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V. POPULATION AND THE ENVIRONMENT: THE VITAL LINKAGES*

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A. ENVIRONMENT AND SUSTAINABLE DEVELOPMENT

As is now widely recognized,[1] economic growth is far from coextensive with sustainable development. Much of the economic growth in the recent past is clearly not sustainable, primarily because of environmental degradation. This situation alters the development outlook profoundly. It may well turn out that past economic advancement has been achieved at a cost to future capacity to supply still more advancement—and even at the more serious cost of an actual decline in human welfare. Indeed, it seems that much economic progress has been achieved through technological innovations that will prove to have been no more than temporary "fixes", merely deferring the day when the accumulated though concealed costs will have to be paid in full.

Consider the case of Green Revolution agriculture, which made it possible for growth in grain production to keep ahead of growth in human numbers throughout the period 1950-1984. There appear to have been certain covert costs, notably in the form of overloading of croplands leading to soil erosion, depletion of natural nutrients and salinization in the case of irrigated areas—these being costs that derived in part from the imperative to produce ever more food for ever more people. Although unnoticed or disregarded for decades, these costs are currently levying a price in terms of cropland productivity. Soil erosion leads to an annual loss in grain output that is roughly estimated at 9 million tons; salinization and waterlogging of irrigated lands, 1 million tons; and a combination of loss of soil organic matter (through burning of livestock manure and crop residues for fuel), shortening of shifting-cultivator cycle and soil compaction, 2 million tons. In addition to this problem, there are various types of damage to the crops themselves: air pollution worth 1 million tons of grain output forgone output forgone each year; flooding, acid rain and increased ultraviolet radiation, another 1 million tons. The total from all these forms of environmental degradation is 14 million tons (Brown, and others, 1990).

This total is to be compared with gains from increased investments in irrigation, fertilizer and other agronomic input worth 29 million tons per annum. Thus, environmental factors are currently causing the loss of almost half of all gains from technology-based advances in agriculture. This is a loss that can all the less be afforded because an additional 28 million tons of grain are needed each year just to cater for the needs of population growth (let alone the demands of enhanced diets). While the net gain in grain output is rather less than 1 per cent per annum, population growth is 1.8 per cent worldwide and 2.1 per cent in developing countries (Brown and others, 1990).

B. CRITICAL LINKAGES

There are several linkages at work between environment and population. Four principal components can be identified: *P*, population itself; *I*, environmental impact; *A*, per capita consumption (determined by income and lifestyle); and *T*, environmentally harmful technology that supplies *A*. The three factors *P*, *A* and *T* interact in multiplicative fashion, i.e., they compound one other's impacts. Thus, whatever the size of *A* and *T*, the role of *P* is bound to be significant even when a population and also its growth rate, are relatively small. For any type of technology, for any given level of consumption or waste and for any given level of poverty or inequality, the more people there are, the greater is the overall impact on the environment. Therefore, the processes involved can be represented in the form of a basic equation, $I = PAT$ (Ehrlich and Ehrlich, 1990).

This basic equation demonstrates why developing countries, with large populations but limited economic advancement, can generate a vast impact on the environment if only because the *P* multiplier on the *A* and *T* factors is so large. Likewise the equation makes clear that developed countries also generate population impacts in so far as the *A* and *T* multipliers for each person are exceptionally large (Ehrlich and Ehrlich, 1990).

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1. Medio ambiente
desarrollo sustentable

To illustrate how the equation interactions work, suppose that, by dint of exceptional effort, humankind managed to reduce the average per capita consumption of environmental resources, (*A* in the equation, by 5 per cent; and to improve its technologies, *T*, so that they caused 5 per cent less environmental injury, on average. This would reduce the total impact, *I*, of humanity by roughly 10 per cent. But unless global population growth, *P*, were restrained at the same time, it would bring the total impact back to the previous level within less than six years (Ehrlich and Ehrlich, 1990).

C. CARRYING CAPACITY

This point brings the discussions to the concept of carrying capacity—a critical and controversial issue. Certain observers (often ecologists) tend to assert not only that it is a key constraint to population growth but that it can readily become an absolute factor. Other observers (often economists) tend to assert that it is such a flexible affair, subject to endless expansion through technology and policy interventions, that it soon ceases to have much operational value.

