Environmental Refugees in a Globally Warmed World

Estimating the scope of what could well become a prominent international phenomenon

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> The gravest effects of climate change may be those on human migration as millions are uprooted by shoreline erosion, coastal flooding and agricultural disruption.
> —Intergovernmental Panel on Climate Change (1990a)

We increasingly hear about environmental refugees. They are people who can no longer gain a secure livelihood in their erstwhile homelands because of drought, soil erosion, desertification, and other environmental problems. In their desperation, they feel they have no alternative but to seek sanctuary elsewhere, however hazardous the attempt. Not all of them have fled their countries; many are internally displaced. But all have abandoned their homelands on a semipermanent if not permanent basis, having little hope of a foreseeable return (Myers 1986, 1993; see also Barker 1989, El-Hinnawi 1985, IOMRPG 1992, Jacobson 1988, UNPF 1993).

It is often difficult to differentiate between refugees driven by environmental factors and those driven by economic problems. In certain instances, cross-border refugees, notably those with moderate though tolerable economic circumstances, are pulled by opportunity for a better economic life elsewhere rather than pushed by environmental destitution. This description ostensibly applies to many Hispanics heading for the United States. But those people who migrate because they suffer poverty are frequently driven by root factors of environmental degradation; indeed, it is their environmental plight as much as any other factor that makes them economically impoverished. This description generally applies to those refugees who migrate to another part of their own country or head off to a neighboring country where economic conditions are little if any better than back home, as is the case of many migrants within Sub-Saharan Africa and the Indian subcontinent. In this instance, with poverty and life on the environmental limits as the main motivating force, it matters little whether the migrants are labeled environmental or economic refugees.

Large numbers of environmental refugees could be among the most significant of all upheavals entrained by global warming

According to recent estimates (Trolldalen et al. 1992, Westing 1992), there are at least 10 million environmental refugees today (roughly half of them in Sub-Saharan Africa), compared with 17 million other refugees (e.g., political, religious, and ethnic) combined. The first figure is certainly on the low side, because governments generally take little official account of this unconventional category of refugees; it is the unrecognized refugees that have shown most increase in recent years until they may now number (roughly estimated) as many as 25 million. Even if we accept a total of only 10 million recognized environmental refugees today, cautious and conservative as the figure is, we can assume their numbers are likely to swell rapidly as burgeoning throngs of impoverished people press ever harder on overloaded environments (Ehrlich and Ehrlich 1990, 1991, Myers 1991, 1992). Worse, their numbers may well increase several if not many times by the time that global warming takes hold (Myers 1993).

What evidence is there to support the latter prognosis for a greenhouse-affected world? This article presents a preliminary analysis to gain a first-cut understanding of the problem in its full character and extent. Some of the analysis is speculative, and in certain instances there is a range of estimates. Plenty has been written about the impacts of global warming, but little attention has been directed to the emergent issue of environmental refugees, and hardly any detailed work has been done to assess the prospect in comprehensive and systematic terms (for introductory efforts, see Jacobson 1988, Tickell 1990). To the extent that there is substance to a prediction of large numbers of environmental

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refugees ahead, it serves as a powerful further rationale for policy measures to slow global warming while there is still time. This article is intended to stimulate debate and further assessment. To reiterate, the analysis presented is essentially exploratory—no more and no less. It seeks to establish the scale and scope of what could well become a prominent phenomenon of the international arena.

A note on the analytic methodology: the article uses the baseline or business-as-usual (little or no control of greenhouse gas emissions) scenario for global warming and sea-level rise, with uncertainty ranges (where available and appropriate) as presented by the Intergovernmental Panel on Climate Change (IPCC; 1990a, 1992a). The marker year used for the article's assessment is 2050, when global warming's impacts are likely to have become widespread and pronounced. It is expected there will be a sea-level rise worldwide of approximately 8–29 cm (with a most likely increase of 18 cm) by 2030, and of 25–110 cm (the best estimate being 46 cm, or approximately half a meter) by 2100 (Warrick 1993, Warrick et al. 1993; see also IPCC 1990a, 1992a); a working estimate for 2050 is 30 cm, and that is the value used in this article. By 2050, according to a medium projection, global population is expected to have almost doubled to 10 billion people, virtually all the increase being in developing countries (United Nations 1992, World Bank 1992a). Moreover, the entire analysis is limited to developing countries, because these areas have the largest populations at risk and because they possess fewest resources (engineering skills, financial means, and institutional capacity) to confront the problem.

Finally, the analysis assumes there will be few protection measures adopted in the form of, for example, sea-wall defenses. True, much could be done to reduce the threat through sea walls, anti-flood levees and dikes, upstream dams, beach nourishment, and other engineering defenses, plus land-use planning to deflect human settlements away from at-risk zones (IPCC 1992b, Titus 1990, 1993, Titus et al. 1991, USNRC 1987). But the costs of such measures are likely to prove unduly high for many developing countries. Let us now consider some individual countries and regions as they undergo the potential impacts of global warming.

