (a) Take aggressive action now to reduce malaria and other climate-sensitive diseases. This would pay large dividends in both the short and long term (Table 3; Goklany 2000, 2003).
   (b) Similarly, take aggressive action now to reduce the prevalence of hunger and malnutrition (see Sect. 4).

[20] World Bank (2002b) proposes that the additional sums come from foreign aid.

   (c) Increase, in a sustainable manner, the productivity and efficiency of agriculture, forestry, fisheries and human activities that place a demand on land and water in order to satisfy human needs for food, clothing, shelter, paper and other material goods. This strategy—a generalization of that proposed in Sect. 4—would produce more usable food and other products per unit of land and water, reducing diversions of land and water, which are the major threats to forests, habitat, and terrestrial and freshwater biodiversity. Reducing water diversions would also relieve water shortages under the reference case and under conditions of climate change.
   (d) Improve our ability to forecast and pinpoint extreme weather events, thereby helping save lives and property.
   (e) Develop institutions for treating and managing land, water and fisheries as economic resources (e.g., develop secure and transferable property rights). Table 5 identifies a sample of actions consistent with strategies 1(a)–(d), and some of their associated climate change related benefits and co-benefits.
2. Solve today's urgent problems that would, incidentally, also reduce atmospheric concentrations of greenhouse gases.
   (a) Stimulate the environmentally sound development of energy sources that rely on low- or no-carbon fuels.
   (b) Stimulate no-regret energy and land conservation measures in all sectors.
   (c) Reduce, if not eliminate, unjustified subsidies which lead to overuse of natural resources such as land, water and energy. This would reduce both GHG emissions and pressures on terrestrial and freshwater biodiversity.
   (d) Intensify R&D and dissemination of agricultural technologies that would reduce soil erosion or reliance on fertilizers (see Sect. 4).
3. Address the root cause of the vulnerability of developing nations to climate change and to other sources of adversity, including hunger, malnutrition, and climate-sensitive infectious and parasitic diseases, which are recognized concerns regarding climate change (Goklany 1995). Developing nations are generally deemed to be the most vulnerable to climate change (and other forms of adversity) largely because they lack adaptive capacity (IPCC 2001a). In particular, they lack economic resources and human capital needed to implement technologies to cope with climate change. As noted in Sect. 2, this can be remedied by ensuring sustainable development. In general, this requires:
   (a) Strengthening or, where appropriate, developing the institutions underpinning the mutually reinforcing forces of economic growth, technological change and trade, e.g., free markets, secure property rights, and honest and predictable bureaucracies and governments (see Table 2). They also include institutions to analyze and evaluate the social, economic and environmental risks and benefits associated with new or improved technologies.
   (b) Improving and/or strengthening the infrastructure and communications networks to facilitate efficient movement of goods, materials, knowledge and ideas.
   (c) Pursuing freer and undistorted trade. This would help boost economic growth and disseminate technology (including knowledge and ideas) worldwide, which gives societies access to technologies invented or improved elsewhere—imagine how much technology would be available if each society had to invent the wheel for itself (not to mention vaccines, computers, spreadsheets, and so forth). Moreover, voluntary movement of food and other goods from surplus to deficit areas would alleviate shifts in competitive advantage caused by warming, or any other factor.

Table 5 A sample of integrated strategies and measures, and their benefits and co-benefits

	Strategy	Improve health	Increase agricultural productivity	Reduce hunger	Reduce air & water pollutant loadings	Reduce biodiversity loss	Increase economic growth[a]	Improve human capital[a]	Advance GHG mitigation
1(a)	Reduce current vulnerabilities to climate-sensitive diseases (CSDs)	Y	Y	Y			Y	Y	Y
	Develop and improve methods to prevent and treat malaria & other CSDs Support the malaria component of Global Program to Combat AIDS, Malaria and TB Improve systems and methods to track incidence and spread of disease	Better health increases productivity in all spheres of endeavor	More productive farm labor increases productivity & growth of the agricultural sector	More productive ag sector helps reduce hunger			More productive labor spurs economic growth	Better health helps develop human capital more fully	Reduced child mortality helps reduce birth rate
1(b)–(d)	Increase productivity of the food and agricultural sector	Y	Y	Y	Y	Y	Y	Y	Y
	R&D to improve crops for growth in poor soil and climatic conditions Improve capabilities for longer term meteorological forecasting Improve systems for timely dissemination of information on weather, crops, farming practices via extension services, etc.	Decline in hunger improves health	Increases food production	Reduces hunger		Reduces human pressures for land & water use	Growth spurred by better health due to less hunger, and greater agricultural productivity	Better health helps develop human capital	1. Reduced child mortality helps reduce birth rate 2. Reduced need for cropland reduces CO_2 emissions and increases sink opportunities