Carrying capacity can be defined as the number of people that the earth can support without irreversibly reducing its capacity to support populations in the future (Ehrlich and others, 1989). Although this is a global-level definition, it also applies at the national level albeit with many qualifications as concerns international relationships of trade, investment etc. In fact, it is a highly complex affair, reflecting food and energy supplies, ecosystem services, human capital, people's lifestyles, cultural constraints, social institutions, political structures and, above all, public policies, among many other factors, all of which interact with one another. Particularly important are two points: carrying capacity is ultimately determined by the component that yields the lowest carrying capacity; and human communities must learn to live off the "interest" of environmental resources rather than off their "principle" (Ehrlich and others, 1989).[2]

There is evidence that human numbers with their consumption of resources, plus the technologies deployed to supply that consumption, already often exceed carrying capacity. In many parts of the world, the three principal and essential stocks of renewable resources, forests, grasslands and fisheries, are being utilized faster than their rate of natural replenishment (Brown and others, 1990).

Consider food production again, this time as a basic issue of the world's carrying capacity. According to the World Hunger Project (Chen and others, 1990), the planetary ecosystem could—with current agrotechnologies, vegetarian diets worldwide, equal distribution of food supplies and all agricultural lands given over to food production (i.e., no coffee, cotton, rubber etc.)—support 5.5 billion people (the early 1992 global population is already 5.4 billion). If they derived 15 per cent of their calories from animal products, as do many people in South America, the total would decline to 3.7 billion. If they obtained 25 per cent of their calories from animal protein, as is the case with most people in Western Europe and Northern America, the world could support only 2.8 billion people.

True, these calculations reflect no more than modern food production technologies. Certain observers (Simon, 1990) protest that such an analysis underestimates the scope for technological expertise to continue expanding the earth's carrying capacity. One can reasonably hope, so the argument goes, that many advances in agrotechnologies will continue to become available. But consider the population/food record over the past four decades. From 1950 to 1984, and thanks largely to remarkable advances in Green Revolution agriculture, there was a 2.6-fold increase in world grain output. That achievement, representing an average increase of almost 3 per cent per annum, raised per capita production by more than one third. From 1985 to 1989, however, there was almost no increase, even though the period saw farmers investing billions of dollars to increase output (fertilizer use alone expanded by 14 per cent), supported by the incentive of rising grain prices and by the restoration to production of idled cropland in the United States. Crop yields "plateaued"; it appeared that plant breeders and agronomists had exhausted the scope for technological innovation. So the 1989 harvest was hardly any higher than that of 1984. Meantime there were an extra 440 million people to feed. While world population increased by almost 8.5 per cent, grain output per capita declined by nearly 7 per cent (Brown and others, 1990).

D. ENVIRONMENTAL DISCONTINUITIES

One sees, then, that growth in human numbers, in conjunction with growth in human consumption and growth in environmentally adverse technology (the *I*

= *PAT* equation), can build up a situation that eventually generates an "overshoot" outcome. In turn, this outcome can precipitate a downturn in the capacity of environmental resources to sustain human communities at their former level, which amounts to a macrolevel change. Designated by ecologists as a "jump effect" of environmental discontinuity, or a threshold effect of irreversible injury, it occurs when ecosystems have absorbed stresses over long periods without much outward sign of damage and then eventually reach a disruption level at which the cumulative consequences of stress appear in critical proportions. One can well anticipate that as human communities continue to expand in numbers, they will exert increasing pressures on ecosystems and natural resource stocks, whereupon environmental discontinuities will surely become more common.

An example has arisen in the Philippines, where the agricultural frontier closed in the lowlands during the 1970s. As a result, multitudes of landless people began to migrate into the uplands, leading to a build-up of human numbers at a rate far greater than that of national population growth. The uplands contain the main remaining stocks of forests in the Philippines, and they feature much sloping land. The result has been a marked increase in deforestation and a rapid spread of soil erosion (Cruz, Zosa-Feranil and Goce, 1988; Myers 1988). In other words, there has occurred a "breakpoint" in patterns of human settlement and environmental degradation. As long as the lowlands were less than fully occupied, it made little difference to the uplands whether there was a lot or a little of lowland space. It was only when scarcely any space remained that the situation altered radically. What had appeared to be acceptable became critical—and the profound shift occurred in a very short space of time.

Similarly, in Costa Rica, agricultural expansion reached both oceans and both frontiers during the 1980s. For the first time in 400 years of their history, Costa Ricans (currently increasing in numbers at 2.5 per cent per annum) have no ready access to new land. Their predominantly agrarian society is having to adjust to a sudden change from land abundance to land scarcity (Augelli, 1984).