Bangladesh

The April 1991 cyclone that struck the country's coastal zone and the accompanying six-meter-high storm surge that penetrated far inland caused the loss of at least 200,000 people (some observers estimate twice as many), and millions were left homeless—all in a single sector of one small country (del Mundo 1992, Haider 1992). Bangladesh is the size of Florida or England, with 114 million people in mid-1993 and the highest population density nationwide on Earth. The Netherlands, the most crowded nation in the developed world, has an overall density only half as high. Moreover, approximately 85% of Bangladeshis live in rural areas, so the whole national territory is congested with people, compared with say the Netherlands, where only 11% of the populace live in the countryside.

In addition, more than half of Bangladesh lies less than 5 m above sea level, leaving it more vulnerable than most other countries to sea-level rise (Broadus 1993, Nicholls and Leatherman in press a,b). Because of the twin factors of population density and low-lying terrain, Bangladesh is unusually susceptible to extreme events, such as cyclones, together with associated phenomena of storm surges and coastal flooding (Flather and Khandker 1993). In recent years, the country has been struck by cyclonic storms at an average rate of 1.5 per year (Broadus 1993; see also Topping et al. 1991). Moreover, global warming may well produce an intensification of the cyclone system, leading to outsize variations of storm surges (Emanuel 1988, Pittock and Flather 1993, Raper 1993).

Bangladesh is also highly susceptible to flooding inland, again because of its low-lying territory. The country straddles the floodplains confluence of three great rivers: the Ganges, Brahmaputra, and Meghna. In effect, 80% of the country is one great delta, where even a slight increase in water level leads to widespread flooding (Brammer 1993, Broadus 1993). Half of the gross domestic product (GDP) is attributable to agriculture (in many developing countries the proportion is one third or less), leaving the national economy all the more prone to flooding damage (Broadus 1993, World Bank 1989).

Consider a sea-level-rise scenario for Bangladesh, based largely on the most detailed analysis to date, viz. Broadus 1993 (see also Ali and Huq 1990, Mahmood 1991, Mahtab 1989, Milliman et al. 1989, Pramanik and Ali 1989). A May 1985 storm surge raised sea level in the northeastern sector of the Bay of Bengal by 2.75 m (Flather and Khandker 1993). The impact of sea-level rise will be augmented by land subsidence, both natural and human caused (the latter mainly through withdrawal of groundwater), virtually throughout Bangladesh's coastal zone (Broadus 1993, Milliman et al. 1989). It is possible that subsidence, if it continues as anticipated due to increased human exploitation of coastal-zone resources (also through damming of rivers upstream, thus reducing sediment flow to estuaries from catchment zones), will exceed the maximal projected sea-level rise by the year 2100 (Turner et al. 1990).

These factors combined could well cause an effective sea-level rise of 0.83 m along Bangladesh's coastline by 2050, comprising 0.13 m through sea-level rise and 0.70 m through subsidence. The analysis cited (Broadus 1993) considers that this rise can be viewed as more or less equivalent to an effective one-meter rise for the purpose of scenario assessment. In conjunction with associated problems, such as storm surges and tidal waves, Broadus calculates a one-meter sea-level rise would precipitate severely adverse impacts for Bangladesh's coastal zone and the immediate hinterland. (The analysis leaves out of the account the further impacts on inland areas up to five meters above sea level, which comprise more than half the country.) The analytic methodology is described by Broadus as "very simplistic," the projections as "highly speculative," and the conclusions as "a very coarse approximation" of economic repercussions. The analysis by Broadus does not include possible measures to reduce the problem.

Although Broadus contends that a one-meter scenario is to be viewed in certain respects as a worst-case outcome, he proposes that a three-meter scenario for 2100 is worth consideration. In light of the bleak outlook for Bangladesh, however, the analysis certainly deserves the attention of political leaders and policy makers. Note, too, that by 2050, Bangladesh is projected to have approximately 220 million people, or almost twice as many as today (United Nations 1992, World Bank 1992a).

The outcome could prove critical for a country that, with a current per-capita gross national product (GNP) of $200, ranks among the most impoverished on Earth, meaning it can deploy few resources—financial and engineering, for example—to resist natural disasters. Seven percent of Bangladesh could permanently disappear beneath the waves, and a much larger area could be regularly overtaken by associated phenomena such as six-meter storm surges reaching 160 kilometers or more inland (World Bank 1989), that is, two-fifths of the way from the coast to the main northern border. In April 1991, it was not so much the cyclone that killed 200,000 or more people, rather it was the in-rush of seawater that drowned them.