Table 5 continued

	Strategy	Improve health	Increase agricultural productivity	Reduce hunger	Reduce air & water pollutant loadings	Reduce biodiversity loss	Increase economic growth[a]	Improve human capital[a]	Advance GHG mitigation
	Develop crops with reduced needs for costly or environmentally unsound inputs Develop crops/practices to extend shelf life, reduce spoilage and wastage, and increase utilization of harvested crops	Decline in hunger improves health Reduces exposure to pesticides	Increases food production	Reduces hunger	Reduces pollutant loadings in soil, air & water	Reduces human pressures for land & water use	Growth spurred by better health due to less hunger, and greater agricultural productivity	Better health helps develop human capital	1. Reduced child mortality helps reduce birth rate 2. Reduced need for cropland reduces CO_2 emissions and increases sink opportunities 3. Reduces N_2O emissions
	Develop crops/practices with lower soil erosion potential		Maintains long term productivity		Reduces pollutant loadings in soil, air & water	Reduces human pressures for land & water use			Reduces CO2 emissions
1(c)–(d)	Increase forest productivity	Y	Y	Y	Y	Y	Y	Y	Y
	R&D to improve forest crops for growth in poor soil and climatic conditions					Reduces pressures for land & water use	Improved growth		
	Improve capabilities for longer term meteorological forecasting								
	Improve systems for timely dissemination of information on weather, crops, farming and forestry practices via extension services, etc.								

Table 5 continued

Strategy	Improve health	Increase agricultural productivity	Reduce hunger	Reduce air & water pollutant loadings	Reduce biodiversity loss	Increase economic growth[a]	Improve human capital[a]	Advance GHG mitigation
Develop crops with reduced needs for costly or environmentally unsound inputs				Reduces pollutant loadings in soil, air & water	Reduces threats to biodiversity	Improved growth		
Develop crops/practices to extend shelf life, reduce wastage, and increase utilization of harvested wood and crops								
Develop crops/practices with lower soil erosion potential				Reduces pollutant loadings in soil, air & water	Reduces threats to biodiversity			

[a] Enhances M&A capacities

(d) Reducing unnecessary subsidies, which can be detrimental to both economic development and technological change.[21] In particular, subsidies for food and agriculture in many OECD nations are not only expensive for the latter, they damage the economies and well-being of many developing nations whose economies and employment are dominated by the agricultural sector (see Table 4) (Watkins and von Braun 2003; Díaz-Bonilla and Gulati 2003; Diao et al. 2003; Oxfam 2004). Subsidies, moreover, by distorting market signals can lead to maladaptation (e.g., overuse of marginal lands, chemical inputs, and water). Thus, reducing subsidies would facilitate both adaptation and mitigation. Efforts to reduce such subsidies at the World Trade Organization show that this task is extremely difficult and slow; full success is not guaranteed.

(e) Implementing the MDGs. As discussed in Sect. 2, such efforts would, by increasing economic growth, improve human well-being and many aspects of environmental quality, particularly in developing nations. It would also increase their ability to develop, improve, obtain and implement mitigation and adaptation technologies that probably would be more appropriate for their particular circumstances. Finally, economic development should help mitigate population-related environmental and natural resource problems (including climate change), as well as advance adaptation (see Sect. 3).

4. Continue to undertake R&D into mitigation and adaptation technologies (including institutions and management practices) that would help humanity sustainably meet its future energy and other natural resource needs, and help cope with problems that climate change would exacerbate. Meanwhile, we should continue to improve our understanding of the science, economics and policy implications of climate change and of potential responses to that change at the local, regional and global levels.
5. Strengthen and, where appropriate, develop institutions to collect, monitor and disseminate, in a timely fashion, robust information on climate, climate change, and its impacts to decision makers at all levels (ranging from individuals, communities, to national, regional and international organizations). These institutions should also transfer information developed in the pursuit of the other strategies listed above, including information on the social, environmental and economic consequences of response options, and how to contain those that might be adverse. Similarly, local extension services should be strengthened and/or developed to provide location-specific information and/or advice to decision makers.

6 Misconceptions that could hinder fuller integration

Fuller integration of adaptation and mitigation could be hindered by several commonly held misconceptions regarding the similarities and differences between adaptation and mitigation. Some of these—adaptation is of limited value in reducing threats to biodiversity and natural systems, or mitigation should be the primary focus of climate change responses now (and in the future)—have already been aired to one degree or another. Additional misconceptions include the following.