This problem of agricultural land shortages is becoming widespread in many if not most developing countries, where land provides the livelihood for an average of almost 60 per cent of the populations and where the great bulk of the most fertile and accessible land has already been taken. During the 1970s, arable areas were expanding at roughly 0.5 per cent per annum. But during the 1980s the rate dropped to half that level; and primarily because of population growth, the amount of per capita arable land declined by 1.9 per cent per annum (Sadik, 1990). Moreover, as far back as 1975 some 25 million square kilometres of lands already supported 1.2 billion people, yet only 563 million of them could be sustainably fed with the low-technology farming methods generally practised. Most of these lands were in semi-arid or montane zones, unusually susceptible to soil erosion and depletion of water systems among other forms of environmental decline; and the population overloading served to aggravate the pace of land degradation (Higgins and others, 1982).

Consider, too, an instance where a potentially renewable resource suddenly becomes overwhelmed by rapid population growth. Most people in the developing world derive their energy from fuelwood. As long as the number of wood collectors does not exceed the capacity of the tree stock to replenish itself through regrowth, the local community can exploit the resource indefinitely. They may keep on increasing in numbers for decades, indeed centuries, and all is well, provided they do not surpass a critical level of exploitation. But what if the number of collectors continues to grow until they exceed the self-renewing capacity of the trees, perhaps exceeding it by only a small amount? Quite suddenly, a point is reached where the tree stock begins to decline. Season by season the self-renewing capacity becomes ever more depleted: the exploitation load remains the same and so the resource keeps on dwindling more and more, meaning in turn there is an ever-increasing overloading of the resource. The vicious circle is set up, and it proceeds to tighten when once the level of exploitation becomes non-linear. Note, in particular, that this scenario applies even if the number of collectors stops growing. The damage is done. But if the number of collectors continues to expand through population growth, the double degree of overloading (derived from an ever-dwindling stock exploited by ever more collectors) becomes compounded. There ensues a positive feedback process that leads to fuelwood scarcity and then all too quickly the stock is depleted to zero. It is a process that occurs all the more rapidly as the stock is progressively depleted.

The essence of the situation is that the pace of critical change can be rapid indeed. As soon as a factor of absolute scale comes into play, the self-sustaining equilibrium becomes disrupted. A situation that seemed as if it could persist into the indefinite future suddenly moves on to an altogether different status. It is as if two lines on a graph approach each other with seeming indifference to each other; then when they cross, the situation is radically transformed.

This non-linear relationship between resource exploitation and population growth is found with respect to many other natural resource stocks, notably fisheries,[3] soil cover, water supplies and pollution-absorbing services of the atmosphere. Whereas resource exploitation may have been growing gradually for a long period without any great harm, the switch in scale of exploitation induced through a phase of population growth can readily result in a slight initial exceeding of the sustainable yield, whereupon the debacle of resource depletion is precipitated with surprising rapidity.

Environmental discontinuities of this type can be expected to become more frequent and to have all manner of adverse repercussions for sustainable development, for two reasons. The first lies with the continuing upsurge in population numbers and their growing demands upon resource stocks. The second lies with the backlog of concealed costs resulting from past exploitation, which, as has been seen, will often levy an expanded price when "technological fixes" no longer suffice to maintain an erstwhile population/environment equilibrium. The rest of this paper presents a few illustrative examples that point up the nature and scope of the likely discontinuities ahead.

E. POPULATION IMPACTS: ILLUSTRATIVE EXAMPLES

Agricultural land degradation

As indicated above, three and a half decades of increasing food output have recently given way to several years of "plateauing" in crop yields. Much of the problem lies with the degradation of agricultural lands after decades of overloading of the natural resource base underpinning agriculture, due in major measure to population pressures. As much as 70,000 square kilometres of farm land are abandoned each year as a result of such degradation, while another 200,000 square kilometres lose virtually all their agricultural productivity (Chisholm and Dumsday, 1987; Tolba, 1989).

A chief form of land degradation is soil erosion (see Anderson and Thampapillai, 1990).[4] Unchecked soil erosion could well cause a decline of from 19 to 29 per cent in food production from rain fed croplands during the period 1985-2010 (Sfeir-Younis, 1986). The problem is due to several factors apart from population growth, notably poverty: impoverished peasants cannot afford the conservation measures needed to protect soil cover. But population growth serves to induce farmers to overuse and even exhaust the soil. Thus, it often happens that agricultural yields are expanded to meet the demands of population growth in the short term, while at a cost to soil cover and fertility that eventually leads to a decline in cropland productivity.