Taken together, by 2050 the expected hazards would destroy homes and holdings in an area containing 7% of today's populace (Broadus 1993; see also Mahtab 1991, Milliman et al. 1989). If population distribution continues as today, the number of people affected in 2050 would be a projected 15 million. Even if the catastrophe could be partially contained through massive engineering works (long-term costs are estimated as high as $10 billion for a country with a present-day GNP of $24 billion; Huq et al. in press), there would be further problems from ripple effects in the form of backwater flooding in inland areas and acute congestion in the new coastal zones (Topping 1990). Moreover, the victims could look for little help from a currently destitute nation that would lose a sizable share of its economic base.

On top of all these problems stemming from the encroaching sea, there could be trouble for Bangladesh from the opposite side of the country, the Himalayas. The three great rivers pouring into Bangladesh carry exceptionally swollen waters after the monsoon strikes the Himalayas. Their combined outflow is two and a half times that of the Mississippi and surpassed only by that of the Amazon (Topping 1990; see also Brammer 1993). Less than one tenth of these rivers' catchments lies within Bangladesh, leaving the country with next to no control over the vast volumes of water pouring into its territory.

In September 1988, river flooding left three-quarters of the country inundated, with 50 million people rendered homeless and $1.5 billion worth of damage (equivalent to 6.5% of GDP or a whole year's economic growth; World Bank 1989); the disaster had nothing to do with waters from the sea. If global warming causes the monsoon system to have a more powerful impact, the rivers' flow into Bangladesh could expand by at least half during the monsoon season (Rasmusson 1989). There would also be increased melting of Himalayan glaciers. Indeed, some experts believe the threat from inland flooding may turn out to be more serious than the better-recognized threat from rising sea level (IPCC 1990a, 1992a).

There is yet another problem: increased saltwater intrusions. Already these intrusions can extend seasonally 150 kilometers inland along river courses (Broadus 1993). A relative sea-level rise of one meter would cause such intrusions to reach even further inland, with adverse repercussions for irrigated cultivation of rice and other crops, and for household water supplies.

The main analysis reviewed (Broadus 1993), based largely on effective sea-level rise, is to be deemed a severe-outcome scenario. But a number of additional adverse factors would make it plausible if not probable in many respects.

Egypt

The River Nile supports a 10-kilometer-wide strip of farmlands plus the delta plain, totalling 35,000 square kilometers or a mere 3.5% of the nation's territory. In this area live 57 million people today, making for a local population density of approximately 1600 per square kilometer, or more than twice the nationwide density of Bangladesh. Already Egypt has difficulty feeding itself, having to import well over half its food (World Bank 1992b). But in a greenhouse-affected world, it may well be that drier conditions will cause a one-fifth drop in the corn yield and a one-third drop in the wheat yield—a prospect that could be aggravated by a marked decline in the Nile River flow (Gleick 1991). Food shortages are likely to be exacerbated still further by sea-level rise through permanent flooding of prime agricultural lands. Moreover, the area worst affected by sea-level rise, the Nile delta, is experiencing rapid natural subsidence (Stanley 1990), aggravated by sediment starvation due to the Aswan High Dam upstream.

According to the latest detailed analysis, again by Broadus (1993; and subject to the caveats he stipulates for his Bangladesh analysis), Egypt could plausibly experience 0.13 m of global sea-level rise and 0.65 m of local subsidence by 2050 (though Stanley [1990] postulates only 0.20 m of subsidence), making a total of 0.78 m of effective sea-level rise. As in the case of Bangladesh, this latter figure is rounded up by Broadus to 1 m. A relative one-meter sea-level rise would permanently flood much of Egypt's delta plain for 30 km inland (El-Raey et al. in press, Milliman et al. 1989). The country could well lose between 12% and 15% of its arable land, containing 14% of the current population of 8 million people. Given that Egypt's population is projected to increase to 103 million by the year 2050, and supposing that population distribution remains the same as today, it is realistic to anticipate that sea-level rise would displace more than 14 million people by 2050 (Broadus 1993).

This prognosis, moreover, is cautious and conservative. There would be additional problems, such as intrusion of saltwater up the foreshortened Nile (Kashef 1983), that would further reduce the irrigated lands supporting virtually the whole of Egypt's agriculture. On the other hand, if the elevation of the coastal city Alexandria, with 4 million people today and projected to contain 8 million by 2030, were to prevent it from being flooded out (expensive engineering works would still be required to counter sea-level rise; El-Raey et al. 1993, Perdomo and Vellinga 1992), then only 7% of the population would be displaced (Broadus 1993).

Other delta areas and coastal lands

All in all, as much as five million square kilometers of coastal lands could be threatened by a one-meter sea-level rise plus storm surges and saltwater intrusions (Hekstra 1990, UNEP 1989). This aggregate area is equivalent to the United States west of the Mississippi, but amounts to only 3% percent of Earth's land surface. Yet, it is home to well over one billion people already, a total projected to rise to at least two billion well before 2050 (it also encompasses one third of the world's croplands and one fifth of market-valued assets; Voigt 1991; see also Wilson 1989). As early as the year 2000, the majority of humankind could be living within 60 km of coastlines (Voigt 1991). As we have seen, cyclone flooding in Bangladesh can extend 160 km inland, though fortunately few coastal zones are as low-lying as Bangladesh's.