[21] Reducing subsidies introduces market forces to bear, which then provides greater incentives for researching and developing conservation technologies (e.g., Goklany 1998, 2002a).

First, mitigation anywhere accrues to everyone's benefit (Dang et al. 2003; Huq and Grubb 2003). Mitigation indeed reduces impacts in all sectors and regions but unless the amount of warming is excessive, the impacts of climate change are not necessarily negative in all areas. Thus, mitigation would increase risks in some areas while reducing them in others, at least in the short to medium term before warming becomes excessive. In fact, IPCC (2001c) suggests that below 1–2°C, the global impact of unmitigated climate change could be positive. Thus, in the next few decades there could be losers and winners because of mitigation. And even if every one wins, the magnitude of the prize will vary from population to population (as will the costs of mitigation). Therefore, not every one will receive benefits commensurate with their costs expended on mitigation. On the other hand, it is more likely that with adaptation, the winners from climate change can capitalize on their gains, while losers can reduce their losses. Thus, adaptation should generally leave everyone better off relative to the post-climate change situation, but not necessarily relative to the pre-climate change situation (unless there are maladjustments) (Goklany 2003).

Second, adaptation is generally thought to entail local (and occasionally, regional) benefits and costs (e.g., Huq and Grubb 2003; Wilbanks et al. 2003; Klein et al. 2003). However, to the extent global benefits are associated with preserving biodiversity, reducing threats to biodiversity could provide global benefits. In fact, the preamble to the Convention on Biological Diversity affirms ''that the conservation of biological diversity is a common concern of humankind.'' Similarly, global benefits can result from efforts to reduce or better treat malaria (or other climate-sensitive diseases), or reducing hunger (and associated public health consequences). Moreover, to the extent such adaptation actions further the ''ultimate objective'' of the UNFCC, namely, to allow ecosystems to adapt naturally, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner, those actions can and have been deemed (by the Global Environment Fund 1998, for instance) to provide global environmental benefits (GEF, Operational Strategy, Chapter 2).

Third, mitigation is frequently deemed to require global cooperation, while adaptation requires national or regional cooperation (Dang et al. 2003; Wilbanks et al. 2003). However, there are some adaptations that are best implemented globally through multilateral cooperation. Consider, for instance, reductions in agricultural subsidies. Despite the fact that such subsidies are detrimental to both the economy and the environment of subsidizing countries (as well as to the economies of their trade partners/competitors), they are notoriously difficult to eliminate because of the politics behind the subsidies—which is why they exist in the first place. Since subsidies are part of the arsenal of economic warfare, just as for military weapons, they are best disarmed multilaterally (under the auspices of the World Trade Organization). Similarly, the rules governing another adaptive technique, trade, are best formulated, and policed, multilaterally.

Other adaptive measures which benefit from multilateral cooperation include the continued operation of global observation and monitoring systems (including early warning systems) and the scientific study of climate change, its impacts, and its response strategies, all of which will help formulate adaptive responses.

Fourth, although some acknowledge that adaptation can be proactive if it is based on projected impacts, it is generally deemed to be reactive (Dang et al. 2003). This, however, is based on a narrow view of what constitutes adaptation. Efforts identified in this paper to advance adaptability or to broadly reduce vulnerability to existing problems that might be heightened by climate change have the virtue that neither their design nor effectiveness depends on the location-specific results or details of any impact assessment or projection of climate change, and yet they would prepare societies better cope with the event of climate change, i.e., they are proactive (see also Goklany 1995).

Fifth, adaptation is, by nature, sectoral (Wilbanks et al. 2003; Klein et al. 2003). While this is true in many respects, several adaptation strategies cut across sectors. They include efforts, noted previously, to broadly enhance adaptability, e.g., building up wealth or the ability to develop and use new technologies by, for instance, strengthening systems for education, research and development (Goklany 1995, 2001a). Similarly, reductions in the vulnerability to malaria would improve nutritional status of affected populations, and increase their capacity to participate more fully in education or the labor force. This strategy, therefore, would also provide benefits across several sectors. Other strategies and measures that would have significant climate change related spillover effects in other sectors include many in Sect. 4 that would reduce hunger while providing co-benefits in terms of public health and reduced pressures on biodiversity (Goklany 2000, 2003).