Thus, population growth plays a substantial part in land degradation. In principle, it would be possible, through improved agricultural policies, agrotechnologies and the like, to safeguard the food resource base and to make it still more productive. But the experience of the 1980s, when population growth became an ever more prominent factor, shows that agricultural lands have been deteriorating in much of Southern Asia, sub-Saharan Africa and the Andean countries, among others, many areas of which have registered declines in per capita food production (Brown and others, 1990). Not only are there many more mouths to feed. Agronomic strategies assume stability in the environmental state of the resource base—an assumption that is no longer true in many agricultural lands. In fact, there are all too few instances where new technologies for soil conservation and crop management have kept pace with the demands of surging human numbers.

Moreover, to cater for increased food needs in the future, most of which arises from population growth, one should theoretically plan for a 50 per cent increase in cultivated lands in developing countries by 2025 (Ehrlich, 1990; Paulino, 1986). Yet, the principal food territories, grain lands, have not increased in extent since 1981, following a 24 per cent expansion since 1950 (on the grounds that there is little suitable land left to mobilize for arable agriculture). Rather, they have been contracting as the amount newly opened has not kept pace with the amount taken out of production because of land degradation. Indeed, the world average of per capita cropland has been declining at a rate that if continued will leave only half as much in 2000 as in 1950 (Brown, 1989).

Overall, and as has been shown above, land degradation of various types is estimated to be causing an annual loss of 12 million tons of grain output (Brown and others, 1990). This loss translates into almost half of all gains in grain output each year. In turn, it has meant rising grain prices as reserve grain stocks have fallen to little more than "pipeline supplies": between 1986 and 1989, rice prices rose by 38 per cent and wheat prices by 48 per cent (Brown and others, 1990). Not only have the 1980s seen little expansion of croplands, but there appears to be even less scope for intensification of food production through the main mode of expanding irrigation. Thus, the environmental constraint of land degradation, already worth 12 million tons of grain per annum, could soon become all the more constraining.

In short, it is becoming apparent that environment and population debacle has been building up for decades in the agricultural sector, covert and largely disregarded until the past few years. Worse, it looks as if it has the makings of a discontinuity crisis during the 1990s. Suppose that the rate of grain output increase continues the pattern since 1985 of falling behind population growth; and that technological responses, plus related responses such as increased investment in agriculture, keep on proving incapable (as they have for much of the 1980s) of supplying the responses that boosted grain output for all of three and a half decades from 1950 onwards—and at the same grain reserves remain inadequate to cope with a crisis. Whatever the current problems of land degradation (they appear set to grow worse if only because of the cumulative impacts of farmers' long-term overloading of their croplands), they will be grossly aggravated, to put it at its best, by the compounding impact of population growth with an additional 900 million people in the developing world during the 1990s. So the decade ahead could well see a combination of mounting grain deficits, surging grain prices and spreading hunger among ever-larger numbers of people (Brown and others, 1990).

Moreover, the meta-problem will hit hardest at those least capable of withstanding it, the 1 billion people that endure absolute poverty. It is precisely these people that generally have the highest fertility rates. Thus, this dimension of the agricultural lands problem will continue to be compounded by the predominant and most persistent factor of all, population growth. With much land degradation deriving from excessive human pressures, the most productive way to reverse the situation surely lies with a reduction in population growth, as early and as rapidly as possible. Otherwise, the prospect is that if current growth rates continue, the overburdened lands of Africa, for example, will need to support an extra 223 million people and those in India, an extra 190 million people by the year 2000.

Tropical deforestation

According to a recent estimate (Myers, 1989a), tropical moist forests lost 142,200 square kilometres of their expanse during 1989. This loss amounted to 1.8 per cent of remaining forests covering slightly less than 8 million square kilometres. In 1979, these forests lost 75,000 square kilometres of their expanse, so the 1989 total represents a 90 per cent increase in the deforestation rate—deforestation here being taken to mean outright destruction of all tree cover, as distinct from degradation of forest ecosystems, which none the less leaves some trees standing.