True, we are unlikely to witness a one-meter rise in sea level even by 2100, or more than a 0.33-meter rise by 2050, according to the latest working estimates (Warrick 1993, Warrick et al. 1993). Only a small proportion of the coastal-zone communities would be affected. But the numbers of displaced people could be significant, although currently difficult to predict except in very general terms.

In addition to Bangladesh and Egypt, the countries at greatest risk by virtue of their low-lying coastal plains with large populations are China and India, together with several other countries facing a lesser though still sizable risk—Indonesia, Thailand, Pakistan, Mozambique, Gambia, Senegal, and Suriname (Nicholls and Leatherman in press a, b; see also Jacobson 1990, Titus 1990, Topping 1990). A country does not have to feature a broad and shallow coastal plain to qualify for the list. Indonesia's coastal zone generally gives way quickly to uplands, yet its 13,000 islands comprise coastlines totalling 81,000 kilometers (Sughandy 1989; compare the United States' 20,000 kilometers and the world's 450,000 kilometers). Nor is the problem limited to sea-level rise. Coastal zones can be severely affected by storm surges. Already some 100–200 million people live below the annual storm surge level (Perdomo and Vellinga 1992).

China

China's coastal zone of 126,000 square kilometers, an area equivalent to New York state, contains 76 million people today. It also features industrial and agricultural activity worth one quarter of the country's GDP (Perdomo and Vellinga 1992). Its population density is higher than that of Bangladesh's nationwide, yet the elevation in the coastal strip is only 1 m (Han et al. 1990, Wang et al. 1992). The zone is also characterized by local subsidence; Shanghai has sunk 2.8 m since the 1920s and may subside a further 1 m by 2100 (Wang et al. in press; see also Hsia-Chuang 1991). An effective one-meter sea-level rise, made up of subsidence in conjunction with actual sea-level rise, would inundate the whole of Shanghai with its 12.4 million people today, projected to increase to 26.8 million by 2030. Flooding would also overtake 96% of the surrounding province, reducing the area available to move the city inland through slow relocation of new buildings (Wang et al. in press).

Even a half-meter sea-level rise would, according to Chinese government estimates (Ruquiu 1990), eliminate the homes of 30 million people today (a minimum of 29–34 million people are at risk in the four major deltas alone; Han et al. 1993). The government further estimates that as many as 100 million people would ultimately be affected to some degree by coastal flooding, albeit without all being obliged to migrate. Nor would there be much room for migrants merely to move a little way inland. In the coastal plain as a whole live 350 million people already, with a congestion quotient as high as for rural areas anywhere on Earth. Although there is no estimate for the coastal-plain population in 2050, we can note that the population for all of China is projected to increase from 1179 million today to 1764 million by 2050, a 50% increase (United Nations 1992). If the same proportionate increase were applied to the coastal-zone sector, the figure of 350 million people today would rise to 525 million in 2050.

It seems realistic to accept the government's estimate that 30 million people would be displaced, a highly conservative estimate. In an alternative calculation (Cline 1992), 72 million people are displaced.

India

In the country's sector of the Bay of Bengal, comprising West Bengal and Orissa states adjacent to Bangladesh, there would be less than 2000 square kilometers and only approximately 1 million people at risk, contrasted with the total of 15 million people estimated for Bangladesh in 2050. The main problem would lie with seven large deltas in several other sectors of India's coastline (Perdomo and Vellinga 1992), five of which cover more than 21,000 square kilometers and support more than 21 million people today (Nicholls and Leatherman in press a,b). India's total coastal-zone population today is 180 million people, of whom almost 80 million, together with 120,000 square kilometers of land, would ultimately be affected by sea-level rise, though not all would necessarily be displaced (Asthana 1993). India's population of 899 million people today is projected to rise to 1599 million by 2050, a 78% increase. If we apply a similar percentage increase to the 80 million coastal-zone dwellers today, the total for 2050 would become 142 million.

Using these background data, because no better estimate is available at present, it seems appropriate to propose that India's total of flood-zone refugees alone could be anywhere between 20 million and 60 million, with 30 million taken here as a conservative working figure. This estimate is among the roughest advanced in this article. It is adopted on the grounds that the total must be in the low tens of millions. The estimate could ultimately turn out to be too cautious by several tens of millions.

Return to the aggregate area cited for all coastal lands at risk, totaling 5 million square kilometers. The expanse includes those sectors of Bangladesh and Egypt already considered, with a combined total of approximately 30 million potential refugees. Let us suppose that all other areas together, including China and India

(30 million each), would generate another 70 million refugees, the additional 10 million refugees occurring in further coastal lands. Plainly, this estimate is rough indeed: it is advanced only with the purpose of enabling us to get to preliminary grips with an issue of major moment. Equally plainly, the figure is conservative.