Finally, Dang et al. (2003, p S84) claim that adaptation could be ''unfair'' since those doing the adapting are ''not always responsible for causing climate change.'' But this depends on how one defines responsibility. While it is possible to assign GHG emissions to nations based on where the act of burning a ton of coal, for instance, physically occurs, we should be cognizant that GHG emissions are the effluvia of a globalized economy. Economic activity in one country helps provide livelihoods and incomes for many inhabitants of other countries, and vice versa. In fact, a substantial portion of economic growth in developing countries is attributable to trade (Goklany 1995), and remittances and tourism from developed countries. Without such economic activities, U.S. emissions, for example, might be lower, but so would jobs and incomes elsewhere. Moreover, the benefits of these activities spill over into things like foreign aid, creation and support of the Internet, medicines for HIV/AIDS, and other items now considered by some to be global public goods (ODS 2004). Fairness therefore requires that benefits accruing to second or third parties should be accounted for before one can determine fairness.

There is yet another dimension to the fairness issue. Some analyses indicate that resources expended on mitigation in the short to medium term (i.e. over the next few decades) could be put to better use in reducing current risks and vulnerabilities (Schelling 1995; Dowlatabadi 1997; Goklany 1992, 2000, 2003; Tol and Dowlatabadi 2001).[22] In fact, an adaptive strategy focusing specifically on today's critical climate-sensitive problems that might be worsened by climate change (e.g., malaria and hunger) would provide benefits in both the short and the long term (Goklany 1992, 2000, 2003). On the other hand, the major share of the benefits of mitigation are likely to occur in the longer term (see Table 3). It might, therefore, be more equitable, especially to present generations, to expend resources on such an adaptive strategy now and defer purely mitigation actions for a few years to when they can better pay for themselves,[23] especially since future generations are, according to the IPCC's scenarios, likely to be wealthier, have greater access to technology and human capital, and should, therefore, be able to solve many of their problems with relatively greater ease (see Figs. 1–4, for instance; Goklany 1992, 2000, 2003).[24]

[22] See Sect. 5.

[23] ''Purely'' mitigation actions would be in contrast to actions that would provide a combination of mitigation and adaptation benefits. To the extent such mitigation measures pay for themselves (considering opportunity costs), they should, of course, be implemented. One of the functions of technology research and development is to constantly increase the universe of affordable measures.

[24] This greater access arises because not only the economic and human resources available to society ought to increase but also the cost of technologies should decline, particularly if R&D is focused on making them more cost-effective (Goklany 2001a).

7 Conclusions

There are at least three keys to systematically identifying integrated strategies for mitigating and adapting to climate change that would also further sustainable development. First, many determinants of a society's adaptive capacity also underlie its mitigative capacity (Goklany 1992, 1995, 2000; Smit et al. 2001; Swart et al. 2003). Second, several of these determinants are themselves indicators of sustainable development (ISDs). Third, climate change would exacerbate some of the most urgent problems facing humanity and the environment today, and which are major hurdles to sustainable development. These problems include hunger, infectious and parasitic diseases, water shortage, coastal flooding and threats to biodiversity (Parry et al. 2001; Goklany 2000, 2003). Hence, progress should be possible on all three fronts—adaptive capacity, mitigative capacity, and sustainable development—with a common set of measures (Goklany 1995, 2003; Smit et al 2001).

One integrated approach toward simultaneously addressing these issues would be to broadly advance various ISDs, even if those indicators are not directly sensitive to climate, since that would also enhance M&A capacities. Strategies to accomplish this include:

- Developing and/or nurturing the institutions, policies, processes, and infrastructure that would concurrently enhance economic growth, technological change, and human and social capital, e.g., free markets in commerce and ideas; secure and well-defined rights to tangible and intellectual property; honest, predictable and fiscally responsible governments and bureaucracies; adherence to the rule of law; incentives for people to invest their labor, intellectual capital and financial resources; institutions to ensure freer and fairer trade; and open and well-supported systems for improving and maintaining public health, education and research. Such efforts must necessarily be perpetual since there are no cut-and-dried recipes for advancing these institutions and policies that would fit all societies at all times, given their varied histories and constantly evolving cultural, social, economic and environmental circumstances.
- Taking specific steps, in the short-to-medium term, to improve critical ISDs, e.g., reducing hunger and disease; improving access to safe water, sanitation and basic public health measures; or developing institutions for managing water and fisheries as economic resources such as conferring secure transferable property rights. Consistent with this strategy, actions could be taken to sustainably increase—now and in the future—the productivity and efficiency of agriculture, forestry, fisheries and other human activities that place a demand on land and water. This would produce more usable food, clothes, houses and other materials per unit of land and water, thereby reducing pressures on natural systems and biodiversity, regardless of whether they are caused by ''normal'' climate, climate change, climate variability or non-climate-sensitive factors. It would also conserve carbon sinks and stores.