How much tropical deforestation can be attributed to population growth? For an exploratory and illuminating assessment (Harrison, 1990), consider the role of expansion of the cropland base on the part of small-scale farmers—already accounting for well over half of all deforestation. During the period 1971-1985, cropland expansion in the entire developing world (i.e., non-forest countries as well) amounted to an average of 0.51 per cent per annum, while population growth amounted to an average of 2.2 per cent per annum and food consumption per person increased by an average of 0.58 per cent per annum. At the same time, technological innovations improved harvest yields to the extent that the area of cropland needed per person actually declined by an average of 2.27 per cent per annum. In addition, there was further encroachment on tropical forests as a result of road building, growth of urban communities and the like, an amount that can be estimated at 588,000 square kilometres during the period, which works out to an average of 0.056 hectare per person of the population increase. Using these various analyses, one can roughly calculate that cropland encroachment on tropical forests, the main form of cropland expansion, totalled about 1.2 million square kilometres during the period, amounting to more than 90 per cent of all deforestation; and of this expansion, population growth was responsible for 79 per cent, the other 21 per cent is attributable to an increase in food consumption per person. Certainly, this is a rough-and-ready mode of calculation, but it serves to throw light on the scope and scale of the contribution of population growth to tropical deforestation.

Even more important, there is vast scope for future population growth to generate still larger throngs of migrant cultivators who will further increase the deforestation rate (Myers, 1992). By the year 2030, about 80 per cent of the projected world population of over 8 billion people are expected to be living in tropical forest countries. This proportion translates into 6.4 billion people, or many more than the current total in the world. Thus, one should anticipate another discontinuity, this time in the form of an acceleration in the rate of deforestation, meaning that, in line with the fuelwood model (given above) of progressively rapid depletion of a resource stock, tropical forests are likely to decline much more quickly than would be expected from a simple linear extrapolation of recent trends. Moreover, the demise of tropical forests will not only lead to a sudden switch in the timber status of countries concerned, namely, from hardwood-exporting to hardwood-importing countries, with all that implies for their trade revenues, but it will also impact adversely upon other sectors, such as watersheds, biodiversity and climate.

Global warming

The first two illustrative examples largely concerned problems in the developing world. Now an instance of global scope is the topic. As has been clearly shown by recent IPCC reports (see IPCC, 1990),[5], the build-up of greenhouse gases in the atmosphere appears set to bring on a phenomenon of global warming. Worldwide emissions of carbon dioxide, the gas that causes half the greenhouse effect, were estimated to have risen from 2.4 billion tons in 1950 to 6.8 billion tons in 1985, for an average increase of 3.1 per cent per annum (Harrison, 1990). (Although these figures are actually outdated, since they take inadequate account of carbon dioxide releases from tropical deforestation, they are retained for purposes of the present calculation.) During the same period, world population grew by an average of 1.9 per cent per annum. The rest of the increase, 1.2 per cent per person per annum on average, ostensibly derived from higher per capita consumption of goods that involve production of carbon dioxide, plus changes in technology. According to this reckoning, population growth was responsible for almost two thirds of the increase in carbon dioxide emissions.

An analysis along these lines is useful as an exploratory assessment of the role of population growth. But a number of other factors pertain. What if economic growth patterns had worked out differently, with alternative levels of demand for fossil fuel energy—especially in so far as a greater proportion of the reduced growth would presumably have taken place in industrialized countries? What if the growth in energy demand and the technology deployed to meet it had worked out in a manner that meant greater per capita consumption because of shifts in, for example, pricing patterns and trends? A host of these "what if" questions could be raised about the analysis, showing that it is far from being so clear-cut as might appear at first glance. Moreover, it says nothing about those sectors of the world population that have been contributing more than others. A disaggregated analysis would present a more revealing picture.

These qualifications notwithstanding, the analysis is specially helpful when one considers the future outlook (Harrison, 1990; see also Holdren, 1990). If carbon dioxide emissions in developing countries continue to grow at the rate of the past 40 years, they will more than double from the 1985 per capita level of 0.8 ton to 1.7 tons by 2025, by which time the populations of those countries also are projected to have almost doubled, rising from 3.7 billion in 1985 to 7.1 billion. This population increase would hence produce almost an additional 5.8 billion tons of carbon dioxide, a total to be compared with the current worldwide total of 6.9 billion tons. Of course, this reckoning implies a linear progression of patterns and trends in consumption etc., whereas economic processes alone are subject to all manner of non-linear changes. All the same, the analysis serves to point out the exceptional potential for global warming inherent in the twin population factors of current large populations and their rapid rate of increase.