We can adduce evidence in support of the figure of the 10 million refugees from other coastal lands by considering a number of other deltas, together with estuaries that would be vulnerable to even a moderate degree of sea-level rise. Among such areas are the mouths of the Hwang Ho and Yangtze rivers in China, the Mekong in Vietnam, the Chao Phraya in Thailand, the Salween and Irrawaddy in Myanmar, the Indus in Pakistan, the Tigris/Euphrates in Iraq, the Zambezi in Mozambique, the Niger in Nigeria, the Gambia in Gambia, the Senegal in Senegal, the Magdalena in Colombia, the Orinoco in Venezuela, the Courantyne and Mazuruni in British Guiana, the Amazon and Sao Francisco in Brazil, and the La Plata in Argentina, plus less extensive areas at the mouths of other major rivers (Delft Hydraulics 1990, Frassetto 1991, Topping 1992). Yet, these low-lying areas feature some of the densest human settlements in the world. In the Mekong delta, for instance, 10 million people now live in areas with elevation no more than 1 m above high tide (Hekstra 1990).

Low-lying deltas and estuaries feature the megametropoles of Shanghai, Manila, Jakarta, Bangkok, Calcutta, Madras, Bombay, Karachi, Lagos, Rio de Janeiro, and Buenos Aires (Frassetto 1991, Perdomo and Vellinga 1992). Their collective populations amounted to 93 million in 1985 and are projected to reach 141 million people as soon as 2000 and as many as 200 to 220 million (for total conurbations) by 2050 (UNPD 1993). Some urban areas are subject to subsidence (Dolan and Goodell 1986). Because of groundwater pumping, Bangkok's subsidence rate is 13 cm a year (Milliman et al. 1989), a rate that if continued will amount to 1 m in only eight years. Subsidence may well increase in many other urban areas as groundwater stocks are increasingly exploited for agriculture, industry, and household needs. In the case of several of these outsize cities, subsidence is expected to contribute to an effective sea-level rise of one meter if not more by 2050 (Dolan and Goodell 1986, Topping 1992).

Suppose that only one eighth of the projected populations of developing-nation cities listed, 210 million in all, were to become displaced by sea-level rise and related troubles such as storm surges and tidal waves. (Although this calculation is again crude, it is based on an early assessment by the United Nations Environment Programme [1989], which postulated a higher proportion, one quarter; the proportion has been reduced to one eighth for current purposes to reflect the reduced amount of sea-level rise now anticipated for 2050, roughly half a meter rather than one meter [Warrick et al. 1993]). So the one-eighth calculation would generate 26 million environmental refugees. Of the 11 cities listed, Shanghai, Calcutta, Madras, and Bombay have already been accounted for through the analyses of China and India above. Their collective populations in 1985 were 38 million, or 41% of the 11-city total of 93 million (Sadik 1991). If we apply the same percentage figure to the 11-city total population of 210 million for 2050, it will amount to 86 million, leaving 124 million for the other 7 cities. It is not unrealistic to suppose that this latter total should generate 26 million environmental refugees.

Note that the 26 million figure is distinctly conservative from a broader standpoint. The megametropoles considered are located on only 6 of the 19 delta/estuary areas listed. Several of the 13 other areas feature sizable urban communities, though not so large as the 11 conurbations considered. Moreover, the refugee total would be higher yet again if we were to include smaller cities (plus smaller deltas and estuaries). Already, two out of three cities with 2.5 million people are located on coasts (Voigt 1991). This analysis serves to affirm as realistic the estimate of 10 million further refugees in additional coastal lands.

Island states

Also at risk are a number of island states such as the Maldives, Kiribati, Tuvalu, and the Marshalls in the Indian and Pacific Oceans, plus a dozen or more such states in the Caribbean. The first group will be acutely vulnerable to sea-level rise and flooding insofar as virtually their entire territories lie only a meter or two above sea level; several of these islands face the prospect of outright elimination. The collective population of the non-Caribbean island states is 24 million today (Topping 1992), projected to surpass 50 million by 2030. Fortunately, only 1 million people at most are likely to find themselves having to evacuate permanently, though as many as 46 million of the 50 million people could find their homes and livelihoods critically affected (Jacobson 1988).

The Caribbean island states may eventually become subject to tropical storms of increased intensity over a longer season. These storms may be sufficient to reduce greatly the suitability of parts of the islands for permanent human habitation.