Importantly, this approach would address the fundamental causes of the vulnerability of developing nations to all forms of adversity, whether or not they are climate-related or climate-change-related, namely, insufficient economic resources and human capital to obtain and use appropriate response technologies to cope with adversity in general. Another co-benefit of this approach is that the pursuit of economic development should reduce birth rates thereby mitigating all manner of population-related environmental and natural resource problems, and reducing population exposure to risks related to those problems, including climate change.

The broad pursuit of sustainable development through adherence to the Millennium Development Goals would be consistent with the above approach. By 2015, the MDGs would, at an additional annual cost of $40–60 billion, at least halve global poverty, hunger, lack of access to safe water and sanitation, child and maternal mortality, and illiteracy, and reverse growth in malaria, AIDS/HIV, and other major diseases. The technologies, practices and institutions needed or devised to meet the MDGs should lower both P(REF,t) and P(UCC,t), i.e., they would address both climate-change- and non-climate-change-related hurdles to sustainable development.

By contrast, mitigation would only address a subset of risks addressed by the MDGs. In particular, the Kyoto Protocol, which is estimated to cost between $25–250 billion per year (in 2010), would, by century's end, reduce P(UCC,t) for most climate change risks by less than 10%[25] while leaving P(REF,t) virtually untouched. Thus, at least for the next several decades, the broad approach outlined above should reduce most climate-sensitive risks by larger amounts and at a lesser cost than the Kyoto Protocol. However, in the longer term, mitigation would be warranted because P(UCC,t) should eventually approach and exceed P(REF,t), and the relative economics of mitigation and adaptation would change. Meantime, it would be prudent to have some mitigation as insurance, particularly if it is associated with no-regret actions or, alternatively, can be obtained concurrently with advances in sustainable development and in M&A capacities.

Instead of a strategy of implementing the MDGs, one could specifically target urgent climate-sensitive problems that currently hinder sustainable development and could be intensified by climate change. While this targeted strategy would address existing problems of malaria and other infectious and parasitic diseases, hunger and malnutrition, water shortage, coastal flooding, extreme weather events, and habitat loss, it would ignore major problems such as access to safe water or sanitation whose relationship to climate change is not well-established, if not tenuous. Therefore, such a targeted strategy would improve overall human well-being by a lesser amount. Nevertheless, it would, in the short-to-medium term, help solve urgent existing climate-sensitive problems, and specifically reduce vulnerabilities to future climate change. For many of these problems, as Table 3 indicates, this particular strategy should, over the next few decades at least, also provide greater benefits (i.e., risk reduction) at lower costs than mitigation-focused strategies. In the near term, the economics of adaptation would look even more favorable if one employs discounting (Goklany 2003).

But the best approach would be to develop a portfolio of strategies and measures some of which would address climate change through mitigation and/or adaptation, others would reduce climate-sensitive hurdles to sustainable development, and yet others would accomplish both, so that, taken together, the portfolio would help reduce the residual impacts of climate-related problems in the most efficient fashion possible (see Eq. 2).

The above approaches and strategies would be consistent with the ''ultimate objective'' of the UN Framework Convention on Climate Change (Article 2) since they would help limit GHG emissions; reduce losses of habitat and conserve migration corridors thereby aiding ''ecosystems to adapt naturally to climate change; ''ensure that food production is not threatened''; and ''enable economic development to proceed in a sustainable manner.'' And, if the level at which GHG concentration becomes ''dangerous'' depends on developing nations' adaptive capacity, this approach could reduce the need for faster or deeper GHG reductions. The potentially inverse relationship between adaptive capacity on one

[25] Coastal flooding, as noted, is an exception to this rule.

hand, and the depth and speed of mitigation on the other, should be an important consideration in developing optimal integrated responses to climate change.

Development of such optimal strategies is, however, hindered by some widely held misconceptions about adaptation which feed arguments that mitigation should be first among equals. Many of these misconceptions—that adaptation is of limited use when it comes to reducing threats to biodiversity and natural systems; that, in contrast to mitigation, adaptation generally provides local or regional benefits rather than global benefits; that adaptation is generally reactive but not proactive—are based on a narrow view of adaptation that downplays, if not ignores, the fact that addressing current climate-sensitive risks would, in addition to providing large near term benefits, also reduce future vulnerabilities to climate change. For instance, as noted, several actions available today would now, and in the event of climate change, concurrently reduce pressures on terrestrial and freshwater biodiversity and the vulnerability to hunger. Such actions, which include measures to sustainably increase the efficiency of agricultural land and water use, would also provide global benefits.