The point about future population growth is exemplified in the case of India. With a current per capita income of only $330 per annum, that is, about one sixtieth of that of the United States, India currently has an electricity capacity of only 55,000 megawatts, about twice that of New York State. Although the country possesses meagre coal reserves, it is exploiting them so fast that it currently ranks as the fourth coal burner in the world. In 1950, its coal use was only 33 million tons; by 1989, it had soared to 191 million tons (while production of crude oil, another fossil fuel, rose from 0.3 million ton to 30.4 million tons; and total power generation increased from 5 billion kilowatt hours to 217 billion. The Government plans a number of energy-based initiatives for development; for instance, to supply electricity to half the houses in the country. This goal alone will require the production of an additional 80,000 megawatts of power, compared with the current total capacity of 55,000 megawatts. It is anticipated that this measure, together with other development plans, will shortly induce a doubling of carbon emissions in India (Dave, 1988; Oppenheimer and Boyle, 1990).

Within this context, a paramount factor lies with population, both its size and its growth rate. The 1992 population of India, 887 million, is growing at 2.1 per cent per annum and is projected to reach 1,043 million by the year 2000 and 1,375 million by 2020. Even with the low per capita income in India (the *A* factor of the *I* = *PAT* equation) and the less than advanced technological capacity (the *T* factor), the huge population (the *P* factor) makes for a disproportionately large potential contribution to global warming. Suppose, however, that India managed to reduce its fertility rate to replacement level (almost half the current number of children per completed family) within the next three or four decades. Suppose, too, that during this same period it did no more than double its per capita use of commercial energy (roughly matching that of China currently), using coal for the purpose. This increase, given the multiplier effect of the huge current population and its rate of growth, would result in carbon dioxide emissions at an annual per capita rate of one ton by 2024 or roughly the world average in 1990. Because of the population factor, this level would still be enough to more than cancel out the benefits of a putatively extreme step elsewhere, viz. the termination forthwith of all coal-burning on the part of the United States without replacing it with any other carbon-containing fuel (Ehrlich and Ehrlich, 1990). The case of India alone presents abundant potential for a climate discontinuity in the making.

Note, moreover, that the developing countries overall currently produce about 30 per cent of worldwide emissions of carbon dioxide, while possessing 77 per cent of the world population. Medium-level population projections to the year 2025 indicate that developing countries could then be accounting for 64 per cent of all emissions (which then would be much larger in total), while possessing 84 per cent of the world population (United States of America, 1990). But if the global population total in 2025 were held to the low projection of 6.3 billion instead of the medium projection of 7.1 billion, and supposing there was no reduction in per capita carbon dioxide emissions, total emissions would be reduced by 1.3 billion tons (Harrison, 1990).

So much for three examples of environmental discontinuities ahead. A few further instances are briefly noted below:

(*a*) Humans currently engage in so much exploitation of plant growth that they are co-opting 40 per cent of all net primary productivity on land each year, leaving 60 per cent for the millions of other species (Vitousek and others, 1986). The question is what will happen when human numbers double, as is projected during the next few decades? It is clear that the remainder of the world's biotas can hardly be left to make out with only 20 per cent of net primary productivity per annum. Grossly reduced biotas would become ecologically unstable at best; there could well emerge an entire series of biotic discontinuities;

(*b*) Human consumption of water has doubled at least twice since the beginning of the twentieth century, and demand could well double again during the next two decades, largely through population growth (Falkenmark, Lundqvist and Widstrand, 1990). This outlook will surely engender all manner of discontinuities for agriculture (especially irrigation agriculture, which is the single largest consumer of water and which currently produces one third of the food), as well as for industry and domestic household needs;

(*c*) Certain of the resource shortages are likely to interact with each other so as to produce a mutually amplifying impact. That is to say, the compounded product would be far greater than the sum of separate impacts; the result would not be additive but multiplicative. This outcome could be particularly deleterious in that a synergized interaction can be an order of magnitude more powerful than otherwise. Consider, for example, a potential synergism in the agricultural sphere with respect to genetic depletion and the greenhouse effect. The higher temperatures and reduced soil moisture expected in a greenhouse-affected world will not be appropriate for most crops, in that they are finely tuned to current climatic regimes. Hence, the need to expand the genetic support for crops will place a premium on germ plasm variability to build up drought resistance among other environmental adaptations. Yet, the gene reservoirs for crop plants are being more rapidly depleted than ever, leaving a critically reduced genetic resource base. Many other such synergisms are probable as development sectors increasingly interact (Myers, 1989b).