Agricultural dislocations

On top of the problems associated with sea-level rise is the prospect of other global-warming effects, such as shifts in monsoon systems and the arrival of severe and persistent droughts, with all that they would entail for agriculture. A temperature rise of only 1°C, likely by 2050 in terms of most projections, could affect monsoon patterns to an extent that would dwarf the direct drought effects of such a temperature rise (IPCC 1990a). The area most vulnerable to monsoon dislocations is the Indian subcontinent, projected to hold 2.1 billion people by 2050. India relies on the monsoon for 70% of its rainfall (Rasmusson 1989); hence, its agriculture is critically dependent on the stable functioning of the monsoon. In broader terms, the entire Asia-Pacific region is exceptionally vulnerable to monsoon-system changes, if only because it contains well over half the world's population today, projected to become a still larger proportion by 2050 (Topping et al. 1991).

Predicting the effects of drought and its repercussions for agriculture is more uncertain. Climatic quirks are less well predicted through global-climate models at regional levels than are monsoon patterns, sea-level rise, and cyclone systems. Areas considered susceptible to drought include much of northern Mexico, northern Chile, northeastern Brazil, eastern Argentina, the Mediterranean basin, the Sahel, the southern quarter of Africa, and sectors of the middle and tropical latitudes of Asia, as well as parts of the United States, southern Canada, southern Europe, and Australia (Schneider 1989). The latter four areas produce much of the surplus food that sustains more than 100 developing countries today.

According to some recent innovative analysis (Daily and Ehrlich 1990) involving drought among a host of other agricultural problems, a plausible global-warming scenario for early next century indicates there could be a 10% reduction in the world grain harvest on average three times a decade. The 1988 droughts in just three of the major grain-producing countries, the United States, Canada, and China, resulted in an almost 5% decline; and a mere 0.5°C increase in temperature could reduce India's wheat crop by 10%.

Given the way the world's grain reserves have dwindled almost to nothing as a result of the late 1980s droughts (Brown et al. 1992, 1993), it is not unrealistic to reckon that each such grain-harvest shortfall would result in huge numbers of starvation deaths—according to the computer-model calculations, from 50 million to 400 million people (Daily and Ehrlich 1990). Megascale famines are held at bay today in part through food shipments from the great grain belt of North America, among other food-exporting regions. In a greenhouse-affected world, this grain belt could become unbuckled to the extent that there would be fewer such shipments as Americans find it harder to feed themselves, let alone other communities.

This analysis has been reinforced by a still more recent and much more detailed assessment (Rosenzweig et al. 1993). This assessment postulates that global warming will reduce cereal production in developing countries by 9–11% by the year 2060. In conjunction with other factors, such as population growth and increased food prices to reflect scarcity, this reduction could cause a projected expansion of 640 million in the number of hungry people, bringing the enfamished total to 1 billion. The date of 2060 used by Rosenzweig extends the analysis a little further into the future than the marker date I am using, 2050. But food shortfalls are expected to start to occur within just a few decades.

Table 1. Categories of environmental refugees in a greenhouse-affected world circa 2050.

Country or region	Total refugees foreseen (millions)
China	30
India	30
Bangladesh	15
Egypt	14
Other delta areas and coastal zones	10
Island states	1
Agriculturally dislocated areas	50
Total	150

Particularly vulnerable would be Africa, where regions at special risk of enduring drought include North Africa, West Africa, the Horn of Africa, and southern Africa (IPCC 1990b). The region's population today is 674 million, projected to reach 2.1 billion by 2050 (a 3.2 times increase; United Nations 1992, World Bank 1992a).

The principal agricultural problem is expected to be lack of soil moisture during the growing seasons. In North Africa, for instance, evapotranspiration would increase by 10% for each temperature increase of 1.5°C. Even without any change in rainfall (it is expected to decline), this evapotranspiration would deplete river flows by more than 10%, causing irrigable croplands to contract (IPCC 1990b; see also Russell et al. 1990, Suliman 1990). In sub-Saharan Africa alone, there is already a food deficit of 12 million tons, predicted to increase to 50 million tons by 2000 and 250 million tons by 2020; the amount of relief food shipped throughout the world today is 12 million tons (Pinstrup-Andersen 1993). Even an optimistic scenario for Africa (e.g., reduced population growth, enhanced soil and water conservation, and expanded irrigation; Kendall and Pimentel 1993) foresees that per capita grain production in 2050 would be well below today's sorely inadequate level. Hence, Africa would be ultravulnerable to even minor climatic disruptions.

Starvation crises of unprecedented scale would surely trigger mass migrations of people from famine-afflicted areas. How many is difficult to say with even a modicum of precision. But for the sake of getting a handle on what could become one of the most significant phenomena of the coming decades, it is reasonable to hazard an informed estimate of 50 million refugees—possibly, or probably, many more. One recent estimate (Suliman 1990; see also Russell et al. 1990, Tamondong-Helin and Helin 1991) postulates 50 million in Africa alone.

Further conceptual dimensions

These estimates of future numbers of environmental refugees are a case of best judgement. They are intended to be exploratory at most. A few of them could be off target by 10 million or even more either way, though more probably on the low side insofar as the analyses are conservative. And even if the overall total were too high by one third, or 50 million people, this refugee problem would still be of altogether unprecedented scale.