Finally, some regard adaptation as inherently inequitable because, arguably, it might let off the hook those responsible for climate change. But neither is it fair for developed nations to expend resources on mitigation now based partly on the premise that it would reduce future climate change risks for developing nations, when the same resources would, in the short-to-medium term, provide greater and faster benefits to precisely those nations by reducing existing—and generally larger—climate-sensitive risks and vulnerabilities. Thus, while mitigation may be inevitable in the longer term, this suggests that in the short-to-medium term the precautionary principle would be well-served by addressing today those urgent climate-related hurdles to sustainable development that could be aggravated by future climate change, especially if that leads to some near term mitigation, advances M&A capacities, and, further, is complemented by efforts to: (a) implement no-regret mitigation actions, and (b) expand and improve the cost-effectiveness of mitigation options (through greater investments in science and technology) so that in the future, mitigation, if and when it becomes necessary, is more affordable and effective (Goklany 2003).

Appendix A

The following methodology was used to generate the relationships between ISDs, (y), income (x), and time, some of which are plotted in Figs. 1–5. First, with the exception of R&D expenditures, data for y and x were obtained for various countries for two separate years, e.g., for life expectancy, 1960 and 1999 were used (since they were for the most recent and oldest years available in World Bank (2001)). Generally, x used GDP per capita in 1995 US$ at market exchange rates (MXR). For R&D expenditures, x used the gross national income per capita in current US$. Second, the relationship that best fit these data was determined using linear, log-linear, and log-log regression analyses (employing ordinary least squares) per the following equation:

$$F(y) = A + B \cdot \Delta + C \cdot F(x),$$

where $F(y) = y$ for linear and log-linear analyses, and log y for log-log analysis; $F(x) = x$ for linear analysis, or log x for log-linear and log-log analyses; Δ is a dummy variable, 0 for the first year and 1 for the second year; and A, B, and C are constants.

Table A Relationships between various indicators, income and time (or technological change)

Indicator *y*	Data source	Units	Initial year	Final year	Number of data points	Type of regression	R^2	*A*	*B**	*C**
Cereal yield	WB (2001)	kg/ha	1961	1999	246	Linear	0.50	1066.0	806.1	0.1189
Food supplies per capita	WRI (2000), WB (2001)	kcal/day	1961	1997	258	Log-linear	0.65	525.5	240.8	581.30
Malnutrition prevalence	WB (2001)	% of children below 5 years	1987	1998	33	Log-linear	0.47	97.67	−7.916[†]	−22.626
Access to safe water	WB (1999)	% of population	1970	1995	121	Log-linear Tobit	0.63; pseudo R^2, 0.11	−46.057	25.149	29.416
Access to sanitation	WB (1999)	% of population	1985	1995	137	Log-linear Tobit	0.57; pseudo R^2, 0.10	−73.841	9.795[†]	40.976
Infant mortality	WB (2001)	Deaths per 1,000 live births	1960	1999	264	Log-log	0.83	3.636	−0.4225	−0.5554
Life expectancy	WB (2001)	Age in years	1960	1999	264	Log-linear	0.69	9.236	8.5751	14.4865
Health expenditures	WB (2002a)	Current US$ per capita	1990	1998	258	Linear	0.89	−67.336	72.473[†]	0.06917
R&D expenditures[§]	WB (2002a)	% of GNI	1997		46	Linear	0.55	0.4956		0.000057
Enrollment in tertiary schools	WB (1999)	% of relevant population	1965	1996	219	Log-log	0.68	−2.149	0.6152	0.7873
Total fertility rate	WB (2002a)	Births per woman of child bearing age	1960	2000	270	Log-linear	0.67	11.027	−1.921	1.8004

* $P < 0.01$, unless otherwise noted; † $P < 0.05$; NS, $P > 0.05$; § R&D expenditure is regressed against gross national income (GNI) per capita (in current US dollars)

The equation that explained the greatest amount of the variation in $F(y)$ was selected as the best-fit equation (see Table A). In each case, the slope (C) had p-values < 0.05. Similarly, B, the displacement of the curve from the first year to the second, had p-values < 0.05 (except for R&D expenditures, since that only used 1 year's worth of data).

For indicators for which theoretical upper or lower limits (e.g., malnutrition and access to safe water and sanitation) had been reached, best fit lines were generated, where appropriate, using a Tobit regression model. In these cases, R^2 shown are for the normal (non-Tobit) model. The pseudo R^2 for the Tobit model are also shown. The values of A, B and C are for the latter model.