CONCLUSION

Population growth, working in conjunction with a number of other constraints, such as faulty methods of economic evaluation, inappropriate technologies and inadequate overall development policies, has resulted in pronounced and pervasive overexploitation of the natural resource underpinnings of economies in the developing world. To some (limited) extent, the problem has been held at bay through various technological "fixes" but the covert costs cannot be deferred indefinitely if only because of critical environmental limitations that are becoming increasingly apparent. Instead of a "limits to growth" scenario, the world is experiencing a "growth of limits" situation.

The upshot is likely to be the emergence of diverse environmental discontinuities, whereby an ostensibly self-sustaining equilibrium is suddenly and radically transformed into "overshoot" status. Although the prospect is attended by a good deal of uncertainty—there are only meagre insights into the resilience of ecosystem workings—prudence dictates a response characterized by systematic caution, notably in accord with the public policy guideline proposed through the precautionary principle. This principle, while little articulated thus far in operational terms, must be grounded in a thorough understanding of the scientific constraints in question, as of the human welfare risks entailed through an adverse outcome.

NOTES

[1] See WCED (1987), Pearce (1988), Daly and Cobb (1989), Barbier (1990) and Costanza (1991).

[2] See also Mahar (1985), Daly and Cobb (1989), Pimentel and Pimentel (1989); and Myers, Ehrlich and Ehrlich (1992).

[3] For a cogent analysis, see Keyfitz (1990).

[4] See also Boardman, Dearing and Foster (1990); and Pimentel (1991).

[5] See also Schneider (1989), Leggett (1990), and Oppenheimer and Boyle (1990).

REFERENCES

Anderson, Jock R., and Jesuthason Thampapillai (1990). *Soil Conservation in Developing Countries: Project and Policy Intervention*. Policy and Research Report, No. 8. Washington, D.C.: The World Bank.

Augelli, J. P. (1984). Costa Rica: transition to land hunger and potential instability. *Yearbook of Conference of Latin Americanist Geographers, 1984*. San Jose, Costa Rica.

Barbier, Edward B. (1990). The farm-level economics of soil conservation: the uplands of Java. *Land Economics* (Madison, Wisconsin), vol. 66, No. 2 (May), pp. 199-211.

Boardman, J., J. A. Dearing and I. D. L. Foster, eds. (1990). *Soil Erosion on Agricultural Land*. New York: Wiley Publishers.

Brown, Lester H. (1988). *The Changing World Food Prospect: The Nineties and Beyond*. Washington, D.C.: Worldwatch Institute.

_______, and others (1990). *State of the World, 1990: A Worldwatch Institute Report on Progress Toward a Sustainable Society*. New York and London: W. W. Norton.

Chen, R. S., and others (1990). *The Hunger Report: 1990*. Providence, Rhode Island: Brown University, World Hunger Program.

Chisholm, Anthony, and Robert Dumsday, eds. (1987). *Land Degradation: Policies and Problems*. New York: Cambridge University Press.

Costanza, Robert, ed. (1991). *Ecological Economics: The Science and Management of Sustainability*. New York: Columbia University Press.

Cruz, Maria Concepcion J., Imelda Zosa-Feranil and Cristela L. Goce (1988). Population pressure and migration: implications for upland development in the Philippines. *Journal of Philippine Development* (Metro Manila) vol. 25, No. 1, pp. 15-46.

Daly, Herman E., and Johan B. Cobb, Jr. (1989). *For the Common Good: Redirecting the Economy Toward Community, the Environment and a Sustainable Future*. Boston, Massachusetts: Beacon Press.

Dave, J. M. (1988). *Policy Options for Development in Response to Global Atmospheric Changes: Case Study for India for Greenhouse Effect Cases*. New Delhi, India: Nehru University.

Ehrlich, Anne H. (1990). Agricultural contributions to global warming. In *Global Warming: The Greenpeace Report*. Jeremy Leggett, ed. Oxford, United Kingdom: Oxford University Press.

Ehrlich, Paul R., and Anne H. Ehrlich (1990). *The Population Explosion*. New York: Simon and Schuster.

Ehrlich, Paul R., and others (1989). *Global Change and Carrying Capacity: Implications for Life on Earth*. Stanford, California: Stanford University, Institute for Population and Resource Studies.

Falkenmark, Malin, Jan Lundqvist and Carl Widstrand, eds. (1990). *Water Scarcity: An Ultimate Constraint in Third World Development*. Tema S, Report No. 14. Linkoping, Sweden: University of Linkoping, Department of Water and Environmental Studies.