The totals could also be affected by questions of classification. Although many people will be threatened by environmental factors in a greenhouse-affected world, will they necessarily become obliged to migrate? Or should they better be viewed for the time being as only at risk, especially insofar as ameliorative measures may be deployed to safeguard them? And if they do move, what constitutes true migration? Some people displaced by sea-level rise may need to move their place of residence only a short distance; certain coastal communities may find that residents need simply move across town, albeit a town that may itself be having to move inland with all the further societal traumas that would entail.

Moreover, several of the megametropolises listed may already be experiencing severe problems due to a 50% or greater increase in population size in their recent past (United Nations 1992). This ultrarapid growth may have already overwhelmed the cities' capacity to cope generally, let alone to confront the particular problems of coastal flooding. Equally to the point, people seeking to escape from coastal flooding by moving across town may find there is little room to accommodate them in already congested and overloaded areas; or they may serve in turn to displace sectors of resident communities. There could be all manner of ripple effects.

Many other environmental problems will have overtaken large numbers of people well before 2050 and thus predispose sizable communities to move elsewhere as soon as the further problems of global warming arrive. For instance, severe water shortages are expected to affect 1.1 billion people in Africa, and 3 billion people worldwide, as early as 2015 (Falkenmark and Widstrand 1992), providing a potent source of further refugees. Other environmental problems with capacity to generate refugees are tropical deforestation (for details of the potential refugees connection, see Ehrlich and Ehrlich 1990, Myers 1992b), and soil erosion and desertification among other forms of land degradation (Myers 1991, Pimentel 1993). These changes will be taking place in countries likely to have experienced doubling and in some cases tripling of their populations by 2050, grossly reducing their capacity to accommodate to environmental problems (Ehrlich and Ehrlich 1990, Myers 1991, 1992a, UNEP 1993).

More important still, global-warming stresses may exert not just an additive effect. They may interact with other environmental stresses in multiplicative fashion, that is, with compounded impact. When such synergistic interactions occur, they generate not a double problem but a superproblem, sometimes with ten times greater impact than the sum of their individual impacts (Jackson and Black 1993, Odum 1993).

For instance, in a greenhouse-affected world many agricultural regions look likely to experience higher temperatures and reduced soil moisture, notably the drought-prone sectors of Africa listed above; yet, most of our agricultural crops are finely tuned to present climatic conditions. Hence, there will be need to expand the genetic underpinnings of our crops—a need that will place a premium on germplasm variability to build up, for example, drought resistance. The same need applies to genetic adaptations for crop plants to counter new pests and diseases, such as are likely to thrive in a greenhouse-affected world. Yet, the gene reservoirs of crop plants are being depleted at unprecedentedly rapid rates, to an extent that already leaves our crops dependent on a critically reduced genetic-resource base.

Further, there will be pressure to grow three times as much food as today to take care of increased numbers of people with increased nutritional expectations. Yet, irrigated lands, which currently supply one third of our food from one sixth of our croplands, could experience reduced water flows during peak-demand seasons due to changes in water runoff patterns in the wake of global warming (Frederick and Gleick 1990).

Similarly, there could be synergistic repercussions from diseases (Schneider 1989, WHO 1992) that readily spread among congested and impoverished communities; these communities are expected often to become all the more congested and impoverished through bearing the extra burden of refugees in large numbers. Thus, there could be prime conditions in which otherwise containable diseases could become pandemics.

These illustrations of synergistic interactions among environmental and other factors serve to point up the many amplified problems of a globally warmed world. In the face of these multifarious and multiplying problems, some communities and countries will probably be able to adapt, others probably not. The degree of probability remains a matter of judgement as long as we have scant quantified understanding of synergisms—a lacuna demonstrated by the fact that few of the previous analyses even mention the phenomenon, let alone the growing prospect, of multiple positive feedbacks in a greenhouse-affected world.

For purposes of this article's assessment, moreover, people who will be at risk of global-warming problems are considered thereby to become probable if not certain refugees. Some observers may respond that this assumption makes the current analysis a worst-case affair. I believe it is rather a real-world appraisal based largely on center-range estimates, albeit in a situation attended by abundant uncertainties.

In turn, a key question is raised about scientific uncertainties, with particular respect to policy responses. What is legitimate caution in the face of uncertainty, especially insofar as uncertainty can cut both ways? Some scientists may object that in the absence of conclusive evidence and analysis, it is better to stick with low estimates of refugee numbers on the grounds that they are more responsible. But note the crucial factor of asymmetry of evaluation. A low estimate, ostensibly safe because it takes a conservative view of such limited evidence as is at hand in documented detail, may fail to reflect the real situation just as much as does an unduly high estimate that is more of a best-judgement affair based on all available evidence with varying degrees of demonstrable validity.