References

Arnell NW (1999) Climate change and water resources. Glob Environ Change 9:S31–S49

Arnell NW, Cannell MGR, Hulme M, Kovats RS, Mitchell JFB, Nicholls RJ, Parry ML, Livermore MTJ, White A (2002) The consequences of CO_2 stabilization for the impacts of climate change. Clim Change 53:413–446

Ausubel JH (1991) Does climate still matter? Nature 350:649–652

Barro RJ (1997) The determinants of economic growth: A cross-country empirical study. MIT Press, Cambridge, MA

Bloom BR (1999) The future of public health. Nature 402(Suppl):C63–C64

Cassman E, Dowlatabadi H (2002) The contextual determinants of malaria. RFF Press, Washington

Caulfield LE, de Onis M, Blossner M, Black RE (2004) Undernutrition as an underlying cause of child deaths associated with diarrhea, pneumonia, malaria, and measles. Am J Clin Nutr 79:1323

Dang HH, Michaelowa A, Tuan DD (2003) Synergy of adaptation and mitigation strategies in the context of sustainable development: the case of Vietnam. Climate Policy 3S1:S81–S96

Diao X, Diaz-Bonilla E, Robinson S (2003) How much does it hurt? The impact of agricultural trade policies on developing countries. International Food Policy Research Institute (IFPRI), Washington

Díaz-Bonilla E, Gulati A (2003) Developing countries and the WTO negotiations. 2002–2003 IFPRI annual report essay. IFPRI, Washington

Dollar D, Kraay A (2000) Growth is good for the poor. Development Research Group, World Bank, Washington

Dowlatabadi H (1997) Assessing the health impacts of climate change. Clim Change 35:137–144

Easterlin RA (1996) Growth triumphant: the twenty-first century in historical perspective. University of Michigan Press, Ann Arbor

Easterly WR (2001) The elusive quest for growth: economists' adventures and misadventures in the tropics. MIT Press, Cambridge, MA

Estabrook B (2002) Staying alive. Wildl Conserv 105:36–41

Fankhauser S (1998) The costs of adapting to climate change. Global Environment Facility, Washington

Fogel RW (1995) The contribution of improved nutrition to the decline of mortality rates in Europe and America. In: Simon JL (ed) The state of humanity. Blackwell, Cambridge, MA, pp 61–71

Frankel JA, Romer D (1999) Does trade cause growth? Am Econ Rev 89:379–399

Future Harvest/ World Conservation Union (IUCN) (2002) Agriculture and biodiversity can survive and thrive together. Available at http://www.futureharvest.org/pdf/ecoagriculture.pdf, visited June 5, 2004

Global Environment Fund (1998) Operational strategy, Chapter 2. Available at http://www.gefweb.org/Operational_Policies/Operational_Strategy/op_stat/op_stat.html, visited June 1, 2004

Goklany IM (1988) Climate change effects on fish, wildlife and other DOI programs. Proceedings: Second North American conference on preparing for climate change, Washington, Climate Institute

Goklany IM (1992) Adaptation and climate change. Paper presented at the annual meeting of the American association for the advancement of science, Chicago, February 6–11

Goklany IM (1995) Strategies to enhance adaptability: technological change, economic growth and free trade. Clim Change 30:427–449

Goklany IM (1998) Saving habitat and conserving biodiversity on a crowded planet. BioScience 48:941–953

Goklany IM (2000) Potential consequences of increasing atmospheric CO_2 concentration compared to other environmental problems. Technology 7S:189–213

Goklany IM (2001a) Economic growth and the state of humanity. Political Economy Research Center, Bozeman, MT