Food and Agriculture Organization of the United Nations (1990). *Interim Report on Forest Resources Assessment*. Rome.

Harrison, Paul (1990). Too much life on Earth? *New Scientist* (London), No. 126, pp. 28-29.

Higgins, Graham M., and others, eds. (1982). *Potential Population Supporting Capacities of Lands in the Developing World*. Technical Report of Project INT/75/P13. Rome: Food and Agriculture Organization of the United Nations, International Institute for Applied Systems Analysis and United Nations Fund for Population Activities.

Holdren, John P. (1990). Energy in transition. *Scientific American* (New York), vol. 263, No. 3 (September), pp. 156-163.

Intergovernmental Panel on Climate Change (1990). *Climate Change: The IPCC Scientific Assessment*, J. T. Houghton, G. J. Jenkins and J. J. Ephraums, eds. Cambridge, United Kingdom, and New York: Cambridge University Press.

Keyfitz, Nathan (1990). *Population Growth Can Prevent the Development that Would Slow Population Growth*. Laxemburg, Austria: International Institute for Applied Systems Analysis.

Leggett, Jeremy, ed. (1990). *Global Warming: The Greenpeace Report*. Oxford, United Kingdom: Oxford University Press.

Mahar, Dennis, and others, ed. (1985). *Rapid Population Growth and Human Carrying Capacity: Two Perspectives*. World Bank Staff Working Paper, No. 690. Washington, D.C.: The World Bank.

Myers, Norman (1988). Environmental degradation and some economic consequences in the Philippines. *Environmental Conservation* (Lausanne), vol. 15, No. 3 (Autumn), pp. 205-214.

______ (1989a). *Deforestation Rates in Tropical Forests and Their Climatic Implications*. London: Friends of the Earth.

______ (1989b). Synergistic interactions and the environment. *BioScience* (Washington, D.C.), vol. 39, No. 8 (September), p. 506.

______ (1992). Tropical forests: the policy challenge. *The Environmentalist* (Lausanne).

______, Paul R. Ehrlich and Anne H. Ehrlich (1992). The population problem: as explosive as ever? In *Maintenance of the Biosphere: Proceedings of the Fourth International Conference on the Environmental Future, Budapest, Hungary, 22-27 April 1990*. Edinburgh, Scotland: Edinburgh University Press.

Oppenheimer, Michael, and Robert H. Boyle (1990). *Dead Heat: The Race Against the Greenhouse Effect*. Oxford, United Kingdom: Oxford University Press; and New York: Basic Books.

Paulino, L. A. (1986). *Food in the Third World: Past Trends and Projections to 2000*. Washington, D.C.: International Food Policy Research Institute.

Pearce, David W. (1988). Economics, equity and sustainable development. *Futures*, (Guildford, United Kingdom), vol. 20, No. 6 (December), pp. 596-605.

Pimentel, David, ed. (1991). *World Soil Erosion and Conservation*. Cambridge, United Kingdom: Cambridge University Press.

______ and Marcia Pimentel (1989). Land, energy and water: the constraints governing ideal U.S. population size. *The NPG Forum*. Teaneck, New Jersey: Negative Population Growth, Inc.

Sadik, Nafis (1990). *The State of World Population, 1990*. New York: United Nations Population Fund.

Schneider, S. Henry (1989). *Global Warming: Are We Entering the Greenhouse Century?* San Francisco, California: Sierra Club Books.

Sfeir-Younis, Alfredo (1986). *Soil Conservation in Developing Countries—A Background Report*. Washington, D.C.: The World Bank.

Simon, Julian Lincoln (1990). *Population Matters: People, Resources, Environment, and Immigration*. New Brunswick, New Jersey: Transaction Publishers.

Tolba, Mostafa K. (1989). Our biological heritage under siege. *BioScience* (Washington, D.C.), vol. 39, No. 10 (November), pp. 725-728.

United States of America Congress (1990). *International Policy Dimensions of Global Warming: U.S. Influence and Regional Trends*. Washington, D.C.: Office of Technology Assessment.

Vitousek, Peter M., and others (1986). Human appropriation of the products of photosynthesis. *BioScience* (Washington, D.C.), vol. 34, No. 6 (May), pp. 368-373.

World Commission on Environment and Development (1987). *Our Common Future*. Oxford, United Kingdom; and New York: Oxford University Press.