A minimalist calculation with apparently greater precision may amount to spurious accuracy. In a situation of uncertainty in which not all factors can be quantified to conventional satisfaction, let us not become preoccupied with what can be precisely counted if that is to the detriment of what basically counts. Undue caution can become recklessness; and as in other situations beset with uncertainty, it will be better for us to find we have been roughly right than precisely wrong (Myers in press).

Aggregate assessment

The total of environmental refugees as calculated here for a greenhouse-affected world is approximately 150 million (Table 1). However rough the reckoning, it supplies an initial insight into the scale of a major emergent problem.

This total amounts to 1.5% of the 10 billion people projected for the world's population in 2050. In contrast, the current 10 million recognized environmental refugees comprise only 0.2% of the global population of 5.5 billion.

Economic, sociocultural, and political consequences

The consequences of large numbers of environmental refugees would be among the most significant of all upheavals entrained by global warming. Refugees arrive with what are often perceived by host communities as alien customs, religious practices, and dietary habits, plus new pathogens and susceptibility to local pathogens. Resettlement is generally difficult, full assimilation is rare. Economic and social upheavals would proliferate, cultural and ethnic problems would multiply, and the political fallout would be extensive.

We are familiar enough with the strains generated for receiver nations today when they have to face throngs of refugees fleeing from drought, famine, floods, and other disasters (Chambers 1986). To quote a former United Nations High Commissioner for Refugees, Prince Saddrudhin Aga Khan, "People flee their homes in search of food or jobs....As the victims move, they carry their famine with them, much as they might carry an infectious disease. They impose intolerable burdens in terms of food requirements on the territory they enter. At the same time, they flood the labor market, creating a slump in wages, and endangering the economic security of the local population. Fuse the two elements, and you have a perfect recipe for widespread human suffering, social disorder and political instability."

It already costs developed nations $8 billion a year to accommodate refugees. This amount is equivalent to a full one seventh of the foreign aid they supply to developing nations. It would serve as a handsome payoff investment to boost foreign aid and tackle more of the refugee problem at the source rather to than wait and pay a higher price through responding to symptoms of the same problem.

Yet, our experience to date offers scant guidance to what could lie ahead concerning costs. As a result of sea-level rise, coastal protection costs worldwide could be on the order of $2.5 trillion to $5.0 trillion, and coastal land loss $15 trillion, making a total of $17.5 trillion to $20 trillion, spread over a period of 50 years (Ayres and Walter 1991; see also Cline 1992, Fankhauser 1992, Nordhaus 1991). The gross world product today is approximately $23 trillion. No estimate is available of the costs of disrupted agriculture in drought-afflicted regions. They could be considerable given the projected food-deficit estimates.

But the refugee reckoning should be expanded to reflect a host of other costs. There would be support costs for maintenance and resettlement. Refugees could probably not make a contribution to their host communities' economies for at least a year or two, a sizable opportunity cost.

Many other indirect costs would be sizable and hard if not impossible to estimate in conventional quantified terms. There would often be little land available to accommodate refugees, notably in regions with two or three times as many people as today. Refugees would tend to crowd into settlement camps or shantytowns, which would become prime breeding grounds for crime, civil disorder, social upheaval, and violence of many sorts (Ayres and Walter 1991). As a result, there could be soaring costs to maintain security, both internal and external (Myers 1993).

There could also be substantial outlays to counter pandemic diseases, plus deficits of food, water, and energy, together with the additional social strife and political turmoil that all these would entrain. It could often be the case that social disintegration would arrive sooner and on a larger scale than environmental breakdown. As Cline (1992) put it, "People have often fought wars to avoid being forced to leave their homelands." Moreover, these problems would often interact in such a way as to generate synergized outcomes, pushing the overall economic cost far beyond what we can realistically envisage in the light of our experience to date.

When we accord due attention to all the factors we can recognize today, plus those with which we are not yet acquainted but that may well emerge in a world altogether beyond our experience, we could suppose that the ultimate additional costs of environmental refugees could match or exceed the costs of easily identifiable and readily quantifiable problems, such as coastal protection measures and coastal land loss. As yet, we have no way of grasping what these further costs could be. It would be a mistake, however, to suppose that because we cannot even identify all these costs, let alone define, assess, and quantify them, they should therefore be left out of the current account. The issue warrants urgent research from both natural-science and social-science standpoints.

Conclusions

Today, refugees are viewed as a peripheral concern, a kind of aberration from the normal order of things. In a greenhouse-affected world of the future, they are likely to become a prominent feature of our one-Earth landscape due to the burgeoning phenomenon of environmental displacement. It requires a leap of the imagination to envisage 150 million destitutes abandoning their homelands, many of them crossing international borders. They would be all the more disruptive in a world struggling to cope with a plethora of environmental problems. Yet, amid discussions of global warming and its impacts, we hear all too little about environmental refugees.

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