Goklany IM (2001b) The precautionary principle: a critical appraisal of environmental risk assessment. Cato Institute, Washington
Goklany IM (2002a) Comparing 20th century trends in U.S. and global agricultural land and water use. Water Int 27:321–329
Goklany IM (2002b) Affluence, technology and well-being. Case West Reserve Law Rev 53:369–390
Goklany IM (2003) Relative contributions of global warming to various climate sensitive risks, and their implications for adaptation and mitigation. Energy Environ 14:797–822
Gwartney J, Holcombe R, Lawson R (1998) The scope of government and the wealth of nations. Cato J 18:163–90
Gwartney J, Lawson R, Park W, Skipton C (2001) Economic freedom of the world: annual report 2001. Fraser Institute, Vancouver, BC
Harvard University Center for International Development and London School of Hygiene and Tropical Medicine (HUCID/LSHTM) (2000) Economics of malaria, Executive summary, on file with author
Huq S, Grubb M (2003) Scientific assessment of the inter-relationships of mitigation and adaptation. Available at http://www.ipcc.ch/activity/cct2a.pdf, visited June 1, 2004
Intergovernmental Panel on Climate Change (IPCC) (1991) IPCC response strategies, IPCC Work Group III Report. Island Press, Washington
IPCC (2001a) Synthesis report. Cambridge University Press, New York
IPCC (2001b) Special report on emissions scenarios. Cambridge University Press, New York
IPCC (2001c) Climate change 2001: impacts, adaptation, and vulnerability. Cambridge University Press, New York
Kane S, Shogren J (2000) Linking adaptation and mitigation in climate change policy. Clim Change 45:75–102
Klein RJT, Schipper EL, Dessai S (2003) Integrating mitigation and adaptation into climate and development policy: three research questions. Tyndall Centre for Climate Change Research Working Paper 40
Lanza, R.P., Dresser BL, Damian P (2000) Cloning Noah's Ark. Scientific American
Office of Development Studies (2004) Global public goods 'A highly-rewarding investment', Briefing Note 3, UNDP. Available at http://www.undp.org/globalpublicgoods/globalization/background.html, visited June 24, 2004
Oxfam International (2004) Dumping on the world: how EU sugar policies hurt poor countries. Oxfam, Washington
McNeely J, Scherr SA (2002) Ecoagriculture: strategies to feed the world and save biodiversity. Island Press, Washington
Mokyr J (1990) The lever of riches: technological creativity and economic progress. Oxford University Press, New York
Norton SW (1998) Poverty, property rights, human well-being: a cross-national study. Cato J 18:233–245
Parry M, Arnell N, Hulme M, Nicholls R, Livermore M (1998) Adapting to the inevitable. Nature 395:741
Parry ML, Arnell N, McMichael T, Nicholls R, Martens P, Kovats S, Livermore M, Rosenzweig C, Iglesia A, Fischer G (2001) Viewpoint. Millions at risk: defining critical climate change threats and targets. Glob Environ Change 11:181–183
Parry ML, Rosenzweig C, Iglesias I, Livermore M, Fischer G (2004) Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Glob Environ Change 14:53–67
Ruse M, Castle D (eds) (2002) Genetically modified foods: debating biotechnology. Prometheus Books, Amherst, NY
Schelling TC (1995) Intergenerational discounting. Energy Policy 23:395–401
Smit B, Pilifosova O, Burton I, Challenger B, Huq S, Klein RJT, Yohe G, Adger N, Downing T, Harvey E (2001) Adaptation to climate change in the context of sustainable development and equity. In: McCarthy JJ et al (eds) Climate change 2001: impacts, adaptation and vulnerability. Cambridge University Press, Cambridge, pp 877–912
Smith JB (1997) Setting priorities for adaptation to climate change. Glob Environ Change 7:39–55
Swart R, Robinson J, Cohen S (2003) Climate change and sustainable development: expanding the options. Climate Policy 3S1:S19–S40
Tol RSJ, Dowlatabadi H (2001) Vector borne diseases, development & climate change. Integr Assess 2:173–181
Waggoner PE (1994) How much land can ten billion people spare for nature? Council for Agricultural Science and Technology, Ames, IA
Waggoner PE, Ausubel JH, Wernick IK (1996) Lightening the tread of population on the land: American examples. Popul Dev Rev 22:531–545
Wambugu F (1999) Why Africa needs biotech. Nature 400:15–16

Watkins K, von Braun J (2003) Time to stop dumping on the world's poor. 2002–2003 IFPRI annual report essay, Washington, IFPRI
Wilbanks TJ, Kane SM, Leiby PN, Perlack RD, Settle C, Shogren JF, Smith JB (2003) Possible responses to global climate change: integrating mitigation and adaptation. Environment 45:28–38
World Bank (1993) World development report 1993. World Bank, Washington
World Bank (1999) World development indicators 1999. World Bank, Washington
World Bank (2001) World development indicators 2001. World Bank, Washington
World Bank (2002a) World development indicators 2002. World Bank, Washington
World Bank (2002b) The costs of attaining the millennium development goals. Available at http://www.worldbank.org/html/extdr/mdgassessment.pdf, visited June 25, 2004
World Bank (2004) World development indicators 2004. World Bank, Washington
World Health Organization (WHO) (1999) World health report 1999. WHO, Geneva
World Resources Institute (WRI) (2000) World resources 2000–2001. WRI, Washington
Yamey G (2004) Roll back malaria: a failing global health campaign. Br Med J 328:1086–1087
Yohe G (2001) Mitigative capacity: the mirror image of adaptive capacity on the emissions side. Clim Change 49:247–262